An Introduction to the Study of Experimental Medicine

by Claude Bernard

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TO THE STUDY OF

EXPERIMENTAL MEDICINE

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EXPERIMENTAL MEDICINE

CLAUDE BERNARD

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■WITH AN INTRODUCTION BY

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INTRODUCTION

The discoverer of natural knowledge stands apart m the modern world, an obscure and slightly mysterious figure By the abstract character of his researches his individuality is obliterated, by the rational form of his conclusions his method is concealed , and at best he can be known only through an effort of the imagination This is perhaps inevitable But the unfortunate effects are enhanced by convention which to-day prescribes a formal, rigorous and impersonal style in the composition of scientific literature Thus while it is no more difficult to know Galileo and Harvey than Cervantes and Milton through their writings, or to perceive their habits and methods of work, psychological criticism will often seek m vain the personality and the behavior of the person behind the modern scientific printed page Yet whoever

fails to understand the great investigator can never know what science really is

Such knowledge is not taught m the schools Even more than the scientific memoir, the treatise and the lecture are formal, logical, systematic, thus truly intelligible and living only to the initiated As much as possible science is made to resemble the world which it describes, m that all vestiges of its fallible and imaginative human origin are removed Since the publication of Euclid's immortal textbook this has been the universal and approved usage Little doubt should remain that it is the best But then the burden must fall upon the student of initiating himself into mysteries which no one will explain to him.

What he lacks is understanding of the art of research and of the inevitable conditions an*d limitations of scientific discovery, an under- standing, m short, of the behavior of the man of genius, not a ration- alized discussion of scientific method The latter may be sought in many learned works and in the teachings of academic philos- ophers, a good account of the former is far to seek It is, there- fore, not the least of the merits of Claude Bernard's An Introduction to the Study of Experimental Medicine that we have here an honest and successful analysis of himself at work by one of the most mtelli-

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gent of modern scientists, a man of genius and a great physiologist This work lays hare, so far as that is possible, what others have concealed

With due regard to such analysis and logical formulation as are indispensable for intelligibility of exposition, Claude Bernard has avoided a 'posteriori, rationalization as he has a, prion dogmatism Thus it is possible to perceive his scientific method as the habit of the man His life is spent m putting questions to nature These questions are the measure of his originality He cannot tell how they arise, but the experimental idea seem3 to him a presentiment of the nature of things Such ideas are, at any rate,

the only fer- tilizing factor m research , without them scientific method is sterile, and great discoveries are those which have given rise to the most luminous ideas

The experiment, accordingly, is always undertaken m view of a preconceived idea, but it matters not whether this idea is vague or clearly defined, for it is but the question, vague or otherwise, which he puts to nature Now, when nature replies, he holds his peace, takes note of the answer, listens to the end and submits to the decision In short, the experiment is always devised with the help of a working hypothesis, the resulting observation is always made without preconceived idea. Such habits are not too easily formed, for man is by nature proud and inclined to metaphysics, but the practice of experimentation will cure these faults

Claude Bernard is at pains to point out that even so modest an abstract description of method does violence, for the sake of clearness, to the complexity of human behavior Beyond this his method is the art of experimentation, an art which rests upon a perfect and habitual familiarity with the objects that he studies and with the details of his experimental procedure

The chapters m which all this is developed are pervaded by a spirit of honesty, simplicity and modesty, the mark of a great in- vestigator It is not difficult while reading them to see the man at work, full of ideas, a marvelous observer, marking and taking note even of that for which he is not looking, always doubting, but serenely and without scepticism, guarding himself from his hypothesis and even from the unconfirmed observation, yet ever confident m the determinism of nature and therefore m the possibility of rational knowledge

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The subject of his investigations -was physiology, m the broadest and m the most modem sense, physiology conceived as the predestined foundation of scientific medicine and as the most important part of biology Thus his science was seen by

Claude Bernard with clear but prophetic vision, for he lived almost a half century before his time He perceived that physiology rests securely upon the physico-chemical sciences, because all that these sciences bring to light is true of organic as of inorganic phenomena Also there is nothing but the difficulty of the task to hinder the reduction of physiological processes to physical and chemical phenomena. And yet this cannot be the last word, for physiology is more than bio-physics and bio-chemistry, biology more than applied physical science He has him- self, elsewhere, put the case as follows

“Admitting that vital phenomena rest upon physico-chemical activities, which is the truth, the essence of the problem is not thereby cleared up , for it is no chance encounter of physico-chemical phenomena which constructs each being according to a pre-existmg plan, and produces the admirable subordination and the harmonious concert of organic activity

“There is an arrangement in the living being, a kind of regu- lated activity, which must never be neglected, because it is m truth the most striking characteristic of living beings

“Vital phenomena possess indeed their rigorously determined physico-chemical conditions, but, at the same time, they subordinate themselves and succeed one another m a pattern and according to a law which pre-exist, they repeat themselves with order, regularity, constancy, and they harmonize in such manner as to bring about the organization and growth of the individual, animal or plant “It is as if there existed a pre-established design of each organ- ism and of each organ such that, though considered separately, each physiological process is dependent upon the general forces of nature, yet taken m relation with the other physiological processes, it reveals a special bond and seems directed by some invisible guide in the path which it follows and toward the position which it occupies

“The simplest reflection reveals a primary quality, a quid pro- pnum of the living

being, m this pre-established organic harmony ” *

* Legons sur lea Phenomenes de la 1 »e Commune aux Antmaux et aux Veg6 taux Paris, 1878, Vol 1, p 50

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I know of no other statement of the case since Aristotle’s which seems to me to present so well a biologist’s philosophy.

It must not be expected, however, to find m the work of Claude Bernard a system, of biological philosophy. He sets forth his views on the philosophy and the method of science, and they are really his views, the very convictions that he carries with him into the labora- tory But they are not a clear system of philosophy, nor a rational and logical scientific method, which neither he nor anyone else can believe m as he goes about his daily work Hence, like everybody’s real beliefs, they shade off into vague, more or less inconsistent, more or less doubtful opinions This is reality itself

The theory of organism is more than a philosophical generaliza- tion , it is a part of the working equipment of the physiologist, ful- filling a purpose not unlike that of the second law of thermodynamics m the physical sciences It has been more or less clearly understood and employed from the earliest times, and Claude Bernard did but perfect it The theory of the constancy of the internal environment, a related theory, we owe almost wholly to Claude Bernard himself There is no better illustration of his penetrating intelligence A few scattered observations on the composition of blood sufficed to justify, m his opinion, the assertion that the constancy of the internal envi- ronment (milieu mteneur) is the condition of free and independent life1 A large part of the physiological research of the last two decades may fairly be regarded as a verification and illustration of this theory, which, as Claude Bernard perceived, serves to interpret many of the most important

physiological and pathological processes It was this theory too that led him to a clear conception of general physiology, which he regarded as the fundamental biological science General physiology, according to him, includes the study of the physico-chemical properties of the environment of the cell, a similar study of the cell itself, beyond this of the physico-chemical relations between cell and environment, and, generally, of the phenomena common to animals and plants This science, of which he is the founder, was destined to remain undeveloped until long after his death To-day, with the aid of a physical chemistry unknown to the

1 This should not he thought of as absolute constancy, and it should be under- stood that variations in the properties of the internal environment may be both cyclical and adaptive, that is functional, but m general may not be random and functionless Claude Bernard's principle is the first approximation which suffices until the subject has been broadly developed

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contemporaries of Claude Bernard, it is fulfilling the promise which he alone could clearly see He never had a more luminous presenti- ment of the nature of things than this vision of the future foundations of biology

No man is a true prophet otherwise than through the possession of such intimate knowledge of a subject that he is able to say, "Thus matters must develop " Such was Claude Bernard's prophecy of the future of his own science His understanding of physiology had become so perfect that the future could not be wholly doubtful He knew where the path must lead, and it is this that makes his book so amazingly modern In other respects he is only a highly intelli- gent man of the third quarter of the nineteenth century Accord- ingly his treatment of some subjects, such as mathematics and physics, is a little old-fashioned, especially on the logical side In general such defects are not only slight, but also unimportant from the medical

standpoint But his discussion of statistics could hardly be written to-day There are indeed those, though few m number, who will agree with his criticisms But, when he wrote, the influence of Galton had not been exerted and nobody realized that statistics afford a method, at once powerful, elegant and exact, of describing a class of objects as a class

Physiology, as defined and understood in this book, with general physiology as its foundation, is the essential medical science Medi- cine has passed through the empirical, the systematic, the nosological and the morphological stages and has entered upon the experimental stage Thus it has finally become physiological, for physiology is the larger part of experimental medicine Such is the principal thesis of the present work, which ought not to be obscured by the con- sideration of incidental topics, no matter how intrinsically important they may be

This opinion, to be sure, does not yet meet with universal ap- proval, and yet I believe that it has been at length fully confirmed by the experience of the twentieth century Nevertheless, the con- firmation was long delayed by the emergence of the bacteriological stage m the evolution of medicine Unforeseen by Claude Bernard, this was the result of the discoveries of his contemporary, Pasteur

To-day, looking backward, we see how it was that bacteriological researches for a long time took the first place which Claude Bernard believed to be already assured to those of his own science When

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Pasteur began the study of micro-organisms a great gap existed m our knowledge of the organic cycle and of natural history His work and that of his successors filled this gap, completed our present theory of the cycle of life and established the natural history of infectious diseases, of fermentations and of the soil This was perhaps the most rapid advance of descriptive knowledge m the history of science For the

moment the researches of physiologists were overshadowed and the work of the young men diverted into the new fields In time bacteriology grew into a fully developed science, perfected its methods, exploited its domain, and then, the most pressing work well done, resigned its leadership of the medical sciences

Meanwhile a profound influence was exerted on what Professor Whitehead has called the intellectual climate Claude Bernard's outlook may he described as biological and philosophical, and such a point of view seems necessary for the understanding of the deeper problems of medicine Pasteur, however, always retained the chem- ist's outlook, and in him the will was more important than the reflec- tive intellect His successors have taken a position hardly more biological and, probably of necessity, have had little interest m rational theory Such a climate is unfavorable to the growth of experimental medicine and especially of general physiology, for both are biological and rational

This had been vaguely understood as early as the times of Galileo, of Borelli, and of Malpighi, when the minds of men were still fresh and not yet enslaved by specialism But even Claude Bernard, be- cause he still lacked the aid of modern physical chemistry, hardly appreciated the possibilities, very limited but very important, of the applications of the fully developed method of rational physical science, when guided and duly restrained by the judgment of a true physiologist, m the study of the ultimate phenomena of life

In default of the physico-chemical foundations, during a period when bacteriology was the dominant influence m medical science, and next to it, perhaps, the highly specialized science of organic chemistry, when the prevailing activity was somewhat nnmtellectual, physiology continued m the old paths Not until after the turn of the century did the movement which Claude Bernard had foreseen make itself felt To-day it is well established and should be generally recognized The result has already been a remarkable increase of experimental investigation and of rational

theorizing m the clinic

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For the first tune mathematics, physics, chemistry and physical chemistry, as aids to physiology, have passed mto the hospitals I believe that, for the reasons which Claude Bernard has explained, this will long remain the way of medical progress and that we have now definitely entered upon the epoch of experimental medicine

All progress entails evils and few experimenters can understand as Claude Bernard did the phenomena of life and the philosophy of the organism For these reasons, and for others not so good, the grow th of experimental medicine gives rise to criticism, as it did a half century ago Experienced physicians, practised m the art of medicine and rightly believing that medicine is still and must always be an art, hut also uncomfortable and suspicious through ignorance of the new development, are not lacking to unite with this opposition So far as grounds for complaint exist they are due to the absence of that high intelligence and skill of the experimenter which are neces- sary to understand and to solve the complex problems of physiology Here one can only plead the palliating circumstance that all human endeavor suffers from the same weaknesses On the other hand, pre- vailing criticism of scientific medicine itself, no less than the earlier criticism of the nineteenth century, finds conclusive answer m this book

Medicine is but a part of human biology and the study of human inheritance, constitution, intelligence and behavior, of adaptation to new conditions of life, and of a host of other subjects far tran- scends the boundaries of medicine But everywhere throughout this vast field physiology has the same importance as m the narrower field of medicine Thus the Introduction may serve as a guide not only for those who are beginning the study of medicine, but for many others as well

The sciences are not equal, nor do they preserve their rank un- changed as

civilization moves on During nearly a quarter of a millennium mechanics led all the others m intellectual interest and m influence upon European civilization It will seem to many not too bold a prophecy, for the reasons that Claude Bernard has set forth, to look forward to a century m which physiology shall take a similar place I venture to believe that that position will be reachc d when the experimental method has made possible a rational science of organism

The physiological researches of Claude Bernard have immor-

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talized his name, hut the present work and his other general writings have hardly attracted the attention which they deserve or exerted the influence of which they are capable This is probably due both to the conflicting influence of bacteriology, organic chemistry and other sciences and, not less, to his own clearness of vision That which he saw as the future of physiology remained for many decades hidden from others and so his writings were only half understood Even general physiology is still hardly aware of the program which he set forth and which it has been unwittingly carrying out There is, however, one well known instance of his influence exerted farther afield As the idea of Balzac's Comedie Humavne was suggested by the biology of the early nineteenth century, so the naturalism of Zola was suggested by the works of Claude Bernard Perhaps the result will not be thought worthy of the cause Yet the instance is significant of the wide bearing of an interpretation of life which may be seen to be peculiarly well suited to the present conditions of the political and social as well as of the natural sciences

Among great men, Claude Bernard should be counted fortunate m that he has not become a mythical figure. Unlike Pasteur, whose discoveries are hardly more remarkable, though their immediate in- fluence has been immeasurably greater, and whose horizon was incon- testably less broad, he remains a plain man, highly

distinguished no doubt, but not obscured by the growth of a legend.

It is possible not only to see him at work, but even to discover his purposes and his feelings The desire to relieve suffering and a sense of duty are clearly apparent, and one may read between the lines the endunng satisfaction that he felt m the society of younger men who owed to him more than they could ever repay But weightier still are the contentment which comes from work well done, the sense of the value of science for its own sake, insatiable curiosity and, above all, the pleasure of masterly performance and of the chase These are the effective forces which move the scientist The first condition for the progress of science is to bring them into play

L J. Henderson

October 11, 1926

CLAUDE BERNARD

Claude Beenaed, bora July 12, 1813, at Saint Julien near Vxllefranche,1 came to Paris in 1832, -with almost no paraphernalia except a tragedy which had never been acted, and a farce-comedy which had had some success at a small theatre m Lyons He showed these first attempts to Saint-Marc Girardm who was temporarily tak- ing Guizot's place at the Sorbonne Girardm advised him to learn a profession to live by, and to write poetry m his spare time* certainly he had no idea that standing before him was a future colleague in the French Academy Young Claude Bernard followed this sensible advice and entered the school of medicine

Though he received his appointment as hospital interne m 1839, he was anything but a brilliant pupil His comrades did not suspect what lay hidden behind the huge forehead of this silent student who paid so little attention to his professors' teaching, that they easily condemned his meditative calm as mere laziness Survivors remember and often describe that revelation, his publications on gastnc sugar, the chorda tympani, the pneumogastnc nerve and the spinal nerve, which suddenly revealed to

the scientific world a sagacious and ingenious experimenter of rare operative skill

Magendie's teaching brought this revolution about. As soon as Claude Bernard set foot in the laboratory of the College de France, his path was marked out The celebrated physiologist's daring though somewhat disorderly experimentation, his pitiless criticism, the scepticism that mcluded even his own discoveries, made a deep and, so to speak, creative impression on the young man's mind. But the pupil was so much more powerful than his master that he took from his teaching only its virtues of independence, and succeeded in keeping doubt within scientific bounds To deep disdain for plaus- ible explanations m which alluring chimeras are concealed, he easily added respect for the facts gathered m tradition, sincere belief when face to face with the unexpected which is often pregnant with dis- covery, respect for searching hypotheses and coordinating theories,

1 Department of the Rhone

without ever attributing to them independent authority or power. Finally what distinguished him especially from Magendie, and gave him his wholly individual character, was love of certainty, — that deep feeling for law, that immovable confidence that, — if the condi- tions m which vital phenomena come to pass are infinitely many, complex and hard to grasp, assemble and master experimentally, — they are none the less surely and fixedly linked to phenomena without any possibility of a quid dtvmum being invoked to explain the seemingly spontaneous irregularities which they present

This is the mam point where Claude Bernard showed his superi- ority, from the first moments of his scientific life The pupil of Magendie, the sceptic, introduced determinism into the realm of physiology Thanks to him, the scientific method, respect for whose laws leads to certainty m the sciences of dead matter, assumed equal authority m the sciences of living beings Sciences are not of two kinds, the

first proud and confident, the rest timid and hesitant , the first sure of commanding and of being obeyed in experiments, the rest always m fear of an influence unknown m essence, force and goal

It required no small effort to banish this menacing unknown from the field of physiology The most celebrated of French physi- ologists, Bichat, had given it asylum, and everyone after him had thought it necessary to reckon with this capricious force, with these vital functions, whose role was to resist the universal laws of matter, which thus made all acts performed by living beings a series of miracles Of course Magendie was not the man to let himself be frightened by this ghost, but he systematically and artificially sim- plified facts so that he only partly mastered them , or else the multi- plicity of conditions governing vital phenomena took away all his theoretical confidence m the result Now, without results there can be no science I must repeat that Claude Bernard, therefore, proved himself, almost from the outset, superior to both Magendie and Bichat, since he felt not only the endless multiplicity of unknown data m physiology, but also their subordination to the general laws of matter and their obedience to the experimental method

Physiology could therefore extend its roots into the solid earth where its older sisters, physics and chemistry, are settled The com- plexity of the problems made it essential, however, to set forth the rules of the experimental method m special formulas with a view to

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the intellectual and manual methods which are especially adapted to physiology Through the whole first phase of his scientific life, Claude Bernard was haunted by this task But the fascination of his laboratoiy and the hunt for discoveries so completely absorbed his time that he could demonstrate the experimental method only as Diogenes demonstrated motion

And never was hunt for discoveries more fruitful In twenty years, Claude Bernard found more dominating facts, not only than the few French physiologists working beside him, but than all the physiologists^ m the world The activity of different glands and particularly of the pancreas, animal glycogenesis, experimental production of diabetes, the existence of the vasomotor nerves and the theory of animal heat, the influence of poisons, studied in themselves and as a means of analyzing physiological phenomena, the endless number of fresh facts, keen deductions and ingenious and suggestive insights, contained not only m his special memoirs but m the four- teen volumes, from his Lessons in Experimental Physiology Applied to Medicine (1885-1886) to his Lessons on Diabetes and Animal Glycogenesis (1811), m which he collected each year the results of his investigations and a summary of his courses, — these things gave him the position of a master unquestiomngly accepted m France and abroad

In official life he also attained the highest rank In 1854, a chair of general physiology was founded for him at the Sorbonne, which in 1868 he surrendered, with beautiful magnanimity and grace, to his pupil, Paul Bert In 1858 he took Magendie’s place m the chair of medicine at the College de France Member of the Academy of Sciences in 1854, he was called m 1868 to take Flou- rens’ seat m the French Academy Finally m 1869, by special de- cree, he entered the Senate , and he was almost the only member of that assembly whom no one ever thought of reproaching for a nomi- nation which to him was so strange a surprise

A few years before these unexpected literary and political honors thus sought him out m his laboratory, a serious event occurred m his life A long and severe disease, during which he and his friends despaired of a favorable outcome, condemned him to physical inac- tivity He had to leave his laboratory, and Paris too, he had to ask of his birthplace, once more and not m vam, the gift of life and health Long months of isolation and rest gave back all his liberty

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of mind For the first time, he had leisure for meditation and for setting m order, on paper, the results of his solitary reflections. A short preface, which was already m proof and which was to have preceded a sort of treatise on operative physiology which remains unfinished, grew, by successive additions, to the size of a pamphlet, then of a book which saw the light m 1865

The Introduction to the Study of Experimental Medicine struck cultivated minds with admiration and astonishment Here physi- ologists were happy to find, reduced to precise formute, set m order with marvellous art, and lighted by examples which themselves were like so many intellectual experiments, — here they were happy to find the rules of the experimental method, watching, seizing and, m spite of its struggles, mastering that organic Proteus of the deceitful metamorphoses Men less taken up with professional difficulties were struck by the magnitude of the problems studied, by the clanty of exposition, the ease and good faith with which they were either solved or proved insoluble Even the style attracted great attention , its original flavor took even the French Academy’s fancy “You have created a style,” said the severe Monsieur Patm, m his speech of welcome. And it was true But how surprised the venerable critic would have been if he had read the earlier books m which Claude Bernard contented himself with enumerating his laboratory impres- sions m a narrative that is often scarcely well ordered The eminent but naive master was never haunted by care for stage effect, his style, whether spoken or written, is the equivalent of his ideas In epi- sodical narrative, he is often dragging and confused, but when a hard problem presents itself, when his thought is forced to fall back as if to conquer an obstacle or make a bound, then he concentrates, purifies and accentuates himself m definite formulae and often m verbal imagery.

As he was m his books, so was Claude Bernard m his courses and his conversation His was not a docile thought, speaking every language and playing every role, and

he never disciplined it to any conventions of profession or of social custom. If it escaped him, he followed it without rebellion, leaving his speech drooping, his lecture m confusion, while he listened to what it softly said to him But if it grew interested m the immediate subject, then the professor or conversationalist, a moment ago so difficult and diffuse, awoke living, inventive, clear, eloquent, with surprising and sudden changes, and

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always with both characteristics of true genius, ease and good faith.

And no one possessed them m higher degree That ease m rais- ing himself to high summits, m acting m the midst of trying difficul- ties, especially struck readers of his admirable articles in the Revue des Deux Mondes What the poet said of the goddess could he said of him mcessu patmt After reading these articles, an eminent man said to me one day “He does not make me merely think I under- stand, as you all do , he makes me really understand ” And m fact he did understand Claude Bernard earned this ease from his physiological method into the philosophic realm No one ever made discoveries more simply, more naively To that first phase of hunt- ing ideas, which consists, as Helvetius said, in seeing and starting the quarry, he brought a sureness of vision, an astounding penetration Most scientific searchers are a kind of somnambulist who see only what they are looking for and what is on the track of their ideas f their eyes are fixed on a point, and they fail to perceive not only what happens aside from that point, but even what appears there unforeseen In one of his pupil’s phrases, Claude Bernard seemed to have eyes all around his head In the course of an experiment, students were stupefied when they saw him point out quite evident phenomena which no one but himself had seen He discovered as others breathed

With ease, good faith That was his ruling characteristic He never swerved from the deep sincerity of a man of science who must seek truth for its own sake and for the

truths which follow from it, without concerning himself with the distant or indirect conclusions which lawyer-like men, with a cause to defend, try to draw from it. No one was ever more passive m deduction, or described deductions with more candid sincerity This is why supporters of different theses could use, and still can use, his writings, turn and turn about When he expounds the cerebral determinism of intellectual activity, the materialists count him as their own, when he declares that thought and the brain are in the same relation as time and a clock, the spiritualists try to enlist him. In reality, he is just a physi- ologist handing over fresh facts to rejuvenate the speculator's endless wrangling

In the narrower realm of physiology and medicine his admirable good faith explains the seeming contradiction between his scientific

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faith and his practical incredulity He always had this double feel- ing m the highest degree, — that if medicine is to he sure of itself, it must have physiology as its necessary base, and that our present- day physiology is still far from supplying us with any practical cer- tainty. He felt the full importance of hiB own discoveries as founda- tions for the medical edifice, but he did not share the illusions of those whose eagerness to transfer them to the realm of clinical or therapeutic applications often made him smile. The feeling for distances, which would have discouraged less valiant men, moved him not at all For strength and perseverance, he did not need the intoxication of illusions So he, who taught that medicine is or should be a science, showed himself thoroughly sceptical about physicians, and when he talked of them, the shade of Sganarelle 2 always seemed to pass before him

The Introduction to the Study of Experimental Medicine marks a fresh phase m the life of Claude Bernard From this period date the philosophic writings which opened the French Academy's doors to him Of this period, too, are the books 8 m which

grouping facts takes precedence over noting details, and m which he returns to his earlier discoveries and strives to bring his subsidiary work to the precision and perfection which present-day science permits

This does not mean that he turned completely away from those regions of the unknown where he had formerly reaped such rich harvests His latest work on the fundamental identity of the prop- erties of tissues and of elementary functions m the animal and vege- table kingdoms, on anesthesia of the lower vegetables by chloroform or ether, and on the general action of toxic substances, shows that the creative spirit was still alive m him

Fresh discoveries were this year to have furnished another proof of his fertile activity He confided this m part to his friends and pupils , and from the few words which escaped him, we may appar- ently conclude that the investigations which he earned out during his last vacation were to throw unexpected light on the theory of fer- mentation This important work of which he said, only four days ago, “What a pity , it would have been good to finish it !” is lost to science

*In Le Midectn malgrS lui by Mol i fere

'Recherches sur lea propnStis des ttssua vivanta Lecont de pathologve ew p&rxmentale, etc

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On December 31 be was stricken m the laboratory of the Col- lege de France, shivering and fever soon came on, and special phe- nomena indicating inflammation of the kidneys Nothing could stop the advance of a disease whose every progress he followed Without any illusions about the fatal catastrophe, he observed with calm eyes, and with a smile denied his scientific family’s pious lies He was one of those whose gaze is undismayed by the unknown Personal feeling must be silent m this immense mourning of science, and yet, the loss of a great man is not all that

moistens the eyes of those about his coffin such kindliness, such simplicity of soul, such naive generosity were united m his genius One’s hand trembles m trying to sketch a few traits of this great and noble character

Nothing m his pure and harmonious life was turned aside from its chief aim Enamored of literature, art and philosophy, Claude Bernard as a physiologist lost nothing by these noble passions, on the contrary, they all helped m developing the science with which he identified himself, and of which he is the highest and most com- plete embodiment He was a physiologist such as no man had been before him “Claude Bernard,” said a foreign scientist, “is not merely a physiologist, he is physiology ”

His very death seems to mark a new era in science For the first time m our country, a man of science will receive those pub- lic honors hitherto reserved for political and military celebrities The cabinet honored itself yesterday m asking parliament, which unanimously agreed to celebrate at state expense the solemn obse- quies of the master who is no more And one phrase of Gam- betta, speaking m the name of the Budget Commission, sums up all that we have said “The light, which has just been extinguished, can- not be replaced ”

Paul Beet

Pans, February 12, 1878

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To Conserve Health and to Cure Disease Medicine is still pursuing a scientific solution of tins problem, which has confronted it from the first 1 The present state of medical practice suggests that a solution is still far to seek During its advance through the centuries, however, medicine has always been driven into action and from numberless ventures in the realm of empiricism has gained useful information Though furrowed and overturned by all manner of systems so evanescent that, one by one, they have disappeared, it has none the less carried on research, acquired ideas and piled up precious materials which in due time will find their place and mean- ing in scientific medicine. To-day, thanks to the great development and powerful support of the physico-chemical sciences, study of the phenomena of life, both normal and pathological, has made progress which continues with surprising rapidity

It is therefore clear to all unprejudiced minds that medicine is turning toward its permanent scientific path By the very nature of its evolutionary advance, it is little by little abandoning the region of systems, to assume a more and more analytic form, and thus gradually to join in the method of investigation common to the experimental sciences

In order to embrace the medical problem as a whole, experi- mental medicine must include three basic parts physiology, pathol- ogy and therapeutics Knowledge of causes of the phenomena of life m the normal state, 1 e , physiology, will teach us to

maintain normal conditions of life and to conserve health Knowledge of diseases and of their determining causes, i e , pathology, will lead us, on the one hand, to prevent the development of morbid conditions,

’See Oours de pathologte exp&nmentale (Medical Times, 1859 1860) — Legem d’ouverture du cours de midecine du College de France Sur la mddecine ex- pinmentale (Gazette mddxcale Pane, April 15, 1864, — Revue des cours sc ten ttfiques Pans, Dec 31, 1864)

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and, on the other, to fight their results with medical agents, 1 e , to cure the diseases

In the empirical period of medicine, which must doubtless still be greatly prolonged, physiology and therapeutics could advance separately, for as neither of them was well established, they were not called upon mutually to support each other m medical prac; tice But this cannot be so when medicine becomes scientific it must then be founded on physiology Since science can be estab- lished only by the comparative method, knowledge of pathological or abnormal conditions cannot be gamed without previous knowl- edge of normal states, just as the therapeutic action of abnormal agents, or medicines, on the organism cannot be scientifically under- stood without first studying the physiological action of the normal agents which maintain the phenomena of life.

But scientific medicine, like the other sciences, can be estab- lished only by experimental means, 1 e , by direct and rigorous ap- plication of reasoning to the facts furnished us by observation and experiment. Considered m itself, the experimental method is noth- ing but reasoning by whose help we methodically submit our ideas to experience, — the experience of facts.

Reasoning is always the same, whether in the sciences that study living beings or m those concerned with inorganic bodies. But each kind of science presents different

phenomena and complexities and difficulties of investigation peculiarly its own. As we shall later see, this makes the principles of experimentation incomparably harder to apply to medicine and the phenomena of living bodies than to physics and the phenomena of inorganic bodies

Reasoning will always be correct when applied to accurate notions and precise facts, but it can lead only to error when the notions or facts on which it rests were originally tainted with error or inac- curacy That is why experimentation, or the art of securing rigorous and well-defined experiments, is the practical basis and, in a way, the executive branch of the experimental method as applied to medi- cine If we mean to build up the biological sciences, and to study fruitfully the complex phenomena which occur m living beings, whether m the physiological or the pathological state, we must first of all lay down principles of experimentation, and then apply them to physiology, pathology and therapeutics Experimentation is un- deniably harder m medicine than m any other science , but for that

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very reason, it 'was never so necessary, and indeed so indispensable The more complex the science, the more essential is it, m fact, to establish a good experimental standard, so as to secure comparable facts, free from sources of error Nothing, I believe, is to-day so important to the progress of medicine

To be worthy of the name, an experimenter must be at once theorist and practitioner While he must completely master the art of establishing experimental facta, which are the materials of science, he must also clearly understand the scientific principles which guide his reasoning through the varied experimental study of natural phenomena We cannot separate these two things head and hand. An able hand, without a head to direct it, ib a blind tool, the head is powerless without its executive hand

The principles of experimental medicine will he explained in this work from the triple point of view of physiology, pathology and medicine But before going into general considerations and special descriptions of the operative procedure proper to each of these divi- sions, I deem it useful to give a few explanations in this introduction in. relation to the theoretic and philosophic side of the method which this hook, after all, treats merely on its practical side

The ideas which we shall here set forth are certainly by no means new , the experimental method and experimentation were long ago introduced into the physico-chemical sciences, which owe them all their brilliancy At different periods, eminent men have treated questions of method in. the sciences, and m onr own day Monsieur Chevreul, m all his works, is explaining very important ideas on the philosophy of experimental science We shall therefore make no claim to philosophy Our single aim is, and has always been, to help make the well-known principles of the experimental method pervade medical science That is why we shall here recapitulate these principles, specially pointing out the precautions to be taken in their application, because of the very special complexity of the phenomena of life We shall consider these difficulties, first m the use of experimental reasoning, and then in the practice of experi- mentation

PART ONE

EXPERIMENTAL REASONING

CHAPTER I

OBSERVATION AND EXPERIMENT

Only 'within very narrow boundaries can man observe the phe- nomena which surround him, most of them naturally escape his senses, and mere observation is not enough To extend his knowl- edge, he has had to increase the power of his organs by means -of special appliances, at the same time he has equipped himself with various instruments enabling him to penetrate inside of bodies, to dissociate them and to study their hidden parts A necessary order may thus be established among the different processes of investiga- tion or research, whether simple or complex the first apply to those objects easiest to examine, for which our senses suffice, the second bring within our observation, by various means, objects and phenom- ena which would otherwise remain unknown to us forever, because m their natural state they are beyond our range Investigation, now simple, again equipped and perfected, is therefore destined to make us discover and note the more or less hidden phenomena which sur- round us

But man does not limit himself to seeing , he thinks and insists on learning the meaning of the phenomena whose existence has been revealed to him by observation So he reasons, compares facts, puts questions to them, and by the answers which he extracts, tests one by another This sort of control, by means of reasoning and facts, is what constitutes experiment, properly speaking, and it is the only process that we have for teaching ourselves about the nature of things outside us

In the philosophic sense, observation shows, and experiment teaches This first distinction will serve as our starting point m examining the different definitions of observation and experiment devised by philosophers and physicians

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I. Various Definitions of Observation and Experiment

Men sometimes seem to confuse experiment with observation Bacon appears to combine them when he says: “Observation and experiment for gathering material,

induction and deduction for elaborating it these are our only good intellectual tools ”

Physicians and physiologists, like most men of science, distin- guish observation from experiment, but do not entirely agree m defin- ing the two terms

Zimmermann 1 expresses himself as follows . “An experiment dif- fers from an observation m this, that knowledge gained through observation seems to appear of itself, while that which an experiment brings us is the fruit of an effort that we make, with the object of knowing whether something exists or does not exist ”

This definition embodies a rather generally accepted opinion According to this definition, observation would be noting objects or phenomena, as nature usually presents them, while experiment would be noting phenomena created or defined by the experimenter We should set up a sort of contrast, in this way, between observers and experimenters the first being passive m the appearance of phenom- ena; the second, on the other hand, taking a direct and active part m producing them Cuvier expressed the same thought m saying “The observer listens to nature, the experimenter questions and forces her to unveil herself ”

At first sight, and considering things m a general way, this dis» tmction between the experimenter’s activity and the observer’s pas- sivity seems plain and easy to establish But as soon as we come down to experimental practice we find that, m many instances, the separation is very hard to make, and that it sometimes even involves obscurity This comes, it seems to me, from confusing the art of investigation, which seeks and establishes facts, with the art of reason- ing, which works them up logically m the search for truth. Now m investigation there may be activity, at once of the mind and of the senses, whether m making observations or m making experiments Indeed, if we chose to admit that observation is characterized by this alone, that men of science note phenomena which nature pro- duces spontaneously and without interference by them, still we could

1 Zimmermaim, Trait 6 sur Vexp&rience en midecvne Pans, 1774 Vol I,

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not conclude that the mind, like the hand, always remains inactive m observation, and we should he led to distinguish under this head two kinds of observations, some passive, others active I assume, for instance, what often occurs, — that some endemic disease appears m a region and presents itself to a physician's observation Here is a spontaneous or passive observation which the physician makes by chance and without being led to it by any preconceived idea. But after observing the first case, if the physician has an idea that the appearance of this disease may well be related to certain special me- teorological or hygienic circumstances, he takes a journey to other regions where the same disease prevails, to see whether it develops under the same conditions. This second observation, made m view of a preconceived idea of the nature and cause of the disease, is what we must obviously call an induced or active observation I should say as much of an astronomer who, m watching the sky, dis- covers a planet passing, by chance, before his telescope , in this case he makes a fortuitous or passive observation, 1 e , without a precon- ceived idea. But, if the astronomer, after noting the aberrations of a planet, goes on to make observations, to seek a reason for them, then I should say that he makes active observations, 1 e , observations produced by a preconceived idea of the cause of the aberration We might multiply instances of this kind ad infinitum, to prove that, in noting natural phenomena that present themselves, the mind is now passive, now active, — which means, m other words, that observations are made, now without a preconceived idea and by chance, and again with a preconceived idea, 1 e , with intention to verify the accuracy of a mental conception

On the other hand, if we concede, as we said above, that experi- ment is characterized by this alone, that men of science note phe- nomena which they have produced artificially and which would not naturally have presented themselves, even then we could not find that the experimenter's hand always actively interfered to

bring about the appearance of these phenomena. In certain caseB indeed we have seen accidents where nature acted for him, and here again, from the point of view of manual intervention, we shall be forced to distinguish between active experiments and passive experiments Let me assume that a physiologist wishes to study digestion and to learn what happens in a living animal’s stomach, he will divide the walls of the abdomen and stomach according to known operative

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rules and will establish what is called a gastric fistula The physi- ologist will certainly think that he has made an experiment, because he has interfered actively to make phenomena appear which did not present themselves naturally to his eyes But now, let me ask, did Dr W Beaumont make an experiment when he came across that young Canadian hunter who had received a point-blank gun-shot m the left hypochondria, and who had a wide fistula of the stomach m the scar, through which one could look inside that organ? Dr. Beaumont took this man into his service and was able to study the phenomena of gastric digestion de vim for several years, as he shows m the interesting journal which he has given us on this subject 2 In the first case, tbe physiologist acted on the preconceived idea of studying digestive phenomena and made an active experiment In the second case, an accident produced a fistula of the stomach, and it presented itself fortuitously to Dr Beaumont According to our definition, he made a passive experiment These examples therefore prove that, m verifying the phenomena called experiments, the experi- menter’s manual activity does not always come m, since it. happens that the phenomena, as we have seen, may present themselves as fortuitous or passive observations

But certain physiologists and physicians characterize observation and experiment somewhat differently For them, observation con- sists m noting everything normal and regular It matters little whether the investigator has produced the appearance of

the phe- nomena himself or by another's hands or by accident, he considers them without disturbing them m their natural state and so makes an observation Thus, according to these authors, observations were made m both examples of gastric fistula cited above, because m both cases we had under our eyes digestive phenomena m their natural state The fistula served only for seeing better and making observa- tions under the most favorable conditions

Experiment, according to the same physiologists, implies, on the contrary, the idea of a variation or disturbance that an investigator brings into the conditions of natural phenomena This definition corresponds, m fact, to a large group of experiments made m physi- ology, which might be called experiments by destruction This form of experimenting, which goes back to Galen, is the simplest; it

*W Beaumont, Experiments and Observations on the Gastno Juict and on Physiological Digestion Boston, 1834

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should suggest itself to the minds of anatomists wishing to learn, m the living subject, the use of parts that they have isolated by dis- section m the cadaver To do this, we suppress an organ m the living subject, by a section or ablation , and from the disturbance pro- duced m the whole organism or m a special function, we deduce the function of the missing organ This essentially analytic, experimen- tal method is put m practice every day in physiology Tor instance, anatomy had taught us that two principal nerves diverge m the face the facial (seventh cranial) and the trigeminal (fifth cranial) , to learn their functions, they were cut, one at a time The result showed that section of the facial nerve brings about loss of movement, and section of the trigeminal, loss of sensation, from which it was con- cluded that the facial is the motor nerve of the face, and the tri- geminal the sensory nerve

We said that, m studying digestion by means of a fistula, we merely make an observation, according to the definition which we are examining But after we have

established the fistula, if we go on to cut the nerves of the stomach, in order to see the changes which result m the digestive function, then, according to the same way of thinking, we make an experiment, because we seek to learn the function of a part from the disturbance which its suppression in- volves And this may be summed up by saying that m experimenta- tion we make judgments by comparing two facts, one normal, the other abnormal

This definition of experiment necessarily assumes that experi- menters must be able to touch the body on which they wish to act, whether by destroying it or by altering it, so as to learn the part which it plays m the phenomena of nature As we shall later see, it is on this very possibility of acting, or not acting, on a body that the distinction will exclusively rest between sciences called sciences of observation and sciences called experimental

But if the definition of experiment which we have just given dif- fers from the definition examined m the first place m that it admits that we make an experiment only when we can vary or can dissociate phenomena by a kind of analysis, still it resembles the first m that it also always assumes an intentional activity on the experimenter’s part, m producing a disturbance of the phenomena. Now it will be easy to show that the operator’s intentional action can often be replaced by an accident Here too, as in the first definition, we

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might distinguish between disturbances occurring intentionally and disturbances occurring spontaneously or unintentionally Indeed taking again the example m which a physiologist cuts the facial nerve to learn its function, I assume that a ball, a sabre cut or a splinter of stone, has cut or destroyed the facial nerve; there will result fortuitously a paralysis of movement, i.e., a disturbance, ex- actly the same as that which the physiologist caused intentionally It is the same m the case of numberless

pathological lesions which are real experiments, by which physicians and physiologists profit, without any purpose on their part to produce the lesions, which result from disease. I emphasize this idea now, because it will be useful to us later, to prove that medicine includes real experiments which are spontaneous, and not produced by physicians 3

I will make one more remark by way of conclusion If indeed we characterize experiment by a variation or disturbance brought into a phenomenon, it is only m so far as we imply that the disturbance must be compared with the normal state. As experiments indeed axe only judgments, they necessarily require comparison between two things, and the intentional or active element m an experiment is really the comparison which the mind intends to make Now, whether the alteration is produced by accident or otherwise, the experimenter's mind compares none the less It is therefore un- necessary to regard as a disturbance one of the facts to be compared, especially as there is nothing disturbed or abnormal in nature, every-thing happens according to laws which are absolute, i e , always normal and determined Effects vary with the conditions which bring them to pass, but laws do not vary Physiological and patho- logical states are ruled by the same forces , they differ only because of the special conditions under which the vital laws manifest themselves

II Gaining Experience and Belting on Observation Is Differ- ent from Making Experiments and Making Observations

The general objection which I make to the preceding definitions is that they give words too narrow a meaning, by taking account of only the art of investigation, instead of considering observation and expenmen t at the same time as the two opposite extremes of experi-

* Lallemand, Proposition# de pathologte tendant d Mavrer plumeun point# de phynologxe Thesis Paris, 1818 2nd edition, 1824

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mental reasoning So -we find these definitions lacking in clearness and generality To give the definition its full usefulness and value, therefore, I think that we must distinguish what pertains to the method of investigation, used to gather facts, from the characteristics of the intellectual method, which utilizes facts and makes them at once the support and the criterion of the experimental method

In French the word experience m the singular means, m general and in the abstract, the knowledge gained m the practice of life When we apply to a physician the word experience m the singular, it means the information which he has gained in the practice of medi- cine It is the same with the other professions, and it is m this sense that we say that a man has gained experience, or that he has experience Subsequently the word experience (experiment) in the concrete was extended to cover the facts which give us experimental information about things

The word observation m the singular, in its general and abstract use, means noting a fact accurately with the help of appropriate studies and means of investigation In the concrete the word ob- servation has been extended to cover the facts noted, and it is in this sense that we speak of medical observations, astronomical observations, etc.

Speaking concretely, when we say "making experiments or mak- ing observations," we mean that we devote ourselves to investigation and to research, that we make attempts and trials m order to gam facts from which the mind, through reasoning, may draw knowledge or instruction

Speaking in the abstract, when we say "relying on observation and gaming experience," we mean that observation is the mind's sup- port m reasonmg, and experience the mind's support m deciding, or still better, the fruit of exact reasoning applied to the interpretation of facts It follows from this that we can gam experience without making experiments, solely by reasonmg appropriately about well-established facts, just as we can make experiments and observations withoilt gaming

experience, if we limit ourselves to notmg facts

Observation, then, is what shows facts, experiment is what teaches about facts and gives experience m relation to anything But as this teaching can come through comparison and judgment only, 1 e , by sequence of reasoning, it follows that man alone is ca- pable of gaming experience and perfecting himself by it

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"Experience," says Goethe, "disciplines man every day " But tins is because man reasons accurately and experimentally about -what he observes ; otherwise he could not correct himself The insane, who have lost their reason, no longer learn from experience, they no longer reason experimentally Experience, then, is the privilege of reason "Only man may verify his thoughts and set them m order, only man may correct, rectify, improve, perfect and so make himself eveiy day more skilful, wise and fortunate Emally for man alone does the art exist, that supreme art of which the most vaunted arts are mere tools and raw material the art of reason, reasoning " *

In experimental medicine, we shall use the word experience m the same general sense m which it is still everywhere used. Men of science learn every day from experience, by experience they con- stantly correct their scientific ideas, their theories, rectify them, bring them into harmony with more and more facts, and so come nearer and nearer to the truth

We can learn, — 1 e , gam experience of our surroundings, — m two ways, empirically and experimentally First there is a sort of teaching or unconscious and empirical experience, which we get from dealing with separate objects But the knowledge which we gam m this way is also accompanied necessarily by vague experimental reasoning which we carry on quite unawares, and m consequence of which we bring together facts to make a judgment about them Ex- perience, then, may be gained by empirical and unconscious reason- ing, but the obscure and

spontaneous movement of the mind has been raised by men of science into a clear and reasoned method, which therefore proceeds consciously and more swiftly toward a definite goal Such is the experimental method m the sciences by which experience is always gamed by virtue of precise reasoning based on an idea born of observation and controlled by experiment In all experimental knowledge, indeed, there are three phases an observation made, a comparison established and a judgment ren- dered By the experimental method, we simply make a judgment on the facts around us, by help of a criterion which is itself just another fact so arranged as to control the judgment and to afford experience Taken m this general sense, experience is the one source of human knowledge The mmd m itself has only the feeling

4 Laromigm^re, Dtscours eur 1’identito (Euvree Vol I, p 329

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of a necessary relation between things it can know the form of that relation only by experience

Two things must, therefore, be considered m the experimental method (1) The art of getting accurate facts by means of rigorous investigation, (2) the art of working them up by means of experi- mental reasoning, so as to deduce knowledge of the law of phe- nomena We said that experimental reasoning always and neces- sarily deals with two facts at a time observation, used as a starting point , experiment, used as conclusion or control Tn reasoning, how- ever, we can distinguish between actual observation and experiment only, as it were, by logical abstraction and because of the position m which they stand

But outside of experimental reasoning, observation and experi- ment no longer exist in this abstract sense, there are only concrete facts in each, to be got by precise and rigorous methods of investiga- tion- We shall see, further on, that the investigator

himself must be analyzed into observer and experimenter, not according to whether he is active or passive m producing phenomena, but according to whether he acts on them or not, to make himself their master

III The Investigator, Scientific Research

The art of investigation is the cornerstone of all the experimental sciences If the facts used as a basis for reasoning are lll-estab- lished or erroneous, everything will crumble or be falsified, and it is thus that errors m scientific theories most often originate in errors of fact

In investigation, considered as the art of experimental research, we find only facts brought to light by investigators and noted as rigorously as possible with the help of the most suitable means There is no further occasion here to distinguish observers from ex- perimenters by the character of the processes of investigation used In the last section I showed that the definitions and distinctions which men have tried to set up on the basis of the investigator's activity or passivity cannot be sustained Observers and experi- menters, indeed, are investigators seeking to note facts to the best of their ability, using more or less complicated means for this purpose according to the complexity of the phenomena that they study. Both need the same manual and intellectual activity, the same

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dexterity, the same spirit of invention, to create and perfect the different pieces of apparatus or instruments for investigation which, for the most part, they have m common Every science has its own kind of investigation and its equipment of special instruments and methods This, after all, is plain enough, since every science is characterized by the nature of its problems and by the variety of the phenomena that it studies Medical investigation is the most com- plicated of all it includes all the methods proper to anatomical, physiological and therapeutic research, and, as it

develops, it also bor- rows from chemistry and physics many means of research which become powerful allies. In the experimental sciences all progress is measured by improvement m the means of investigation. The whole future of experimental medicine depends on creating a method of research which may be applied fruitfully to the study of vital phe- nomena, whether m a normal or abnormal state I shall not here dwell on the necessity of such a method of investigation m experi- mental medicine, and I shall not even attempt to enumerate the difficulties I shall limit myself to saying that my whole scientific life is devoted to contributing my share to the immense work which modem science will have the glory of having understood, and the merit of having begun, while leaving to future ages the task of con- tinuing and finally establishing it. The two volumes which will form my work on the Principles of Experimental Medicine will be devoted solely to elaborating the methods of experimental investiga- tion applied to physiology, pathology and therapeutics. But as no one man can consider all aspects of medical investigation, I shall limit myself further m this vast subject, by dealing especially with systematization of the methods of zoological vivisection It can- not be gainsaid that this is the most delicate and difficult branch of biological investigation , but I deem it the most fruitful and per- haps the most immediately useful for the advancement of expen- mental medicine.

In scientific investigation, minutiae of method are of the highest importance The happy choice of an animal, an instrument con- structed m some special way, one reagent used instead of another, may often suffice to solve the most abstract and lofty questions Every time that a new and reliable means of expenmental analysis makes its appearance, we invariably see science make progress m the questions to which this means of analysis can be applied On

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the contrary, a had method or defective processes of research may cause the gravest errors, and may retard science by leading it astray In a word, the greatest scientific truths are rooted m details of experimental investigation whifch form, as it were, the soil m which these truths develop

One must be brought up m laboratories and live m them, to appreciate the full importance of all the details of procedure m investigation, which are so often neglected or despised by the false men of science calling themselves generalizes Yet we shall reach really fruitful and luminous generalizations about vital phenomena only in so far as we ourselves expentiient and, m hospitals, amphi- theatres, or laboratories, stir the fetid or throbbing ground of life It has somewhere been said that true science is like a flowering and delectable plateau which can be attained only after climbing craggy steeps and scratching one’s legs against branches and brushwood If a comparison were required to express my idea of the science of life, I should say that it is a superb and dazzlmgly lighted hall which may be reached only by passing thiough a long and ghastly kitchen.

IV Obsebvees and Experimentebs , the Sciences of Observa- tion AND OF ExPEBIMENT

We have just seen that, from the point of view of the art of in- vestigation, observation and experiment should be considered only as facts brought out by investigators, and we have added that methods of investigation do not differentiate the men who observe from the men who experiment Where then, you will ask, is the difference between observers and experimenters ? It is here we give the name observer to the man who applies methods of investigation, whether simple or complex, to the study of phenomena which he does not vary and which he therefore gathers as nature offers them We give the name experimenter to the man who applies methods of in- vestigation, whether simple or complex, so as to make natural phe- nomena vary, or so as to alter them with some purpose or other, and to make

them present themselves m circumstances or conditions m which nature does not show them In this sense, observation is investigation of a natural phenomenon, and experiment is investiga- tion of a phenomenon altered by the investigator We shall see that this distinction, apparently quite external and depending simply on a

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definition of words, still supplies the one meaning with which to grasp the important difference sepaiatmg sciences of observation from sciences of experimentation or experimental sciences We said, m an earlier paragraph, that the words observation and experi- ment, taken m an abstract sense, mean, the first, purely and simply noting' a fact, the second, testing an idea by a fact. But if we consider observation merely m this abstract sense, we cannot deduce from it any science of observation By simply noting facts, we can never succeed m establishing a science Pile up facts or observations as we may, we shall be none the wiser To learn, we must neces- sarily reason about what we have observed, compare the facts and judge them by other facts used as controls But one observation may serve as control for another observation, so that a science of obser- vation is simply a science made up of observations, 1 e , a science m which we reason about facts observed m their natural state, as we have already defined them An experimental science, or science of experimentation, is a science made up of experiments, 1 e , one m which we reason on experimental facts found m conditions created and determined by the experimenter himself

Certain sciences, like astronomy, will always remain sciences of observation, because the pnenomena studied are outside our sphere of action , but terrestrial sciences may be, at once, sciences of observation and experimental sciences Let me add that all these sciences begin as sciences of pure observation, only as we go into the analysis of phenomena do they become experimental, because the observer,

turning experimenter, invents methods of investigation to penetrate bodies and vary the conditions of phenomena. Experimentation is only utilizing methods of investigation peculiar to experi menters.

Now experimental reasoning is absolutely the same, whether m sciences of observation or m experimental sciences We find the same judgment by comparison based on two facts, one used as start- ing point, the other as conclusion, of our reasoning Only m the sciences of observation, the two facts are always observations , while m the experimental sciences, the two facts may be taken exclusively from experimentation, or at the same time from experimentation and from observation, according to the special case and according to how deeply we go into experimental analysis A physician observing a dis- ease m different circumstances, reasoning about the influence of these

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circumstances, and deducing consequences which are controlled by other observations, — this phjsician reasons experimentally, even though he makes no experiments But if he wishes to go further, and to know the inner mechanism of the disease, he will have to deal with hidden phenomena, and so he will experiment, but he will still reason in the same way

A naturalist observing animals in all the conditions necessary to their existence, and deducing from these observations consequences verified and controlled by other observations, — such a naturalist uses the experimental method even though he performs no experiments, properly speaking But if he has to go on to observe phenomena inside the stomach, he is forced to 1m ent more or less complex methods of experimentation m order to look inside a cavity hidden from sight. His experimental reasoning, nevertheless, is the same , Reaumur and Spallanzani alike appty the experimental method when making their observations of natural history or

their experiments with digestion When Pascal made a barometric observation at the bottom of the Tour Saint Jacques, and later took another at the top of the towei, we must admit that he performed an experiment, yet here were simply two comparative observations of air pressure car- ried out m view of the preconceived idea that this pressure should vary according to height. On the other hand, when Jennei,0 m observing a cuckoo on a tree, used a spy-glass so as not to frighten it, he made a mere observation, because he did not compare this cuckoo with a previous cuckoo, to deduce a conclusion from the observation and to form a judgment about it In the same way an astronomer first makes observations and then reasons about them to deduce a system of ideas which he controls by observations made m conditions suited to his purpose The astronomer reasons like an experimenter, because the experience which he gams implies judgment throughout and comparison between two facts bound together m the mind by an idea.

However, as we have said already, we must clearly differentiate astronomers from the men of science concerned with terrestrial sci- ence, m that astronomers limit themselves perforce to observation, as they cannot go into the skies to experiment on the planets In this power of the investigator to act on phenomena, precisely here

* Jenner, On the natural history of the cuchoo (Philosophical Transactions, 1788, Chap XVI, p 432)

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is the difference separating the so-called sciences of experimentation from those of observation.

Laplace considers astronomy a science of observation, because we can only observe the movements of the planets, we cannot reach them, indeed, to alter their course and to experiment with them. “On earth,” said Laplace, “we make phenomena vary by experi- ments ; in the sky, we carefully define all the phenomena presented to us

by celestial motion.” 6 Certain physicians call medicine a sci- ence of observations, because they wrongly think that experimenta- tion is inapplicable to it

Fundamentally, all sciences reason m the same way and aim at the same object They all try to reach knowledge of the law of phe- nomena, so as to foresee, vary or master phenomena. Astrono- mers foretell the movements of the stars, they deduce from them a quantity of practical ideas, but they cannot alter celestial phenom- ena by experimentation as do chemists and physicists the phenomena of their sciences

If then, from the point of view of philosophic method, there is no essential difference between sciences of observation and sciences of experimentation, still there is a real one from the point of view of the practical consequences, which man deduces from them, and the power which he gams by their means In sciences of observation, man observes and reasons experimentally, but he does not experi- ment, and in this sense we might say that a science of observation is a passive science In sciences of experimentation, man observes, but in addition he acts on matter, analyzes its properties and to his own advantage brings about the appearance of phenomena which doubtless always occur according to natural laws, but in conditions which nature often has not yet achieved With the help of these active experimental sciences, man becomes an inventor of phenom- ena, a real foreman of creation; and under this head we cannot set limits to the power that he may gam over nature through future progress in the experimental sciences

The question remains whether medicine should continue a science of observation or become an experimental science Medicine must doubtless begin as simple clinical observation Then, since the human organism is m itself a harmonious unit, a little world (micro- cosm) contained m the great world (macrocosm), men have actually

•Laplace Systime du mondc Chap II

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maintained that life is indivisible and that we should limit our- selves to observing the phenomena presented to us as a whole by liv- ing organisms, whether well or sick, and should content ourselves with reasoning on the facts observed But if we admit that we must so limit ourselves, and if we posit as a principle that medicine is only a passive science of observation, then physicians should no more touch the human body than astronomers touch the planets Hence, normal and pathological anatomy, vivisection applied to physiology, pathology and therapeutics, — all would become completely useless Medicine so conceived can lead only to prognosis and to hygienic prescriptions of doubtful utility, it is the negation of active medicine, i e , of real and scientific therapeutics

This is by no means the place to begin examining so important a definition as that of experimental medicine I propose to treat this question later with all necessary amplification I shall limit mj self here to saying that I think that medicine is destined to be an experimental and progressive science, and precisely because of my conviction in this respect, I am putting together this work with the object of contributing my share toward encouraging the development of scientific and experimental medicine

V Experiment Is Fundamentally Oney Induced Observation

Despite the important difference, which we have just pointed out, between the so-called sciences of observation and of experimentation, observers and experimenters still have the common and immediate object, m their investigations, of establishing and noting facts and phenomena as rigorously as possible, and with the help of the most appropriate means , they behave exactly as if they were dealing with two ordinary observations In both cases, indeed, a fact is simply noted , the only difference is this, — as the fact which an experimenter must verify does not present itself to him naturally, he must make it appear, 1 e , induce it, for a special reason and with a definite ob- ject Hence we may say that an experiment is

fundamentally just an observation induced with some object or other In the experimental method, search for facts, i e , investigation, is always accompanied by reasoning, so that experimenters usually make an experiment to control or verify the value of an experimental idea. Hence, in this

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case, the experiment is an observation induced with the object of control

Still, to complete our definition and to extend it to the sciences of observation, it is worth recalling here that, to verify an idea, it is not always absolutely necessary to make an experiment or an obser- vation ourselves We shall have recourse to experimentation per- force only when the observation to be induced is not already pre- pared in nature But if an observation has already been made, either naturally or accidentally, or even by another investigator, then we may take it ready made, and produce it simply to serve as verifica- tion of the experimental idea And this may be summed up again by saying that, m this case, the experiment is just an observation produced for the purpose of control It follows that, to reason ex- perimentally, we must usually have an idea and afterwards induce or produce facts, 1 e , observations, to control our preconceived idea

We shall examine later the importance of preconceived experi- mental ideas, let it suffice us now to say that the idea, by virtue of which we undertake an experiment, may be more or less clearly defined, according to the nature of the subject and according to the state of perfection of the science m which we are experimenting Indeed the guiding idea of an experiment should include everything already known about the subject, so as to direct our search more surely toward problems whose solution may be fruitful m the ad- vancement of science In established sciences, like physics and chemistry, experimental ideas are deduced m logical sequence from ruling theories, and are submitted with a clearly defined meaning to tbe control of

experiment , but m the case of a science m its Infancy, like medicine, where complex and obscure questions are still to be studied, experimental ideas do not always emerge from rather vague conceptions What then must he done * Must we abstain and wait for observations to present themselves spontaneously and so bring us clearer ideas2 We might often wait long and even m vain, in any case we gam by experimenting But m this instance we can guide ourselves only by a kind of intuition, as we catch sight of prob- abilities, and if the subject is entirely dark and unexplored, physi- ologists should not be afraid even to act somewhat at random, so as to try, — permit me the common expression, — fishing m troubled -fraters This amounts to saying that m the midst of the functional disturbances which they produce, they may hope to see some unex-

pected phenomena emerge which may give direction to their re- search Such groping expeiiments, which are very common m physi- ology and therapeutics because of the complex and backward state of these sciences, may be called erpci intents to sec, because they are intended to make a first obsenation emerge, unforeseen and unde- termined in advance, but whose appearance may suggest an experi- mental idea and open a path for research

There are instances, then, m which we experiment without hav- ing a probable idea to verify However, experimentation m this instance is none the less intended to induce an observation, only it induces it with a view to finding an idea which shall point out a later path to follow in investigation We may therefore say that the ex- periment is then an observation induced with the object of bringing to birth an idea

To sum up, the investigator seeks and concludes , he includes both observations and experiments, he pursues the discovery of new ideas, even while seeking facts from which to draw a conclusion, or an experiment calculated to control other ideas

In a general and abstract sense, an experimenter, then, is a man who produces or induces, in definite conditions, observed facts, to derive from them the instruction which he wishes, — that is, experi- ence An observer is a man who gathers observed facts and who decides whether they have been ascertained by the help of appro- priate means Thus it is that experimenters must at the same time be good observers, and that m the experimental method, experiment and observation always advance side by side

VI lx Experimental Reasoning, Experimenters Are Hot Separate from Observers

Men of science who mean to embrace the principles of the ex- perimental method as a whole, must fulfill two classes of conditions and must possess two qualities of mind which are indispensable if they are to reach their goal and succeed m the discovery of truth First, they must have ideas which they submit to the control of facts , but at the same time they must make sure that the facts which serve as starting point or as control for the idea are correct and well established , they must be at once observers and experimenters Observers, we said, purely and simply note the phenomena before

their eyes They must be anxious only to forearm themselves against errors of observation which might make them incompletely see or poorly define a phenomenon To this end they use every instrument which may help make their observations more complete Observers, then, must be photographers of phenomena , their observations must accurately represent nature We must observe without any pre- conceived idea, the observer’s mmd must be passive, that is, must hold its peace, it listens to nature and writes at nature’s dictation

But when a fact is once noted and a phenomenon well observed, reasoning intervenes, and the experimenter steps forward to interpret the phenomenon.

An experimenter, as we have already said, is a man inspired by a more or less probable but anticipated interpretation of observed phenomena, to devise experiments which, m the logical order of his anticipations, shall bring results serving as controls for his hypothesis or preconceived idea To do this, an experimenter re- flects, tries out, gropes, compares, contrives, so as to find the experi- mental conditions best suited to gam the end which he sets before him Of necessity we experiment with a preconceived idea An experimenter's mmd must be active, i e , must question nature, and put all manner of queries to it according to the various hypotheses which suggest themselves

But when the conditions of an experiment are once established and worked up according to the mind's preconceived idea, an induced or premeditated observation will, as we said, result. Phenomena then appear which the experimenter has caused, but which must now be noted, so as to learn next how to use them to control the experimental idea which brought them to birth Now, from the moment when the result of an experiment appears, the experi- menter is confronted with a real observation which he has induced and must note, like any other observation, without any preconceived idea. The experimenter must now disappear or rather change him- self instantly into an observer , and it is only after he has noted the results of the experiment exactly, like those of an ordinary observa- tion, that his mmd will come back, to reason, compare and decide whether his experimental hypothesis is verified or disproved by these very results To maintain the comparison suggested above, I may say that our experimenter puts questions to nature ; but that, as soon as she speaks, he must hold his peace , he must note her answer, hear

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her out and in e\erj case accept her decision It has been said that the experimenter must force nature to unveil herself Yes, the ex- perimenter doubtless forces nature to

unveil herself by attacking her with all manner of questions, he must never answer for her nor listen partially to her answers by taking, from the results of an experiment, only those which support or confirm his hypothesis. We shall see later that this is one of the great stumbling blocks of the experimental method An experimenter, who clings to his precon- ceived idea and notes the results of his experiment only from this point of view, falls inevitably into error, because he fails to note what he has not foreseen and so makes a partial observation An experimenter must not hold to his idea, except as a means of inviting an answer from nature But he must submit his idea to nature and be ready to abandon, to alter or to supplant it, in ac- cordance with what he learns from observing the phenomena which, he has induced

Two operations must therefore be considered m any experiment. The first consists m premeditating and bringing to pass the condi- tions of the experiment, the second consists m noting the results of the experiment It is impossible to devise an experiment without a preconceived idea, devising an experiment, we said, is putting a question , we never conceive a question without an idea which invites an answer I consider it, therefore, an absolute principle that ex- periments must always be devised m view of a preconceived idea, no matter if the idea be not very clear nor very well defined As for noting the results of the experiment, which is itself only an induced observation, I posit it similarly as a principle that we must here, as always, observe without a preconceived idea

In the experimenter, we might also differentiate and separate the man who preconceives and devises an experiment from the man who carries it out or notes its results In the former, it is the scientific investigator’s mind that acts, m the latter, it is the senses that observe and note What I am setting forth is most strikingly proved m the case of Francois Huber 7 Though blind, this great naturalist left us admirable experiments which he conceived and afterward had carried out by his serving man, who, for his part, had not a single scientific idea So Huber was the directing mind

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* Francois Huber, Novvelles Observations sur let Abet lies, 2nd edition, ex- panded by hiq son, Pierre Huber, Geneva, 1814

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de\ ised the experiment , but he was forced to borrow another's senses The serving man stood for the passive senses, obedient to the mind m carrying out an experiment devised m the light of a preconceived idea

People who condemn the use of hypotheses and of preconceived ideas m the experimental method make the mistake of confusing in- vention of an experiment with noting its results We may truly say that the results of an experiment must be noted by a mind stripped of hypotheses and preconceived ideas But we must beware of proscribing the use of hypotheses and of ideas when devising ex- periments or imagining means of observation On the contrary, as we shall soon see, we must give free rem to our imagination , the idea is the essence of all reasoning and all invention All progress depends on that It cannot be smothered or driven away on the pretence that it may do harm , it must only he regulated and given a criterion, which is quite another matter

The true scientist is one whose work includes both expen- mental theory and expenmental practice (1) He notes a fact, (2) d propos of this fact, an idea is born m his mind, (3) m the light of this idea, he reasons, devises an experiment, imagines and brings to pass its material conditions, (4) from this experiment, new phenomena result which must be observed, and so on and so forth The mind of a scientist is always placed, as it were, between two observations one which serves as starting point for reasoning, and the other which serves as conclusion

To make myself clearer, I have endeavored to separate the dif- ferent operations of expenmental reasoning Bnt when it all takes place at the same time in the head of a

scientist, abandoning him- self to investigation m a science as vague as medicine still is, then the results of observation are so entangled with the bases of experiment that it would be alike impossible and useless to try to dis- sociate, from their inextricable mingling, each one of these terms It is enough to remember the pnnciple that an a pnon idea, or better, an hypothesis, is a stimulus to experiment, and that we must let our- selves go with it freely, provided that we observe the results of our experiment rigorously and fully If an hypothesis is not verified and disappears, the facts which it has enabled us to find aTe none the less acquired as indestructible materials for science

Observers and experimenters, then, correspond to different phases

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of experimental research The observer does not reason, he notes, the experimenter, on the other hand, reasons and grounds himself on acquired facts, to imagine and induce rationally other facts But though in theory and abstractly we may differentiate observers from experimenters, it seems impossible to separate them m practice, since we see that one and the same investigator, perforce, is alternately observer and experimenter

Things happen constantly, indeed, m this way when a single man of science discovers and explains a whole scientific question un- aided But it more often happens in the evolution of science, that different parts of experimental reasoning are shared by several men Some of these, both m medicine and m natural history, merely gather and assemble observations, others manage to formulate more or less ingenious and more or less probable hypotheses based on these obser- vations, then others come m to create conditions favoring the birth of an experiment to control these hypotheses, finally others apply themselves more especially to generalizing and systematizing the results obtained by the different observers and experimenters

This parceling out of the experimental domain is useful, because each one of its various parts is all the better cultivated In fact we can easily conceive that, m certain sciences, the means of observation and experimentation are such specialized instruments that their manage- ment and use require a certain manual dexterity or the sharpening of certain senses But while I accept specialization m the practice, I reject it utterly in the theory of science I believe, indeed, that making generalization one's specialty is anti-philosophic and anti- scientific, in spite of what has been proclaimed by a modem philo- sophic school which piques itself on its scientific basis

Experimental science, however, cannot advance on a single side of the method taken separately, it goes ahead only by the union of all parts of the method converging toward a common goal Men nho gather observations are useful only because their observations aie afterward introduced into experimental reasoning, m other words, endless accumulation of observations leads nowhere Men, who formulate hypotheses a propos of observations gathered by others, are useful only m so far as men seek to verify these hypotheses by ex- perimenting, else these hypotheses, unverified or unvenfiable by experiment, would engender nothing but systems and would bring us back to scholasticism Men who experiment, despite all their dex-

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tenty, cannot solve problems nnless they are inspired by a fortunate hypothesis based on accurate and well-made observations. Finally men who generalize can make lasting theories only m so far as they themselves learn all the scientific details that these theories are intended to represent. Scientific generalization must proceed from particular facts to principles , and principles are the more stable as they rest on deeper details, just as a stake is the firmer, the farther it is driven into the ground

We see, then, that the elements of the scientific method are inter- related Facts are

necessary materials, but their working up by experimental reasoning, i e , by theory, is what establishes and really builds up science Ideas, given form by facts, embody science A scientific hypothesis is merely a scientific idea, preconceived or pro- visioned A theory is merely a scientific idea controlled by experi- ment Reasoning merely gives a form to our ideas, so that every- thing, first and last, leads back to an idea. The idea is what estab- lishes, as we shall see, the starting point or the pnmum movens of all scientific reasoning, and it is also the goal m the mind’s aspiration toward the unknown

CHAPTER II

THE A PRIORI IDEA AND DOUBT IN EXPERIMENTAL

REASONING

Evekioxe first works out bis own ideas about wbat be sees and is inclined to interpret natural phenomena by anticipation before knowing them through experience This tendency is spontaneous, a preconceived idea always has been and always will be the first flight of an investigating mind But the object of the experimental method is to transform this a priori conception, based on an intuition or a vague feeling about the nature of things, into an a, posteriori inter- pretation founded on the experimental study of phenomena. This is why the experimental method is also called the a posteriori method

Man is by nature metaphysical and proud He has gone so far as to think that the idealistic creations of his mind, which correspond to his feelings, also represent reality Hence it follows that the experimental method is by no means primitive or

natural to man, and that only after lengthy wanderings m theological and scholastic discussion has he recognized at last the sterility of his efforts m this direction At this point man becomes aware that he cannot dictate laws to nature, because he does not contain within himself the knowledge and criterion of external things, and he understands that to find truth he must, on the contrary, study natural laws and submit his ideas, if not his reason, to experience, that is, to the criterion of facts Yet for all that, the method of work of the human mind is not changed at bottom. The metaphysician, the Scholastic, and the experimenter all work with an a pnon idea. The differ- ence is that the scholastic imposes his idea as an absolute truth which he has found, and from which he then deduces consequences by logic alone The more modest experimenter, on the other hand, states an idea as a question, as an interpretative, more or less probable anticipa- tion of nature, from which he logically deduces consequences which, moment by moment, he confronts with reality by means of experi- ment He advances, thus, from partial to more general truths, but without ever daring to assert that he has grasped the absolute truth

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Indeed if we Reid it at any point whatever, we should have it every- ' where , for the absolute leaves nothing outside itself

An experimental idea, then, is also an a priori idea, but it is an idea that presents itself m the form of an hypothesis the consequences of which must be submitted to the criterion of experiment, so that its value may be tested The experimenter’s mmd differs from the metaphysician’s or the scholastic’s m its modesty, because experiment makes him, moment by moment, conscious of both his relative and his absolute ignorance In teaching man, experimental science re- sults in lessening his pride more and more by proving to him every day that primary causes, like the objective reality of things, will be hidden from him forever and that he can know

only relations Here is, indeed, the one goal of all the sciences, as we shall see further on

The human mmd has at different periods of its evolution passed successively through feeling , reason and experiment . First, feeling alone, imposing itself on reason, created the truths of faith or the- ology Reason or philosophy, the mind's next mistress, brought to birth scholasticism At last, experiment, or the study of natural phenomena, taught man that the truths of the outer world are to be found ready formulated neither m feeling nor m reason These are indispensable merely as guides, but to attain external truths we must of necessity go down into the objective reality of things where they lie hidden m their phenomenal form

Thus, m the natural progress of things, appeared the experimental method which includes everything and which, as we shall soon see, leans successively on the three divisions of that unchangeable tripod sentiment, reason and experiment In the search for truth by means of this method, feeling always takes the lead, it begets the a prion idea or intuition , reason or reasoning develops the idea and deduces its logical consequences But if feeling must be clarified by the light of reason, reason m turn must be guided by experiment

I Experimental Truths Are Objective or External

The experimental method is concerned only with the search for objective truths, not with any search for subjective truths

As there are two lands of functions m man's body, the first, con- scious functions, the rest not, so m his mmd there are two kinds of

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truths or notions, some conscious, inner or subjective, the others unconscious, outer or objective Subjective truths are those flowing from principles of which the mind is conscious, and which bring it the sensation of absolute and necessary evidence The

greatest truths, indeed, are at bottom simply a feeling m our mind , that is what Descartes meant by his famous aphorism

We said, on the other hand, that man would never know either the primary cause, nor the essence of thmgs Hence truth never shows itself to his mind except m the form of a connection or of a necessary and absolute relation But this connection may be abso- lute only m so far as its conditions are simple and subjective, that is, when the mind is aware of knowing them all Mathematics em- bodies the relations of things in conditions of ideal simplicity It follows that these principles or relations, once found, are accepted by the mind as absolute truths, i e , truths independent of reality We see now that all logical deductions in a piece of mathematical reason- ing are just as certain as their principle, and that they do not require verification by experiment That would be trying to place the senses above reason , and it would be absurd to seek to prove what is abso- lutely true for the mind and what it could not conceive otherwise

But when man stops working with subjective relations, the condi- tions of which his mind has created, and tries to learn about the objective relations of nature which he has not created, then at once the inner and conscious criterion fails him He is, of course, still aware that m the objective or outer world truth consists, in the same way, of necessary relations , but he lacks knowledge of the conditions of these relations Only if he had created these conditions, indeed, could he possess absolute knowledge of them and absolute under- standing

Still man must believe that the objective relations between phenomena of the outer world might attain the certainty of subjective truths if they were reduced to a state of simplicity that his mind could completely grasp Thus, m the study of the simplest of natural phenomena, experimental science has laid hold on certain relations which appear absolute Such are the propositions which serve as principles m theoretical mechanics and in some branches of mathe- matical phjsics In these sciences, indeed,

we reason by logical deduction which we do not submit to experiment, because we admit, as in mathematics, that the principle being true the deductions are

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true also Still, there is a wide difference to note m this respect, that the starting point here is no longer a subjective and conscious truth, but an objective and unconscious truth, borrowed from obser- vation or experiment How this truth is never more than relative to the number of experiments and observations that have been made. Even if no observation has so far disproved the truth m question, still the mind does not therefore imagine that things cannot happen otherwise, so that it is only by hypothesis that we admit the principle as absolute That is why the application of mathematical analysis to natural phenomena, even very simple ones, may have its dangers if experimental verification is entirely rejected In this case, mathematical analysis becomes a blind instrument, if we do not from time to time retemper it m the furnace of experiment. I here express a thought uttered by many great mathematicians and great physicists , and in order to recall one of the moat authoritative opin- ions m this field, I will cite what my learned associate and friend, J. Bertrand, wrote on this subject m his fine tribute to Senarmont “Eor the physicist, geometry should be only a powerful ally when it has pushed its principles to their last consequences, it can do no more, and the uncertainty of the starting point can only be in- creased by the blind logic of analysis, if experiment at each step does not serve as compass and ruler.” 1

Theoretical mechanics and mathematical physics make the connec- tion then between mathematics proper and the experimental sciences They include the simplest cases But as soon as we go into physics and chemistry, and especially biology, the phenomena are complicated by so many relations that the principles, embodied m theories to which we have been able to rise, are only provisional and

are so hypothetical that our deductions, even though very logical, are abso- lutely uncertain and can m no case dispense with experimental verification

In short, man may relate all his reasonings to two criteria the one, inner and conscious, is sure and absolute, the other, outer and unconscious, is experimental and relative

When we reason about outer objects, but consider them m their relation to ourselves according to the pleasure or displeasure which they occasion us m proportion to their utility or their disadvantages,

ij Bertrand, Eloge de M 86narmont, address given at the sixth annual public meeting of the SociStS de eeoours dee omw den sciences

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we still possess an inner criterion in. our sensations So, when we reason about our own actions, we again have a sure guide, because we are conscious of what we are thinking and of what we are feeling But if we wish to judge the actions of another man and to know the motives which make him act, then it is quite different Doubt- less we see before our eyes the man’s movements and the acts which, we are sure, are expressions of his feeling and his will What is more, we also admit that there is a necessary relation between actions and their cause , but what is this cause 2 We do not feel it ourselves, we are not aware of it as m our own case , we are therefore forced to interpret and imagine it from the movements that we see and the words that we hear So we must verify the man’s acts, one by an- other, we consider how he behaves m such and such circumstances, and m short, we turn to the experimental method In like manner j when a man of science considers the natural phenomena which surround him and which he wishes to know m themselves and m their complex mutual relations of causation, every inner criterion fails him, and he is forced to invoke experiment to verify the sup- positions and the reasonings that he is

making about them Experi- ment, then, according to Goethe's expression, becomes the one medi- ator between the objective and the subjective,2 that is to say, between the man of science and the phenomena which surround him

Experimental reasoning is the only reasoning that naturalists and physicians can use in seeking the truth and approaching it as nearly as possible Indeed, m its very character as an outer and unconscious criterion, experiment gives only relative truth, without being able to prove to the mind that it knows truth absolutely

An experimenter facing natural phenomena is like a spectator watching a dumb show He is in some sort the examining magistrate for nature , only instead of grappling with men who seek to deceive him by lying confessions or false witness, he is dealing with natural phenomena which for him are persons whose language and customs he does not know, persons living m the midst of circumstances un- known to him, yet persons whose designs he wishes to learn For this purpose he uses all the means within his power He observes their actions, their gait, their behavior, and he seeks to disengage their cause by means of various attempts, called experiments He

' Goethe, CEuvres d'histotre naturelle, translation by M Ch Martins, Intro duction, p 1

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uses every imaginable artifice, and, as tbe popular expression goes, be often makes a false plea m order to learn tbe truth In all this, tbe experimenter reasons necessarily according to bis own character and lends to nature bis own ideas He makes suppositions about tbe cause of actions taking place before bis eyes , and to learn whether the hypothesis which serves as groundwork for his interpretation is correct, he takes measures to make facts appear which m the realm of logic may be either the confirmation or the negation of the idea which he has conceived Now, I repeat, only

this logical verification can teach him and give him experience The naturalist observing animals whose behavior and habits he wishes to know, the physiol- ogist and the physician wishing to study the hidden functions of liv- ing bodies, the physicist and the chemist defining the phenomena of inert matter, — they are all m the same situation, they have mani- festations before them which they can interpret only with the help of the experimental criterion, the only one which we need to consider here

II Intuition or Feeling Begets the Experimental Idea

We said above that the experimental method rests successively on feeling, reason and experiment

Feeling gives rise to the experimental idea or hypothesis, le, the previsioned interpretation of natural phenomena The whole experimental enterprise comes from the idea, for this it is which induces experiment Reason or reasoning serves only to deduce the consequences of this idea and to submit them to experiment

An anticipative idea or an hypothesis is, then, the necessary starting point for all experimental reasoning Without it, we could not make any investigation at all nor learn anything, we could only pile up sterile observations If we experimented without a pre- conceived idea, we should move at random, but, on the other hand, as we have said elsewhere, if we observed with preconceived ideas, we should make bad observations and should risk taking our mental conceptions for reality

Experimental ideas are by no means innate They do not arise spontaneously, they must have an outer occasion or stimulant, as Is tbe case m all physiological functions To have our first idea of things, we must see those things, to have an idea about a natural

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phenomenon, we must, first of all, observe it. The mind of man cannot conceive an

effect without a cause, so that the sight of a phenomenon always awakens an idea of causation All human knowl- edge is limited to working back from observed effects to their cause Following an observation, an idea connected with the cause of the observed phenomenon presents itself to the mind We then inject this anticipative idea into a tram of reasoning, by virtue of which we make experiments to control it.

Experimental ideas, as we shall later see, may arise either a priori of a fact observed by chance or following some experimental venture or as corollaries of an accepted theory For the moment, we may merely note that the experimental idea is by no means arbi- trary or purely imaginative, it must always have a support in ob- served reality, that is to say, in nature The experimental hypoth- esis, in short, must always be based on prior observation An- other essential of any hypothesis is that it must be as probable as may be and must be experimentally verifiable Indeed if we made an hypothesis which experiment could not verify, m that very act we should leave the experimental method to fall into the errors of the scholastics and makers of systems

A propos of a given observation, no rules can be given for bring- ing to birth m the brain a correct and fertile idea that may be a sort of intuitive anticipation of successful research The idea once set forth, we can only explain how to submit it to the definite pre- cepts and precise rules of logic from which no experimenter may depart, but its appearance is wholly spontaneous, and its nature is wholly individual A particular feeling, a quid propnum con- stitutes the originality, the inventiveness, or the genius of each man A new idea appears as a new or unexpected relation which the mind perceives among things All intellects doubtless resemble each other, and m all men similar ideas may arise m the presence of certain simple relations between things, which everyone can grasp But like the senses, intellects do not all have the same power or the same acuteness , and subtle and delicate relations exist which can be felt, grasped and unveiled only by minds more perceptive, better endowed, or placed m intellectual surroundings which predispose them favorably

If facts necessarily gave birth to ideas, every new fact ought to beget a new idea True, this is what most often takes place, for

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new facts exist, the character of which makes the same new idea come to all men, placed m the same circumstances as respects previous in- formation But facts also exist which mean nothing to most minds, while they are full of light for others It even happens that a fact or an observation stays a very long time under the eyes of a man of science without m any way inspiring him, then suddenly there comes a ray of light, and the mmd interprets the fact quite dif- ferently and finds for it wholly new relations The new idea ap- pears, then, with the rapidity of lightning, as a kind of sudden reve- lation, which surely proves that m this case the discovery inheres m a feeling about things which is not only individual, but which is even connected with a transient condition of the mmd The experi- mental method, then, cannot give new and fruitful ideas to men who have none, it can serve only to guide the ideas of men who have them, to direct their ideas and to develop them so as to get the best possible results The idea is a seed, the method is the earth fur- nishing the conditions m which it may develop, flourish and give the best of fruit according to its nature But as only what has been sown m the ground will ever grow in it, so nothing will be developed by the experimental method except the ideas submitted to it The method itself gives birth to nothing Certain philosophers have made the mistake of according too much power to method along these lines

The experimental idea is the result of a sort of presentiment of the mmd which thinks thmg3 will happen m a certain way In this connection we may say that we have m our minds an intuition or feel- ing as to the laws of nature, but we do not know their form We can learn it only from experiment

Men with a presentiment of new truths are rare m all the sci- ences , most men

develop and follow the ideas of a few others Those who make discoveries are the promoters of new and fruitful ideas. We usually give the name of discovery to recognition of a new fact, but I think that the idea connected with the discovered fact is what really constitutes the discovery Facts are neither great nor small m themselves A great discovery is a fact whose appearance m science gives rise to shmmg ideas, whose light dispels many obscuri- ties and shows us new paths There are other facts which, though new, teach us but little, they are therefore small discoveries Finally, there are new facts which, though well observed, teach nothing to any-

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one, they remain, for the moment, detached and sterile in science, they are what we may call raw facts or crude facts

Discovery, then, is a new idea emerging in connection with a fact found by chance or otherwise Consequently, there can be no method for making discoveries, because philosophic theories can no more give inventive spirit and aptness of mind to men, who do not possess them, than knowledge of the laws of acoustics or optics can give a correct ear or good sight to men deprived of them by nature But good methods can teach us to develop and use to better purpose the faculties with which nature has endowed us, while poor methods may prevent us from turning them to good account Thus the genius of inventiveness, so precious in the sciences, may be diminished or even smothered by a poor method, while a good method may increase and develop it In short, a good method promotes' scientific devel- opment and forewarns men of science against those numberless sources of error which they meet m the search for truth, this is the only possible object of the experimental method In biological science, the role of method is even more important than m other sciences, because of the immense complexity of the phenomena and the countless sources of error which

complexity brings into experi- mentation Yet even from the biological point of view, we can- not claim to treat the experimental method completely here , we must limit ourselves to giving a few general principles for the guidance of minds applying themselves to research in experimental medicine

III Expebimentees Must Doubt, Avoid Fixed Ideas, and Always Keep Theie Fkeedom of Mind

The first condition to be fulfilled by men of science, applying themselves to the investigation of natural phenomena, is to maintain absolute freedom of mind, based on philosophic doubt Yet we must not be m the least sceptical , we must believe m science, 1 e , in deter- minism, we must believe m a complete and necessary relation be- tween things, among the phenomena proper to living beings as well as m all others, but at the same time we must be thoroughly con- vinced that we know this relation only m a more or less approximate way, and that the theories we hold are far from embodying change- less truths When we propound a general theory m our sciences,

we are sure only that, literally speaking, all such theories are false They are only partial and provisional truths which are necessary to us, as steps on which we rest, so as to go on with investigation; they embody only the present state of our knowledge, and consequently they must change with the growth of science, and all the more often when sciences are less advanced m their evolution. On the other hand, our ideas come to us, as we said, in view of facts which have been previously observed and which we interpret afterward Now countless sources of error may slip into our observations, and m spite of all our attention and sagacity, we are never sure of having seen everything, because our means of observation are often too imperfect The result of all this is, then, that if reasoning guides us m expei imental science, it

does not necessarily force its deductions upon us Our mind can always remain free to accept or to dispute these deductions If an idea presents itself to us, we must not reject it simply because it does not agree with the logical deductions of a reigning theory We may follow our feelings and our idea and give free rein to our imagination, as long as all our ideas are mere pre- texts for devising new experiments that may supply us with con- vincing or unexpected and fertile facts

The freedom which experimenters maintain is founded, as I said, on philosophic doubt Indeed, we must be aware of the un- certainty of our reasonings on account of the obscurity of their starting point The starting point, fundamentally, always rests on hypotheses or theories more or less imperfect, according to the state of development of the sciences In biology, and especially m medi- cine, theories are so precarious that the experimenter maintains almost all his freedom In chemistry and physics the facts are simpler, the sciences are more advanced, the theories more secure, and the experimenter must take more account of them and allow greater importance to the deductions of experimental reasoning based on them But still he must never accept these theories at their face value In our day, we have seen great physicists make discoveries of the first rank by means of experiments devised m a way that lacked all logical relation to admitted theories Astronomers have enough confidence in the principles of their science to build up mathematical theories with them, but that does not prevent them from testing and verifying them by direct observations, this very precept, as we have seen, must not be neglected m theoretical mechanics. But m math©-

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matics, when we start from an axiom or principle whose truth is absolutely necessary and conscious, freedom no longer exists , truths once established are immutable Geometricians are not free to ques- tion whether the three angles of a

triangle are or are not equal to two right angles, consequently they are not free to reject the logical consequences deduced from this principle

If a doctor imagined that his reasoning had the value of a mathe- matician's, he would be utterly in error and would be led into the most unsound conclusions This is unluckily what has happened and still happens to the men whom I shall call systematizers These men start, in fact, from an idea which is based more or less on ob- servation, and which they regard as an absolute truth They then leason logically and without experimenting, and from deduction tc deduction they succeed in building a system which is logical, but which has no sort of scientific reality Superficial persons often let themselves be dazzled by this appearance of logic, and discussions worthy of ancient scholasticism are thus sometimes renewed m our day The excessive faith m reasoning, which leads physiologists to a false simplification of things, comes, on the one hand, from igno- rance of the science of which they speak, and, on the other hand, from lack of a feeling for the complexity of natural phenomena That is why we sometimes see pure mathematicians, with very great minds too, fall into mistakes of this kind , they simplify too much and rea- son about phenomena as they construct them m their minds, but not as they exist m nature

The great experimental principle, then, is doubt, that philosophic doubt which leaves to the mind its freedom and initiative, and from which the virtues most valuable to investigators m physiology and medicine are derived We must trust our observations or our the- ories only after experimental verification If we trust too much, the mind becomes bound and cramped by the results of its own rea- soning, it no longer has freedom of action, and so lacks the power to break away from that blind faith m theories which is only scien- tific superstition

It has often been said that, to make discoveries, one must be ignorant This opinion, mistaken m itself, nevertheless conceals a truth It means that it is better to know nothing than to keep m mind fixed ideas based on theories whose confirmation we

constantly seek, neglecting meanwhile everything that fails to agree with them

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Nothing could be worse than this state of mind, it is the very opposite of inventiveness Indeed a discovery is generally an un- foreseen relation not included m theory, for otherwise it would be foreseen In this respect, indeed, an uneducated man, knowing ' nothing of theory, would be m a better attitude of mind , theory would not embarrass him and would not prevent him from seeing new facts unperceived by a man preoccupied with an exclusive theory But let us hasten to say that we certainly do not mean to raise igno- rance into a principle The better educated we are and the more ac- quired information we have, the better prepared shall we find our minds for making great and fruitful discoveries Only we must keep our freedom of mind, as we said above, and must believe that m nature what is absurd, according to our theories, is not always impossible

Men who have excessive faith m their theories or ideas are not only ill prepared for making discoveries , they also make very pool observations Of necessity, they observe with a preconceived idea, and when they devise an experiment, they can see, m its results, only a confirmation of their theory In this way they distort obser- vation and often neglect very important facts because they do not further their aim This is what made us say elsewhere that we must never make experiments to confirm our ideas, but simply to control them , 3 which means, m other terms, that one must accept the results of experiments as they come, with all their unexpectedness and irregularity

But it happens further quite naturally that men who believe too firmly m their theories, do not believe enough m the theories of] others So the dominant idea of these despisers of their fellow/* is to find others’ theories faulty and to try to contradict them The difficulty, for science, is still the same They make experiments

only to destroy a theory, instead of to seek the truth At the same time, they make poor observations, because they choose among the results of their experiments only what suits their object, neglecting whatever is unrelated to it, and carefully setting aside everything which might tend toward the idea they wish to combat By these two opposite roads, men are thus led to the same result, that is, to falsify science and the facts

» Claude Bernard, Lecons sur les propriety et les alterations dee Uquides de Vorganxsme Pans, 1859, Premise leqon

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Accordingly, we must disregard our own opinion quite as much as the opinion of others, when faced by the decisions of experience If men discuss and experiment, as we have just said, to prove a preconceived idea m spite of everything, they no longer have free- dom of mind, and they no longer search for truth Theirs is a narrow science, mingled with personal vanity or the diverse passions of man Pnde, however, should have nothing to do with all these vain disputes When two physiologists or two doctors quarrel, each to maintain his own ideas or theories, m the midst of their contra- dictory arguments, only one thing is absolutely certain that both theories are insufficient, and neither of them corresponds to the truth The truly scientific spirit, then, should make us modest and kindly We really know very little, and we are all fallible when facing the immense difficulties presented by investigation of natural phenomena The best thing, then, for us to do is to unite our efforts, instead of dividing them and nullifying them by personal disputes In a word, the man of science wishing to find truth must keep his mind free and calm, and if it be possible, never have his eye bedewed, as Bacon says, by human passions

In scientific education, it is very important to differentiate, as we shall do later, between determinism which is the absolute prin- ciple of science, and theories which

are only relative principles to which we should assign but temporary value m the search for truth In a word, we must not teach theories as dogmas or articles of faith By exaggerated belief m theories, we should give a false idea of science, we should overload and enslave the mind, by taking away its freedom, smothering its originality and infecting it with the taste for systems

The theories which embody our scientific ideas as a whole are, of course, indispensable as representations of science They should also serve as a basis for new ideas But as these theories and ideas are by no means immutable truth, one must always be ready to abandon them, to alter them or to exchange them as soon as they cease to represent the truth In a word, we must alter theory to adapt it to nature, but not nature to adapt it to theory

To sum up, two things must be considered m experimental science method and idea- The object of method is to direct the idea which arises in the interpretation of natural phenomena and m the search for truth The idea must always remain independent, and we must

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no more chain it with scientific beliefs than with philosophic or religious beliefs, we must be bold and free m setting forth our ideas, must follow our feeling, and must on no account linger too long in childish fear of contradicting theories If we are thoroughly steeped m the principles of the experimental method, we have noth- ing to fear, for, as long as the idea is correct, we go* on developing it , when it is wrong, experimentation is there to set it right We must be able, then, to attack questions even at the risk of going wrong We do science better service, as has been said, by mistakes than by confusion, which means that we must fearlessly push ideas to their full development, provided that we regulate them and are always careful to judge them by experiment The idea, m a word, is the motive of all reasoning, m science as

elsewhere But everywhere the idea must be submitted to a criterion In science the criterion is the experimental method or experiment, this criterion is indis- pensable, and we must apply it to our own ideas as well as to those of others

IV The Independent Character of the Experimental Method

'From all that has so far been said, it follows necessarily, that no man’s opinion, formulated m a theory or otherwise, may be deemed to represent the whole truth in the sciences It is a guide, a light, but not an absolute authority The revolution which the experimental method has effected in the sciences is this it has put a scientific criterion m the place of personal authority

The experimental method is characterized by being dependent only on itself, because it includes within itself its criterion, — experi- ence It recognizes no authority other than that of facts and is fiee from personal authority When Descartes said that we must trust only to evidence or to what is sufficiently proved, be meant that we must no longer defer to authority, as scholasticism did, but must rely only on facts firmly established by experience

The result of this is that when we have put forward an idea or a theory m science, our object must not be to preserve it by seeking everything that may support it and setting aside everything that may weaken it. On the contrary, we ought to examine with the greatest care the facts which apparently would overthrow it, be- cause real pi ogress always consists m exchanging an old theory

which includes fewer facts for a new one which includes more This proves that we have advanced, for m science the best precept is to alter and exchange our ideas as fast as science moves ahead Our ideas are only intellectual instruments which we use to break into phenomena, we must change them when they have served their purpose, as we change a blunt lancet that we have used long enough

The ideas and theories of our predecessois must be preserved only m so far as they represent the present state of science, but they are obviously destined to change, unless we admit that science is to make no further progress, and that is impossible In this con- nection, we should perhaps make a distinction between mathematical sciences and experimental sciences As mathematical truths are immutable and absolute, the science of mathematics grows by sim- ple successive juxtaposition of all acquired truths As truths m the experimental sciences, on the contrary, are only relative, these sciences can move forward only by revolution and by recasting old truths m a new scientific form

In the experimental sciences, a mistaken respect for personal authority would be superstition and would form a real obstacle to the progress of science at the same time, it would be contrary to the examples given us by the great men of all time Great men, indeed, are precisely those who bring with them new ideas and destroy errors They do not, therefore, respect the authority of their own predeces- sors, and they do not expect us to treat them otherwise

This non-submission to authority, which the experimental method regards as a fundamental precept, is by no means out of harmony with the respect and admiration which we bear to the great men preceding us, to whom we owe the discoveries at the base of the sciences of to-day 4

In the experimental sciences, great men are never the pro- moters of absolute and immutable truths Each great man belongs to his time and can come only at his proper moment, m the sense that there is a necessary and ordered sequence m the appearance of scientific discoveries Great men may be compared to torches shining at long intervals, to guide the advance of science They light up their time, either by discovering unexpected and fertile

4 Claude Bernard, Cours de midecvne expinmentdle, legon cFouveriure [Gazette mid, April 15, 1864)

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phenomena which open up new paths and reveal unknown horizons, or by generalizing acquired scientific facts and disclosing truths which their predecessors had not perceived If each great man makes the science which he vitalizes take a long step forward, he never pre- sumes to fix its final boundaries, and he is necessarily destined to be outdistanced and left behind by the progress of successive genera- tions Great men have been compared to giants upon whose shoul- ders pygmies have climbed, who nevertheless see further than they This simply means that science makes progress subsequently to the appearance of great men, and piecisely because of their influence The lesult is that their successors know many more scientific facts than the great men themselves had m their day But a great man is, none the less, still a great man, that is to say, — a giant

There are, indeed, two sides to science m evolution on the one hand, what is acquned already, and on the other hand, what remains to be acquired In the already acquired, all men are more or less equal, and the great cannot be distinguished from the rest Medio- cre men often have the most acquired knowledge It is m the darker regions of science that great men are recognized, they are marked by ideas which light up phenomena hitherto obscure and carry science forward

To sum up, the experimental method draws from within itself an impersonal authority which dominates science It forces this au- thority even on great men, instead of seeking, like the scholastics, to prove from texts that they are infallible and that they have seen, said or thought everything discovered after them Every period has its own sum total of errors and of truths Certain mistakes are, m a sense, mheient m their period, so that only the subsequent prog- ress of science can reveal them The progress of the experimental method consists m this, — that the sum of truths grows larger m pro- portion as the sum of error grows less But each one of these par- ticular truths is added to the rest to establish more general truths In this

fusion, the names of promoters of science disappear little by little, and the further science advances, the more it takes an im- personal form and detaches itself from the past To avoid a mistake which has sometimes been committed, I hasten to add that I mean to speak here of the evolution of science only In art and letters, per- sonality dominates everything There we are concerned with a spon- taneous creation of the mind, that has nothing m common with the

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noting of natural phenomena, m which the mind must create nothing The past keeps all its worth m the creations of art and letters , each individuality remains changeless m time and cannot be mistaken for another A contemporary poet has characterized this sense of the personality of art and of the impersonality of science in these words, — “Art is myself , science is ourselves ”

The experimental method is the scientific method which pro- claims the freedom of the mind and of thought It not only shakes off the philosophical and theological yoke , it does not even accept any personal scientific authority This is by no means pnde and boast- fulness, experimenters, on the contrary, show their humility m rejecting personal authority, for they doubt their own knowledge also and submit the authority of man to the authority of experience and of the laws of nature

Physics and chemistry, as established sciences, offer us the independence and impersonality which the experimental method demands But medicine is still m the shades of empiricism and suffers the consequences of its backward condition We see it still more or less mingled with religion and with the supernatural Superstitution and the marvellous play a great part in it Sorcerers, somnambulists, healers by virtue of some gift from Heaven, are held as the equals of physicians Medical personality is placed above science by physicians themselves , they seek their authority m tradi- tion, m doctrines or m medical tact This state of affairs is the clearest of proofs that

the experimental method has by no means come into its own m medicine

The experimental method, the free thinker’s method, seeks only scientific truth Feeling, from which everything emanates, must keep its complete spontaneity and all its freedom for putting forth experimental ideas, reason also must preserve that freedom to doubt, which forces it always to submit ideas to the test of experi- ment Just as, in other human actions, feeling releases an act by putting forth the idea which gives a motive to action, so m the experimental method feeling takes the initiative through the idea Feeling alone guides the mind and constitutes the pnmurn movens of science Genius is revealed m a delicate feeling which correctly foresees the laws of natural phenomena, but this we must never for- get, that correctness of feeling and fertility of idea can be established and proved only by experiment

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Y. Induction and Deduction in Experimental Reasoning

We have so far dealt with the influence of the experimental idea . Let us now consider how the method, while always forcing upon rea- son the dubitative form, may guide it more safely m the search for truth

We said elsewhere that experimental reasoning is practised on observed phenomena, or observations , but it is really applied only to the ideas which the phenomena have aroused m our mind The essence of experimental reasoning, then, will always be an idea which we introduce into a piece of experimental reasoning in order to sub- mit it to the criterion of facts, 1 e , to experiment.

There are two forms of reasoning first, the investigating or in- terrogative form used by men who do not know and who wish to learn , secondly, the demonstrating or affirmative form employed by men who know or think they know, and who wish to teach others

Philosophers seem to have differentiated these two forms of rea- soning under the

names of inductive reasoning and deductive rea- soning They also accept two scientific methods the inductive method or induction, proper to the experimental physical sciences, and the deductive method or deduction, belonging more particularly •to the mathematical sciences

It follows that the one special form of experimental reasoning with which we must deal here is induction

Induction has been defined as the process of moving from the particular to the general, while deduction is the reverse process mov- ing from the general to the particular I certainly shall not presume to engage m a philosophic discussion which would here be out of place and beyond my competence, only m my capacity as experi- menter I shall content myself with saying that it seems to me very difficult, m practice, to justify this distinction and clearly to separate induction from deduction If the experimenter's mmd usually pro- ceeds by starting from particular observations and going back to principles, to laws, or to general propositions, it also necessarily proceeds from the same general propositions or laws and reaches particular facts which it deduces logically from these principles Only, when a principle is not absolutely certain, we must always make a temporary deduction requiring experimental verification All the seeming varieties of reasoning depend merely on the nature of

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the subject treated and on its greater or less complexity But m all these cases, the human mind always works m the same way, with syllogisms , it cannot behave otherwise

Just as man goes forward, m the natural movement of his body, only by putting one foot m front of the other, so m the natural inoiement of bis mind, man goes forward only by putting one idea m front of another In other words, the mmd, like the body,

needs a primary pomt of suppoit The body’s point of suppoit is the ground which the foot feels, the mind’s point of support is the known, that is, a truth or a principle of which the mmd is aware Man can learn nothing except by going from the known to the un- known , but on the other band, as science is not infused into man at birth, and as be knows only what be learns, we seem to be m a vicious circle, urhere man is condemned to inability to learn any- thing He would be so, m fact, if his reason did not include a feeling for relations and for deteimimsm, which are the criteria of truth , but m no case can he gam this truth or approach it, except through reasoning and experience

It would be incorrect to say that deduction pertains only to mathematics and induction to the other sciences exclusively Both forms of reasoning, investigating (inductive) and demonstrating (deductive), pertain to all possible sciences, because m all the sci- ences there are things that w e do not know and other things that we know or think we know

When mathematicians study subjects unfamiliar to them, they use induction, like physicists, chemists or physiologists To prove this point, I need only cite the words of a great mathematician

Thus Euler expresses himself m a memoir entitled De xnduc- tione ad plenum certitwhnem evehenda-

“Notum est plerumque numerum proprietates pnmum per solam mductionem observatas, quas demceps geometrae solidis demon- strationibus confirmare elaboraverunt , quo negotio m pnmis Eer- matius summo studio et satis felici successu fuit occupatus ” 5

The principles or theories which serve as foundations for a sci- ence, whatever it may be, have not fallen from the sky, they were necessarily reached by investigation, inductive or interrogative rea- soning, as we may choose to call it It was first necessary to observe

‘Euler, Acta acadcnnae scxentiarum impenahs Petropohtanae, pro anno MDCOLXXX, pars posterior, p 38, Par 1

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something which happened within ourselves or outside of us. From the experimental point of view there are ideas, in the sciences, which we call a- prion, because they are a starting point for experimental reasoning (see page 27 and the following pages), but from the point of view of ideogenesis they are really a posteriori ideas In a word, induction must have been the primitive, general form of rea- soning, and the ideas which philosophers and men of science con- stantly take for a priori ideas are at bottom really a posteriori ideas

Mathematicians and naturalists are alike when going m search of principles Both use induction, make hypotheses, and experiment, that is to say, make attempts to verify the accuracy of their ideas But when mathematicians and naturalists reach their principles, then they part company. Indeed, as I have already said elsewhere, the mathematician’s principle is absolute, because it is not applicable to objective reality just as it is, but to relations between things con- sidered m extremely simple conditions which the mathematician chooses and, m some sort, creates m his mind Now, as he is thus sure that he need not introduce into his reasoning other conditions than those which he has defined, the principle remains absolute, conscious, adequate for the mind, and his logical deduction is equally certain and absolute he no longer requires experimental verifica- tions, logic is enough

A naturalist is m a very different position , the general proposi- tion which he has reached, or the principle on which he relies, is rela- tive and provisional, because it embodies complex relations which he is never sure that he can know Hence, his principle is uncer-1 tain, since it is unconscious and inadequate for the mind, hence, deductions, though quite logical, always remain doubtful, and so he must necesanly

appeal to experiment to verify the conclusion of his deductive reasoning The difference between mathematicians and naturalists is capital m respect to the certainty of their principles and of the conclusions to be drawn from them , but the mechanism of deductive reasoning is exactly the same for both Both start from a proposition, only the mathematician says Given this start- ing point, such and such a particular case necessarily results The naturalist says If this starting point is correct, such and such a particular case will follow as a consequence

When starting from a principle, the mathematician and (he naturalist, therefore, both use deduction Both reason by making a

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syllogism , only, for the naturalist the conclusion of the syllogism is doubtful and requires verification, because its principle is uncon- scious 8 Such experimental or dubitative reasoning is the only kind that we can use when reasoning about natural phenomena, if we wished to suppress doubt and if we dispensed with experiment, we should no longer have any criterion by which to know whether we were m the wrong or m the right, because, I repeat, the principle is unconscious, and one must therefore appeal to our senses

From all this I should conclude that induction and deduction be- long to all the sciences I do not believe that induction and deduc- tion are really two forms of reasoning essentially distinct By nature man has the feeling or idea of a principle that rules partic- ular cases He always proceeds instinctively from a principle, ac- quired or invented by hypothesis, but he can never go forward m reasoning otherwise than by syllogism, that is, by proceeding from the general to the particular

In physiology, a given organ always works through one and the same mechanism , only, when the phenomenon occurs under different conditions or m a different environment, the function takes on a different aspect , but fundamentally its

character remains the same In my opinion there is only one way of reasoning for the mind, just as there is only one way of walking for the body But when a man goes ahead on solid flat ground, by a straight road whose whole ex- tent he knows and sees, he advances toward his goal at an assured and rapid pace On the conti ary, when a man follows a winding road m the dark and over unknown hilly ground, he dieads preci- pices and goes forward cautiously, step by step Before taking a second step, he must make sure that he has placed his first foot on a spot that is firm, then go forward m the same way verifying ex- perimentally, moment by moment, the solidity of the ground, and always changing the direction of his advance according to what he encounters Such is the experimenter who must never go beyond fact m his searching, lest he risk losing his way In the two pre- ceding examples the man goes forward over different ground and m varied surroundings, but he goes forward none the less by the same physiological method In the same way, when an experimenter simply deduces relations from definite phenomena by means of known

*1 e , Not a postulate and not exclusively an affair of the mind note *

Translator’s

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and established principles, bis reasoning develops m a secure and necessary -way, while, if he finds himself m the midst of complex relations and with the support only of vague, provisional pnn- eiples, the same experimenter must then go forward cautiously and must submit to experiment each one of the ideas which he successively puts forward But, m both these cases, the mind still reasons m the same way and by the same physiological method, only it starts from a more or less binding principle

When any sort of phenomenon strikes us in. nature, we work out our idea of the cause determining it Man m his primal ignorance imagined divinities connected with

each phenomenon To-day men of science acknowledge forces or laws it is they that govern phenomena. An idea that comes to us at the sight of a phenomenon is called a, prion Now we shall later easily show that this a pnon idea, which rises m us a propos of a special fact, always contains implicitly and, m some sort, without our knowledge, a principle to which we tend to refer the special fact, so that when we think that we are moving from a special case to a principle, 1 e , making an induction, we are really making a deduction, only the expenmenter guides him- self by an assumed or provisional principle which he alters moment by moment, because he is searching m almost total darkness In proportion as we gather facts, our principles become more and more general and more secure, so we gam the certainty that we deduce But nevertheless, m the experimental sciences, our principle must always remain provisional, because we are never certain that it in- cludes only the facts and conditions of which we are aware In short, our deductions are always hypothetical until verified experi- mentally An experimenter, therefore, can never be in the posi- tion of the mathematician, precisely because experimental reasoning, by its very nature, is always dubitative If we wish, we can call the experimenter's dubitative reasoning induction, and the mathemati- cian's affirmative reasoning deduction , but the distinction will then apply to the certainty or uncertainty of our starting point m reason- ing, not to the way m which we reason

VI Doubt in Experimental Reasoning

I will summarize the preceding paragraph by saying that there seems to me to be only one form of reasoning deduction by syllogism

The mind, even if it wished, could not reason otherwise, and if this were the place for it, I might try to support my proposition by physiological arguments But to find scientific truth, we, after all, have little need to know how our mind reasons, it is

enough to let it reason naturally, and m that case it will always start from a principle to reach a conclusion All we need do here is to insist on a precept which will always forearm the mind against the count- less sources of error that may be met m applying the experimental method

This general precept, one of the foundations of the experimental method, is doubt it is expressed by saying that the conclusion of our reasoning must always remain dubitative when the starting point or the principle is not an absolute truth We have seen that there is no absolute truth apart from mathematical principles, m all nat- ural phenomena the principles from which we start, like the conclu- sions which we reach, embody only relative truths The experi- menter's stumbling block, then, consists m thinking that he knows what he does not know, and m taking for absolute, truths that are only relative Hence, the unique and fundamental rule of scien- tific investigation is reduced to doubt, as great philosophers, moreover, have already proclaimed

Experimental reasoning is precisely the reverse of scholastic reasoning Scholasticism must always have a fixed and indubitable starting point, and, unable to find it either m outer things or m reason, it borrows it from some irrational source, such as revela- tion, tradition, a conventional or an arbitrary authority The starting point once settled, scholastics or systematizers deduce logi- cally all the consequences, even invoking as arguments observation or experience of facts when they are favorable , the one condition is that the starting point shall remain immutable and shall not vary with their experiences and observations, but on the contrary that facts shall be so interpreted as to adapt themselves to it Experimenters, on the contrary, never accept an immutable starting point, their prin- ciple is a postulate, all of whose consequences they logically deduce, hut without ever considering it absolute or beyond the reach of ex- periment The chemists' elements are elements only until proof to the contrary All the theories which serve as starting points for physicists, chemists, and with still more reason physiologists, are true

only until facts are discovered which they do not include, or

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which contradict them When these contradictory facts are shown to be firmly established, far from stiffening themselves against ex- perience, like the scholastics or systematizers, experimenters, on the contrary, hasten to safeguard their starting point, to modify their theory, because they know that this is the only way to go forward and to make progress m science Experimenters, then, always doubt even their starting point, of necessity they keep a supple and modest mind and accept contradiction, on the one condition that it be proved Scholastics or systematizers never question their starting point, to which they seek to refer everything, they have a proud and intol- erant mind and do not accept contradiction, since they do not admit that their starting point may change Men of system are also dis- tinguished from men of experimental science by the fact that the first impose their idea, while the second always give it just for what it is worth Finally, another essential characteristic, which differentiates experimental reasoning from scholastic reasoning, is the fertility of the one and the sterility of the other The scholastic who believes himself m possession of absolute certainty comes to naught, this can easily be understood, since by his absolute principle, he puts himself outside of nature, m which everything is lelative The experimenter, on the contrary, who always doubts and who does not believe that he possesses absolute certainty about anything, succeeds in mastering the phenomena that surround him and m extending his power ovei nature Man can do, then, more than he knows, and true experimental science gives him power only m showing him his ignorance Possessing absolute truth matters litrle to the man of science, so long as he is certain about the rela- tions of phenomena to one another Indeed, our mind is so limited that we can know neither the beginning nor the end of things, but ive can grasp the middle, 1 e , what

surrounds us closely.

Systematic or scholastic reasoning is natural to inexperienced, proud minds, it is only by thorough experimental study of nature that we succeed m acquiring the experimenter's doubting mind That takes a long time , of those who think they are following the experimental path m physiology and m medicine, many, as wo shall see later, are still scholastics As for me, I am convinced that only study of nature can give scholars a true perception of science Phi- losophy, which I consider an excellent gymnastic for the mm d, has systematic and scholastic tendencies in spite of itself, which would

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be harmful to men. of science properly so-called After all, no method can replace that study of nature ■which makes true men of science without that study, all that philosophers have said and all that I myself have repeated after them m this introduction would remain inapplicable and sterile

I do not think, therefoie, as I said above, that it is very profitable for men of science to discuss definitions of induction and of deduc- tion, nor, for that matter, the question whether we advance bj one or the other of these so-called processes of mind Baconian induc- tion, however, has become famous and has been made the founda- tion of all scientific philosophy Bacon was a great genius, and his great restoration of the sciences is sublime as an idea, we are captivated and earned along in spite of ourselves, m reading the Novum Organum and the Augmentum Scientwrum We are fas- cinated by a medley of scientific gleams, clothed m the loftiest of poetic forms Bacon felt the stenlity of scholasticism , he well under- stood and foresaw the importance of experiment for the future of the sciences Tet Bacon was not a man of science, and he did not understand the mechanism of the experimental method To prove this, it would be enough to cite the hapless attempts

which he made Bacon advises us to fly from hypotheses and theones, 7 we have seen, however, that they are auxiliaries of the method, indispensable as scaffolding is necessary m building a house Bacon, as is always the case, had extravagant admirers and detractors Without taking one side or the other, I will say that, while recognizing Bacon's genius, I believe no more than J de Maistre 8 that he endowed the human intellect with a new instrument, and it seems to me, as to M de Kemusat,0 that induction does not differ from the syllogism Moreover,, I believe that great experimenters appeared before all precepts of experimentation, as great orators preceded all treatises on rhetoric Consequently, even m speaking of Bacon, it does not seem to me permissible to say he invented the experimental method, that method which Galileo and Torricelli so admirably practised and which Bacon never could use

When Descartes 10 starts from universal doubt and repudiates

' Bacon, CEuvres, edition, Francois Riaux, Introduction, p 30 * J de Maistre, Examen de la philosophic de Bacon ' M. de Rtemsat, Bacon, sa me, son temps et sa philosophic, 1857 "Descartes, Discount tur la mithode

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authority, he gives much more practical precepts for the experimenter than those that Bacon gives for induction We have seen, indeed, that only doubt promotes experiment, it is doubt, finally, -which determines the form of experimental reasoning

In connection with medicine and the physiological sciences, how- ever, it is important to determine at what point to apply doubt, so as to distinguish it from scepticism, and to show how scientific doubt becomes an element of the greatest certainty The sceptic disbe- lieves m science and believes m himself, he believes enough m him- self to dare deny science and to assert that it is not subject to

definite, fixed laws The doubter is a true man of science, he doubts onlv himself and his interpretations, but he believes m science, m the experimental sciences, he even accepts a criterion or absolute scien- tific principle This principle is the determinism of phenomena, which is as absolute m the phenomena of living bodies as m those of inorganic matter, as we shall later assert (page 65).

Finally, m concluding this section, we may say that in all experi- mental reasoning there are two possibilities either the experi- menter's hypothesis will be disproved or it will be proved by ex- periment When experiment disproves his preconceived idea, the experimenter must discard or modify it But even when experi- ment fully proves his preconceived idea, the experimenter must still doubt, for since he is dealing with an unconscious truth, his reason still demands a counterproof

YII The Principle of the Experimental Criterion

We have just said that one must doubt, but by no means be sceptical A sceptic, indeed, who believes nothing, no longer has a foundation on which to establish his criterion, and consequently he finds it impossible to build up a science, the sterility of his unhappy mind results at once from the error of his perception and from the imperfection of his reason. After having posited the principle that investigators must doubt, we added that doubt will apply only to the soundness of their opinions, or of their ideas as experimenters, or to the value of their means of investigation, as observers, but never to determinism, the very principle of experimental science. Eet us return m a few words to this fundamental point

Experimenters must doubt their intuition, i e , the a pnon idea

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or the theory •which serves as their starting point, this is "why it is an absolute principle always to submit one's idea to the experimental criterion so as to test its value But just what is the foundation of this experimental criterion? This question

may seem superfluous, after having repeatedly said that facts judge the idea and give us experience Facts alone are real, it is said, and we must leave the matter to them, wholly and exclusively Again, it is a fact, a sheer fact, men often repeat , there is no use m discussing, we must accept it Of course I admit that facts are the only realities that can give form to the experimental idea and at the same time serve as its control , but this is on condition that reason accepts them I think that blind belief m fact, which dares to silence reason, is as dangerous to the experimental sciences as the beliefs of feeling or of faith which also force silence on reason In a word, m the experi- mental method as m everything else, the only real criterion is reason A fact is nothing in itself, it has value only through the idea connected with it or through the proof it supplies We have said elsewhere that, when one calls a new fact a discovery, the fact itself is not the discovery, but rather the new idea derived from it , in the same way, when a fact proves anything, the fact does not itself give the proof, but only the rational relation which it establishes between the phenomenon and its cause This relation is the scientific truth which we now must discuss further

Let us recall how we characterized mathematical truths and ex- perimental truths Mathematical truths, once acquired, we said, are conscious and absolute truths, because the ideal conditions m which they exist are also conscious and known by us m an absolute way Experimental truths, on the contrary, are unconscious and relative, because the real conditions on which they exist are un- conscious and can be known by us only in their relation to the pres- ent state of our science But if the experimental truths, which serve as foundation for our reasoning, are so wrapped up m the complex reality of natural phenomena that they appear to us only m shreds, these experimental truths rest, none the less, on principles that are absolute because, like those of mathematical truths, they speak to our consciousness and our reason Indeed the absolute principle of experimental science is conscious and necessary determinism m the conditions of phenomena So that, given no matter what natural phenomenon, experimenters can never acknowledge variation m the

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embodiment of this phenomenon, unless new conditions have at the same time occurred m its coming to pass, what is more, they have an a prion certainty, that these variations are determined by rig1- orous, mathematical relations Experiment only shows us the form of phenomena, but the relation of a phenomenon to a definite cause is necessary and independent of experiment , it is necessarily mathe- matical and absolute Thus we see that the principle of the cri- terion m experimental sciences is fundamentally identical with that of the mathematical sciences, since m each case the principle is ex- pressed by a necessary and absolute relation between things Only m the experimental sciences these relations are surrounded by numerous, complex and infinitely varied phenomena which hide them from our sight. With the help of experiment, we analyze, we dissociate these phenomena, m order to reduce them to more and more simple rela- tions and conditions In this way we try to lay hold on scientific truth, 1 e , find the law that shall give us the key to all variations of the phenomena. Thus experimental analysis is our only means of going m search of truth m the natural sciences, and the absolute determinism of phenomena, of which we are conscious a prion > is the only criterion or principle which directs and supports us In spite of our efforts, we are still very far from this absolute truth ; and it is probable, especially m the biological sciences, that it will never be given us to see it m its nakedness But this need not dis- courage us, for we are constantly neanng it , and moreover, with the help of our experiments, we grasp relations between phenomena which, though partial and relative, allow us more and more to ex- tend our power over nature

It follows from the above that, if a phenomenon, m an experiment, had such a contradictory appearance that it did not necessarily con- nect itself with determinate causes, then reason should reject the fact as non-scientific We should wait or by direct experiments seek the source of error which may have slipped into the

observation Indeed, there must be error or insufficiency m the observation, for to accept a fact without a cause, that is, indeterminate m its necessary conditions, 13 neither more nor less than the negation of science So that, m the presence of such a fact, men of science must never hesitate, they must believe m science and doubt their means of investigation They will, therefore, perfect their means of observation and will make every effort to get out of the darkness , but they

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■will never deny the absolute determinism of the phenomena, be- cause it is precisely the recognition of determinism that character- izes true men of science

In medicine, we are often confronted with poorly observed and indefinite facts which form actual obstacles to science, in. that men always bring them up, saying it is a fact, it must be accepted National science based, as we have said, on a necessary determinism, must never repudiate an accurate and well-observed fact, but on the same principle, it ought not to encumber itself with apparent facts collected without precision, and possessing no kind of meaning, which are used as a double-edged weapon to support or disprove the most diverse opinions In short, science rejects the indeterminate , and m medicine, when we begin to base our opinions on medical tact, on inspiration, or on more or less vague intuition about things, we are outside of science and offer an example of that fanciful medi- cine which may involve the greatest dangers, by surrendering the health and life of the sick to the whims of an inspired ignoramus. True science teaches us to doubt and, in ignorance, to refrain

VIII Peoof and Counterpboof

We said above that experimenters, who see their ideas confirmed by an experiment, should still doubt and require a counterproof Indeed, proof that a given condition always precedes or accom- panies a phenomenon does not warrant concluding with certainty that a given condition is the immediate cause of that phenomenon It must

still be established that, when this condition is removed, the phenomenon will no longer appear If we limited ourselves to the proof of presence alone, we might fall into error at any moment and believe in relations of cause and effect where there was nothing but simple coincidence As we shall later see, coincidences form one of the most dangerous stumbling blocks encountered by experimental scientists m complex sciences like biology It is the post hoc, ergo propter hoc of the doctors, into which we may very easily let ourselves be led, especially if the result of an experiment or an observation supports a preconceived idea

Counterproof, then, is a necessary and essential characteristic of the conclusion of experimental reasoning It is the expression of philosophic doubt earned as far as possible Counterproof de-

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cides whether the relation of cause to effect, which we seek m phe- nomena, has been found To do this, it removes the accepted cause, to see if the effect persists, relying on that old and absolutely true adage sublata causa > tolhtur effectus This is what we still call the expenmentum cruets

We must not confuse a counterexpenment or counterproof with what has been called comparative experiment As we shall later see, this is only a comparative observation resorted to, m complex circumstances, to simplify phenomena and to forearm oneself against unforeseen sources of error, counterproof, on the contrary, is a counterjudgment dealing directly with the experimental conclu- sion and forming one of its necessary terms Indeed, proof, in science, never establishes certainty without counterproof Analysis can be absolutely proved only when the synthesis, which demonstrates it, provides the counterproof or counterexperiment Similarly a synthesis made at the outset should be demonstrated later by analy- sis Feeling for this necessary, experimental counterproof con- stitutes the scientific feeling par

excellence It is familiar to physi- cists and chemists, but it is far from being as well understood by physicians In most cases, when we see two phenomena m physiology or medicine going together and following one another m a con- stant order, we think we may conclude that the first is the cause of the second This would be a false judgment m very many cases, statistical tables of presence or of absence never establish experi- mental demonstrations In complex sciences like medicine, we must at the same time make use of comparative experiment and of counter- proof Some physicians fear and avoid counterproof, as soon as they make observations m the direction of their ideas, they refuse to look for contradictory facts, for fear of seeing their hypothesis vanish We have already said that this is a very poor spirit, if we mean to find truth, we can solidly settle our ideas only by trying to destroy our own conclusions by counterexperiments Now the only proof that one phenomenon plays the part of cause m relation to another is by removing the first, to stop the second

I shall not further emphasize this principle of the experimental method at this point, because I shall later take the opportunity to return to it, giving special examples which will explain my thought. Let me summarize by saying that expenmenters should always push their investigation to the point of counterproof, without that, their

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experimental reasoning 'would not be complete Counterproof estab- lishes the necessary determinism of phenomena, and thus alone can satisfy reason to which, as we have said, we must always bring back any true scientific criterion

Experimental reasoning, whose different terms we have examined in the preceding section, sets itself the same goal m all the sciences Experimenters try to reach determinism , with the help of reasoning and of experiment they try to connect natural phenomena with their necessary conditions or, m other words, with their

immediate causes By this means, they reach the law which enables them to master phenomena All natural philosophy is summarized m knowing the law of phenomena. The whole experimental problem may be re- duced to foreseeing and directing phenomena But this double goal can be attained, m living bodies, only by certain special prin- ciples of experimentation which we must point out in the following chapters

PAET TWO

EXPERIMENTATION WITH LIVING BEINGS

CHAPTER I

EXPERIMENTAL CONSIDERATIONS COMMON TO LIVING THINGS AND INORGANIC BODIES

I The Spontaneity oe Living Beings Is no Obstacle to the Use of Experimentation

The spontaneity enjoyed by beings endowed with life has been one of the principal objections urged against the use of experi- mentation m biological studies Every living being indeed appears to us provided with a kind of inner force, which presides over mani- festations of life more and more independent of general cosmic in- fluence m proportion as the being rises higher in the scale of organi- zation In the higher animals and m man, for instance, this vital force seems to result m withdrawing the living being from general physico-chemical influences and thus making the experimental ap- proach very difficult

Inorganic bodies offer no parallel, whatever their nature, they are all devoid of spontaneity As the manifestation of their prop- erties is therefore absolutely bound up m the physico-chemical con- ditions surrounding them and forming their

environment, it follows that the experimenter can reach them and alter them at will

On the other hand, all the phenomena of a living body are m such reciprocal harmony one with another that it seems impossible to separate any part without at once disturbing the whole organ- ism. Especially m higher animals, their more acute sensitiveness brings with it still more notable reactions and disturbances

Many physicians and speculative physiologists, with certain anatomists and naturalists, employ these various arguments to attack experimentation on living bemgs They assume a vital force in opposition to physico-chemical forces, dominating all the phenomena

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of life, subjecting them to entirely separate laws, and making the organism an organized whole which the experimenter may not touch without destroying the quality of life itself They even go so far as to say that inorganic bodies and living bodies differ radically from this point of view, so that experimentation is applicable to the former and not to the latter Cuvier, who shares this opinion and thinks that physiology should be a science of observation and of de- ductive anatomy, expresses himself thus “All parts of a living body are interrelated , they can act only m so far as they act all together , trying to separate one from the whole means transferring it to the realm of dead substances, it means entirely changing its essence” If the above objections were well founded, we should either have to recognize that determinism is impossible m the phenomena of life, and this would be simply denying biological science , or else we should have to acknowledge that vital force must be studied by special methods, and that the science of life must rest on different principles from the science of inorganic bodies These ideas, which were current in other times, are now gradually disappearing, but it is essential to extirpate their very last spawn, because the so-called vitalistic ideas still remaining m certain minds are really an

obstacle to the progress of experimental science

I propose, therefore, to prove that the science of vital phenomena must have the same foundations as the science of the phenomena of inorganic bodies, and that there is no difference in this respect be- tween the principles of biological science and those of physico-chem- ical science Indeed, as we have already said, the goal which the experimental method sets itself is everywhere the same, it consists m connecting natural phenomena with their necessary conditions or with their immediate causes In biology, since these conditions are known, physiologists can guide the manifestation of vital phenomena as physicists guide the natural phenomena, the laws of which they have discovered , but m doing so, experimenters do not act on life Yet there is absolute determinism m all the sciences, because every phenomenon being necessarily linked with physico-chemical conditions, men of science can alter them to master the phenomenon, i e , to prevent or to promote its appearing As to this, there is absolutely no question m the case of inorganic bodies I mean to prove that it is the same with living bodies, and that for them also

determinism exists

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II Manifestation of Pbopebties of Living Bodies Is Con- nected with the Existence of Ceetain Physico-Chemical Phenomena Which Regulate Their Appearance

The manifestation of properties of inorganic bodies is connected with surrounding conditions of temperature and moisture by means of which the experimenter can directly govern mineral phenomena Living bodies at first sight do not seem capable of being thus influenced by neighboring physico-chemical conditions, but that is merely a delusion depending on the animal having and maintaining within himself the conditions of warmth and moisture necessary to the appearance of vital phenomena The result is that an inert body, obedient to cosmic conditions, is linked

with all their variations, while a living body on the contrary remains independent and free m its manifestations , it seems animated by an inner force that rules all its acts and liberates it from the influence of surrounding physico- chemical variations and disturbances This quite different aspect of the manifestations of living bodies as compared with the behavior of inorganic bodies has led the psysiologists, called vitalists, to at- tribute to the former a vital force ceaselessly at war with physico-chemical forces and neutralizing their destructive action on the living organism According to this view, the manifestations of life are determined by spontaneous action of this special vital force, instead of being, like the manifestations of inorganic bodies, the necessary re- sults of conditions or of the physico-chemical influences of a surround- ing environment But if we consider it, we shall soon see that the spontaneity of living bodies is simply an appearance and the result of a certain mechanism m completely determined environ- ments, so that it will be easy, after all, to prove that the behavior of living bodies, as well as the behavior of inorganic bodies, is domi- nated by a necessary determinism linking them with conditions of a purely physico-chemical order

Let us note, first of all, that this kind of independence of living beings m the cosmic environment appears only m complex higher animals Inferior beings, such as the infusoria, reduced to an ele- mentary organism, have no real independence These creatures exhibit the vital properties with which they are endowed, only under the influence of external moisture, light or warmth, and as soon as one or more of these conditions happens to fail, the vital manifes-

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tation ceases, because the parallel physico-chemical phenomenon has stopped. In vegetables the manifestation of vital phenomena is linked m the same way with conditions of warmth, moisture and light m the surrounding environment It is the

same again with cold-blooded animals, the phenomena of life are benumbed or stimulated accord- ing to the same conditions Now the influences producing or re- tarding vital manifestations m living beings are exactly the same as those which produce, accelerate or retard manifestations of phys- ico-chemical phenomena in inorganic bodies, so that instead of fol- lowing the example of the vitalists m seeing a kind of opposition or incompatibility between the conditions of vital manifestations and the conditions of physico-chemical manifestations, we must note, on the contrary, in these two orders of phenomena a complete parallelism and a direct and necessary relation Only in warm-blooded animals do the conditions of the organism and those of the surrounding en- vironment seem to be independent, m these animals indeed the manifestation of vital phenomena no longer suffers the alternations and variations that the cosmic conditions display, and an inner force seems to 30m combat with these influences and m spite of them to maintain the vital forces m equilibrium But fundamentally it is nothing of the sort , and the semblance depends simply on the fact that, by the more complete protective mechanism which we shall have occasion to study, the warm-blooded animal’s internal environment comes less easily into equilibrium with the external cosmic environ- ment. External influences, therefore, bring about changes and dis- turbances m the intensity of organic functions only m so far ns the protective system of the organism’s internal environment becomes insufficient m given conditions.

TTT. Physiological Phenomena in the Highek Animals Take Place in Peeeected Intebnal Oeganio Envikonments En- dowed with Constant Phisico-Ohemical Properties

Thoroughly to understand the application of experimentation to living beings, it is of the first importance to reach a definite judgment on the ideas which we are now explaining When we examino a higher, 1 e., a complex living organism, and see it fulfill its different functions in the general cosmic environment common to all the pho-

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nomena of nature, it seems to a certain extent independent of this environment But this appearance results simply from our deluding ourselves about the simplicity of vital phenomena The external phe- nomena which we perceive m the living being are fundamentally very complex, they are the resultant of a host of intimate properties of organic units whose manifestations are linked together with the physico-chemical conditions of the internal environment m which they are immersed In our explanations we suppress this inner en- vironment and see only the outer environment before our eyes But the real explanation of vital phenomena rests on study and knowledge of the extremely tenuous and delicate particles which form the organic units of the body This idea, long ago set forth m biology by great physiologists, seems more and more true m propor- tion as the science of the organization of living beings makes progress. We must, moreover, learn that the intimate particles of an organ- ism exhibit their vital activity only through a necessary physico- chemical relation with immediate environments which we must also study and know. Otherwise, if we limit ourselves to the survey of total phenomena visible from without, we may falsely believe that a force m living beings violates the physico-chemical laws of the gen- eral cosmic environment,]ust as an untaught man might believe that Borne special force m a machine, rising in the air or running along the ground, violated the laws of gravitation Now, a living organism is nothing but a wonderful machine endowed with the most marvellous properties and set going by means of the most complex and delicate mechanism There are no forces opposed and struggling one with another, m nature there can be only order and disorder, harmony or discord

In experimentation on inorganic bodies, we need take account of only one environment, the external cosmic environment, while m the higher living animals, at least two environments must be considered, the external or extra-organic

environment and the internal or mtra- orgamc environment In my course on physiology at the Faculty of Sciences, I explain each year these ideas on organic environment, — new ideas which I regard as fundamental m general physiology, they are also necessarily fundamental m general pathology, and the same thoughts will guide us m adapting experimentation to living beings, For, as I have said elsewheie, the great difficulties that we meet m expei mentally determining \ital phenomena and m applying suit-

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able means to altering them are caused by tbe complexity involved in tbe existence of an internal organic environment.1

Physicists and chemists experimenting on inert bodies need con- sider only the external environment, by means of the thermometer, barometer and other instruments used m recording and measuring the properties of the external environment, they can always set them- selves m equivalent conditions For physiologists these instruments no longer suffice, and yet the internal environment is just the place where they should use them. Indeed, the internal environment of living beings is always m direct relation with the normal or patho- logical vital manifestations of organic units In proportion as we ascend the scale of living beings, the organism grows more complex, the organic units become more delicate and require a more perfected internal environment The circulating liquids, the blood serum and the mtra-orgamc fluids all constitute the internal environment In living beings the internal environment, which is a true product of the organism, preserves the necessary relations of exchange and equilibrium with the external cosmic environment , but m proportion as the organism grows more perfect, the organic environment becomes specialized and more and more isolated, as it were, from the sur- rounding environment In vegetables and m cold-blooded animals, as we have

said, this isolation is less complete than m warm-blooded animals , in the latter the blood serum maintains an almost fixed and constant temperature and composition. But these differing condi- tions do not constitute differences of nature m different living beings, they are merely improvements m the isolating and protecting mech- anisms of their environment Vital manifestations m animals vaiy only because the physico-chemical conditions of their internal envi- ronments vary, thus a mammal, whose blood has been chilled either by natural hibernation or by certain lesions of the nervous system, closely resembles a really cold-blooded animal m the properties of its tissues

To sum up, from what has been said we can gam an idea of the enormous complexity of vital phenomena and of the almost insuper- able difficulties which their accurate determination opposes to physi- ologists forced to carry on experimentation m the internal or organic

‘Claude Bernard, Logons ffur la physiologic et la pathologic du systdme nervous Lcgon d'ouvcrture, Dec 17, 1850 Paris, 1858, Vol I—Oours de patho logic expfnmcntale (The Medical Times, 1860)

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environments These obstacles, however, cannot terrify us if we are thoroughly convinced that we are on the right road Absolute de- teimimsm exists indeed m every vital phenomenon, hence biological science exists also, and consequently the studies to which we are deiotmg ourselves will not all be useless General physiology is the basic biological science toward which all others converge Its prob- lem is to determine the elementary condition of vital phenomena Pathology and therapeutics also rest on this common foundation By noimal activity of its organic units, life exhibits a state of health , b\ abnormal manifestation of the same units, diseases are character- ized , and finally through the organic environment modified by means of

ceitam toxic or medicinal substances, therapeutics enables us to act on the oigamc units To succeed m solving these various prob- lems, we must, as it were, analyze the organism, as we take apart a machine to review and study all its works , that is to say, before suc- ceeding m expei imenting on smaller units we must first experiment on the machinery and on the organs We must, therefore, have re- course to analytic study of the successive phenomena of life, and must make use of the same experimental method which physicists and chemists employ m analyzing the phenomena of inorganic bodies The difficulties which result from the complexity of the phenomena of living bodies arise solely m applying experimentation , for funda- mentally the object and principles of the method are always exactly the same

IV The Aim of Experimentation Is the Same in Study of

Phenomena of Living Bodies as in Study of Phenomena of Inorganic Bodies

If the physicist and the physiologist differ m this, that one busies himself with phenomena taking place m inorganic matter, and the other with phenomena occurring m living matter, still thej do not differ m the object which they mean to attain Indeed, they both set themselves a common object, viz , getting back to the immediate cause of the phenomena which they are studying

Now, what wre call the immediate cause of a phenomenon is noth- ing but the physical and material condition m which it exists or ap- peals The object of the experimental method or the limit of every scientific research is theiefore the same for living bodies as for inor- ganic bodies , it consists m finding the relations which connect any

phenomenon with its immediate cause, or putting it differently, it consists m defining the conditions necessary to the appearance of the phenomenon Indeed, when an experimenter succeeds m learning the necessary conditions of a

phenomenon, he is, m some sense, its master, he can predict its course and its appearance, he can promote or prevent it at will. An experimenter's object, then, is reached, through science, he has extended his power over a natural phe- nomenon.

We shall therefore define physiology thus the science whose object it is to study the phenomena of living beings and to determine the ma- terial conditions m which they appear. Only by the analytic or ex- perimental method can we attain the determination of the conditions of phenomena, m living bodies as well as in inorganic bodies, for we reason m identically the same way m experimenting in all the sciences

For physiological experimenters, neither spiritualism nor mate- rialism can exist These words belong to a philosophy which has grown old, they will fall into disuse through the progress of science. We shall never know either spirit or matter; and if this were the proper place I should easily show that on one side, as on the other, we quickly fall into scientific negations. The conclusion is that all such considerations are idle and useless. It ib our sole concern to study phenomena, to learn their material conditions and manifesta- tions, and to determine the laws of those manifestations.

Pirst causes are outside the realm of science , they forever escape us m the sciences of living as well as m those of inorganic bodies The experimental method necessarily turns aside from the chimerical search for a vital principle , vital force exists no more than mineral force exists, or, if you like, one exists quite as much as the other. The word, force, is merely an abstraction which we use for linguistic convenience For mechanics, force is the relation of a movement to its cause. For physicists, chemists and physiologists, it is fun- damentally the same As the essence of things must always remain unknown, we can learn only relations, and phenomena are merely the results of relations. The properties of living bodies are revealed only through reciprocal organic relations A salivary gland, for in- stance, exists only

because it is m relation with the digestive system, and because its histological units are in certain relations one with anothei and with the blood Destroy these relations by isolating the

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units of the organism, one from another m thought, and the salivary gland simply ceases to be.

A scientific law gives us the numerical relation of an effect to its cause, and that is the goal at which science stops When we have the law of a phenomenon, w'e not only know absolutely the conditions determining its existence, but we also have the relations applying to all its variations, so that we can predict modifications of the phe- nomenon m any given circumstances

As a coiollary to the above we must add that neither physiologists nor physicians need imagine it their task to seek the cause of life or the essence of disease That would be entirely wasting one’s time m pursuing a phantom The words, life, death, health, disease, have no objective reality We must imitate the physicists m this matter and say, as Newton said of gravitation “Bodies fall with an accelerated motion whose law we know that is a fact, that is reality But the first cause which makes these bodies fall is utterly unknown To picture the phenomenon to our minds, we may say that the bodies fall as if there were a force of attraction toward the centre of the earth, quasi esset attractio But the force of attraction does not exist, we do not see it, it is merely a word used to abbreviate speech ” When a physiologist calls m vital force or life, he does not see it , he merely pronounces a word , only the vital phenomenon ex- ists, with its material conditions, that is the one thing that he can study and know

To sum up, the object of science is everywhere the same to learn the material conditions of phenomena But though this goal is the same m the physico-chemical

and m biological sciences, it is much harder to reach in the latter because of the mobility and complexity of the phenomena which we meet

V The Necessary Conditions of Natural Phenomena Aw Absolutely Determined in Living Bodies as Well as in Inorganic Bodies

We must acknowledge as an experimental axiom that in living beings as well as m inorganic bodies the necessary conditions of every phenomenon are absolutely determined That is to say, m other terms, that when once the conditions of a phenomenon are known and fulfilled, the phenomenon must always and necessarily be reproduced

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at the will of the experimenter Negation of this proposition would be nothing less than negation of science itself Indeed, as science is simply the determinate and the determinable, we must perforce accept as an axiom that, m identical conditions, all phenomena are identical and that, as soon as conditions are no longer the same, the phenomena cease to be identical This principle is absolute m the phenomena of inorganic bodies as well as in those of living beings, and the influence of life, whatever view of it we take, can nowise alter it As we have said, what we call vital force is a first cause analogous to all other first causes, m this sense, that it is utterly unknown It matters little whether or not we admit that this force differs essentially from the forces presiding over manifestations of the phenomena of inorganic bodies, the vital phenomena which it governs must still be determinable, for the force would otherwise be blind and lawless, and that is impossible The conclusion is that the phenomena of life have their special law because there is rigorous determinism m the various circumstances constituting conditions necessary to their existence or to their manifestations, and that is the same thing Now m the phenomena of living bodies as m those of inorganic bodies, it is only through experimentation, as I have

al- ready often repeated, that we can attain knowledge of the condi- tions which govern these phenomena and so enable us to master them.

Everything so far said may seem elementary to men cultivating the physico-chemical sciences But among naturalists and especially among physicians, we find men who, in the name of what they call vitalism, express most erroneous ideas on the subject which concerns us They believe that study of the phenomena of living matter can have no relation to study of the phenomena of inorganic matter They look on life as a mysterious supernatural influence which acts arbi- trarily by freeing itself wholly from determinism, and they brand as materialists all who attempt to reconcile vital phenomena with definite organic and physico-chemical conditions These false ideas are not easy to uproot when once established m the mind , only the progress of science can dispel them But vitahstic ideas, taken m the sense which we have just indicated, are just a kind of medical superstition, — a belief m the supernatural Now, m medicine, belief m occult causes, whether it is called vitalism or is otherwise named, encourages ignorance and gives birth to a sort of unintentional quack- ery, that is to say, the belief m an inborn, indefinable science Con-

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fidence m absolute detenmmsm m the phenomena of life leads, on the contrary, to real science, and gives the modesty •which comes from the consciousness of our little learning and the difficulty of science This feeling incites us, m turn, to work toward knowledge, and to this feeling alone, science m the end owes all its progress

I should agree with the vitalists if they would simply recognize that living beings exhibit phenomena peculiar to themselves and un- known m inorganic nature I admit, indeed, that manifestations of life cannot be wholly elucidated by the physico-chemical phenomena known m inorganic nature I shall later explain my

view of the part played m biology by physico-chemical sciences, I will here simply say that if vital phenomena differ from those of inorganic bodies m complexity and appearance, this difference obtains only by virtue of determined or determinable conditions proper to themselves So if the sciences of life must differ from all others m explanation and in special laws, they are not set apart by scientific method Biology must borrow the experimental method of physico-chemical sciences, but keep its special phenomena and its own laws

In living bodies, as in inorganic bodies, laws are immutable, and the phenomena governed by these laws are bound to the conditions on which they exist, by a necessary and absolute determinism I use the word determinism here as more appropriate than the word fatalism, -which sometimes serves to express the same idea Determin- ism m the conditions of vital phenomena should be one of the axioms of experimenting physicians If they are thoroughly imbued with the truth of this principle, they will exclude all supernatural inter- vention from their explanations , they will have unshaken faith m the idea that fixed laws govern biological science , and at the same time they will have a reliable criterion for judging the often variable and contradictory appearance of vital phenomena Indeed, starting with the principle that immutable laws exist, experimenters will be con- vinced that phenomena can never be mutually contradictory, if they are observed in the same conditions , and if they show variations, the} will know that this is necessarily so because of the intervention or in- terference of other conditions which alter or mask phenomena There will be occasion thenceforth to try to learn the conditions of these variations, for there can be no effect without a cause Determinism thus becomes the foundation of all scientific progress and criticism If we find disconcerting or even contradictory results m performing

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an experiment, we must never acknowledge exceptions or contradic- tions as real That would he unscientific We must simply and nec- essarily decide that conditions m the phenomena are different, whether or not we can explain them at the time

I assert that the word exception is unscientific, and as soon as laws are known, no exception indeed can exist, and this expression, like so many others, merely enables us to speak of things whose causa- tion we do not know Every day we hear physicians use the words, ordinarily, more often, generally, or else express themselves numer- ically by saying, for instance nine times out of ten, things happen m this way I have heard old practitioners say that the words “always” and “never” should be crossed out of medicine I condemn neither these restrictions nor the use of these locutions if they are used as empirical approximations about the appearances of phenomena when we are still more or less ignorant of the exact conditions m which they exist But certain physicians seem to reason as if exceptions were necessary , they seem to believe that a vital force exists which can arbitrarily prevent things from always happening alike , so that exceptions would result directly from the action of mysterious vital force Now this cannot be the case, what we now call an exception is a phenomenon, one or more of whose conditions are unknown , if the conditions of the phenomena of which we speak were known and determined, there would be no further exceptions, medicine would be as free from them as is any other science For instance, we might formerly say that sometimes the itch was cured and sometimes not, but now that we attack the cause of this disease, we cure it always Formerly it might be said that a lesion of the nerves brought on paralysis, now of feeling, and again of motion, but now we know that cutting the anterior spinal nerve paralyzes motion only Motor paralysis occurs consistently and always, because its condition has been accurately determined by experimenters

The certainty with which phenomena are determined should also be, as we have said, the foundation of experimental criticism, whether applied to one’s self or to others A phenomenon, indeed, always ap- pears m the same way if conditions are

similar, the phenomenon never fails if the conditions are present, just as it does fail to appear if the conditions are absent Thus an experimenter who has made an experiment, m conditions which he believes were determined, may happen not to get the same results in a new series of investigations

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as m his first observation, m repeating the experiment, with fresh precautions, it may happen again that, instead of his first result, he may encounter a wholly different one In such a situation, what is to be done? Should we acknowledge that the facts are indetermi- nable ? Certainly not, since that cannot be We must simply acknowledge that experimental conditions, which we believed to be known, are not known We must more closely study, search out and define the experimental conditions, for the facts cannot be contradictory one to another, they can only be indeterminate Facts never exclude one another, they are simply explained by differences m the condi- tions m which they are born So an experimenter can never deny a fact that he has seen and observed, merely because he cannot redis- cover it In the third part of this introduction, we shall cite in- stances in which the principles of experimental criticism which we have just suggested, are put m practice

VI To Have Determinism for Phenomena, in Biological as in Physico-Chemical Sciences, We Must Eeduce the Phenomena to Experimental Conditions as Definite and Simple as Possible

As a natural phenomenon is only the expression of ratios and relations and connections, at least two bodies are necessary to its appearance So we must always consider, first, a body which reacts or which manifests the phenomenon, second, another body which acts and plays the part of environment in relation to the first It is impossible to imagine a body wholly isolated m nature, it would no longer be real, because there would be no relation to manifest its existence

In phenomenal relations, as nature presents them to us, more or less complexity always prevails In this respect mineral phenomena are much less complex than vital phenomena , this is why the sciences dealing with inorganic bodies have succeeded in establishing them- selves more quickly In living bodies, the complexity of phenomena is immense, and what is more, the mobility accompanying vital characteristics makes them much harder to grasp and to define

The properties of living matter can be learned only through their relation to the properties of inorganic matter, it follows that the biological sciences must have as their necessary foundation the

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physico-chemical sciences from which they borrow their means of analysis and their methods of investigation Such are the neces- sary reasons for the secondary and backward evolution of the sci- ences concerned with the phenomena of life But though the com- plexity of vital phenomena creates great obstacles, we must not be appalled, for, as we have already said, unless we deny the possi- bility of biological science, the principles of science are everywhere the same So we may be sure that we are on the right road and that m time we shall reach the scientific result that we are seeking, that is to say, determinism m the phenomena of living beings We can reach knowledge of definite elementary conditions of phe- nomena only by one road, viz , by experimental analysis .Analysis dissociates all the complex phenomena successively into more and more simple phenomena, until they are reduced, if possible, to just two elementary conditions Experimental science, m fact, considers in a phenomenon only the definite conditions necessary to produce it Physicists try to picture these conditions to themselves, more or less ideally m mechanics or mathematical physics Chemists suc- cessively analyze complex matters, and m thus reaching either ele- ments or definite substances (individual compounds or chemical spe- cies), they attain the elementary or irreducible

conditions of phe- nomena In the same way, biologists should analyze complex organ- isms and reduce the phenomena of life to conditions that cannot be analyzed m the present state of science

Experimental physiology and medicine have no other goal. When faced by complex questions, physiologists and physicians, as well as physicists and chemists, should divide the total problem into sim- pler and simpler and more and more clearly defined partial prob- lems They will thus reduce phenomena to their simplest possible material conditions and make application of the experimental method easier and more certain All the analytic sciences divide problems, m order to experiment better By following this path, physicists and chemists have succeeded m reducing what seemed the most complex phenomena to simple properties connected with well-defined mineral species By following the same analytic path, physiologists should succeed m reducing all the vital manifestations of a complex organism to the play of certain organs, and the action of these organs to the properties of well-defined tissues or organic units Anatomico- physiological experimental analysis, which dates from Galen, has just

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this meaning, and histology, m pursuing the same problem to-day, is naturally coming closer and closer to the goal

Though we can succeed m separating living tissues into chemical elements or bodies, still these elementary chemical bodies are not elements for physiologists In this respect biologists are more like physicists than chemists, for they seek to determine the properties of bodies and are much less preoccupied with their elementary com- position In the present state of the science, it would be impos- sible to establish any relation between the vital properties of bodies and their chemical composition, because tissues and organs endowed with the most diverse properties

are at times indistinguishable from the point of view of their elementary chemical composition Chem- istry is most useful to physiologists m giving them means of sepa- rating and studying individual compounds, true organic products which play important parts m the phenomena of life

Organic individual compounds, though well defined m their properties, are still not active elements m physiological phenomena , like mineral matter, they are, as it were, only passive elements m the organism For physiologists, the truly active elements are what we call anatomical or histological units Like the organic individual compounds, these are not chemically simple , but physiologi- cally considered, they are as simplified as possible in that their vital properties are the simplest that we know, — vital properties which vanish when we happen to destroy this elementary organized part However, all ideas of ours about these elements are limited by the present state of our knowledge, for there can be no question that these histological units, m the condition of cells and fibres, aie still complex That is why certain naturalists refuse to give them the names of elements and propose to call them elementary organisms This appellation is m fact more appropriate , we can perfectly well picture to ourselves a complex organism made up of a quantity of distinct elementary organisms, uniting, joining and grouping to- gether m various ways, to give birth first to the different tissues of the body, then to its various organs, anatomical mechanisms are themselves only assemblages of organs which present endlessly varied combinations in living beings When we come to analyze the com- plex manifestations of any organism, we should therefore separate the complex phenomena and reduce them to a certain number of simple properties belonging to elementary organisms, then syn-

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thetically reconstruct the total organism in thought, by reuniting and ordering the

elementary organisms, considered at first separately, then m their reciprocal relations

When physicians, chemists or physiologists, by successive experi- mental analyses, succeed m determining the ineducible element of a phenomenon m the present state of then science, the scientific prob- lem is simplified, but its nature is not changed thereby , and men of science are no nearer to absolute knowledge of the essence of things Nevertheless, they have gained what it is tiuly important to obtain, to wit, knowledge of the necessary conditions of the phenomenon and determination of the definite relation existing between a body mani- festing its propei ties and the immediate cause of this manifestation The object of analysis, m biological as m physico-chemical science, is, after all, to determine and, as far as possible, to isolate the condi- tions governing the occurrence of each phenomenon We can act on the phenomena of nature only by reproducing the natural conditions m which they exist , and we act the more easily on these conditions m proportion as they have first been better analyzed and reduced to a greater state of simplicity Heal science exists, then, only from the moment when a phenomenon is accurately defined as to its nature and rigorously determined in relation to its material condi- tions, that is, when its law is known Before that, we have only groping and empmcism

VII In Living Bodies, Just as in Inorganic Bodies, the Existence oe Phenomena Is Always Doubly Conditioned

The most superficial examination of what goes on around ns shows that all natural phenomena result from the reaction of bodies one against another There always come under consideration the body, m which the phenomenon takes place, and the outward circum- stance 01 the environment which determines or invites the body to exhibit its properties The conjunction of these conditions is essen- tial to the appearance of the phenomenon If we suppress the environment, the phenomenon disappeais, just as if the body had been taken away The phenomena of life, as well

as those of inor- ganic bodies, are thus doubly conditioned On the one hand, we have the organism m which vital phenomena come to pass, on the other hand, the cosmic environment in which living bodies, like mor-

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game bodies, find the conditions essential to the appearance of their phenomena- The conditions necessary to life are found neither m the organism nor m the outer environment, hut m both at once Indeed, if we suppress or disturb the organism, life ceases, even though the environment remains intact, if, on the other hand, we take away or vitiate the environment, life]ust as completely disap- pears, even though the organism has not been destroyed

Thus phenomena appear as results of contact or relation of a body with its envnonment Indeed, if we absolutely isolate a bod} m our thought, we annihilate it m so doing, and if, on the con- trary, we multiply its relations with the outer world, we multiply its properties

Phenomena, then, are definite relations of bodies, we always conceive these relations as resulting from forces outside of matter, because we cannot absolutely localize them m a single body For physicists, universal attraction is only an abstract idea, manifesta- tion of this force requires the presence of two bodies, if only one body is present, we can no longer conceive of attraction For ex- ample, electricity results from the action of copper and zinc m cer- tain chemical conditions, but if we suppress the interrelation of bodies, electricity, — an abstraction without existence m itself, — ceases to appear In the same way, life results from contact of the organism with its environment, we can no more understand it through the organism alone than through the environment alone It is therefore a similar abstraction, that is to say, a force which appears as if it were outside of matter

But however the mind conceives the forces of nature, that can- not alter an

experimenter’s conduct m any respect For him the problem reduces itself solely to determining the material conditions m which a phenomenon appears These conditions ones known, he can then master the phenomenon , by supplying or not supplying them, he can make the phenomenon appear or disappear at will Thus physicists and chemists exert their power over inorganic bodies, thus physiologists gain empire over vital phenomena Living bodies, however, seem at first sight to elude the experimenter’s action We see the higher organisms uniformly exhibit their vital phenomena, m spite of variations m the surrounding cosmic environment, and from another angle we see life extinguished m an organism after a certain length of time without being able to find reasons in the

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external environment for this extinction But, as we have already said, there is an illusion here, resulting from incomplete and super- ficial analysis of the conditions of vital phenomena Ancient sci- ence was able to conceive only the outer environment , but to establish the science of experimental biology, we must also conceive an inner environment I believe I was the first to express this idea clearly and to insist on it, the better to explain the application of experi- mentation to living beings Since the outer environment, on the other hand, infiltrates into the inner environment, knowing the latter teaches us the former’s every influence Only by passing into the inner, can the influence of the outer environment reach us, whence it follows that knowing the outer environment cannot teach us the actions born m, and proper to, the inner environment The general cosmic environment is common to living and to inorganic bodies, but the inner environment cieated by an organism is special to each living being Now, here is the tiue physiological environment, this it is which physiologists and physicians should study and know, for by its means they can act on the histological units which are the only effective agents m vital

phenomena Nevertheless, though so deeply seated, these units are m communication with the outer world , they still live m the conditions of the outer environment perfected and regulated by the play of the 01 ganism The organism is merely a living machine so constiucted that, on the one hand, the outer en- vironment is m free communication with the inner organic environ- ment, and, on the othei hand, the organic units have protective func- tions, to place m reserve the materials of life and uninterruptedly to maintain the humidity, warmth and other conditions essential to vital activity Sickness and death are merely a dislocation or dis- turbance of the mechanism which legulates the contact of vital stimulants with organic units In a word, vital phenomena are the result of contact between the oiganic units of the body with the inner physiological environment , this is the pivot of all ex- perimental medicine Physiologists and physicians gam mastery over the phenomena of life by learning which conditions, in this inner environment, are normal and which abnormal, for the appear- ance of vital activity m the organic units , for apart from complexity of conditions, phenomena exhibiting life, like physico-chemical phe- nomena, result from contact between an active bodv and the environ- ment m which it acts

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VIII In Biological as in Physico-Chemical Science, Deter- minism Is Possible, Because Matter in Living as in In- organic Bodies Can Possess No Spontaneity

To sum up, the stud} of life includes two things (1) Study of the properties of organized units, (2) study of the organic environ- ment, i e , study of the conditions which this environment must fulfill to permit the appearance of vital activities Physiology, pathology and therapeutics rest on this double knowledge, apart from this, neither medical science nor any truly scientific or effectual thera- peutics exists

In living organisms it is convenient to distinguish between three kinds of definite

bodies first, chemical elements, second, organic and inorganic individual compounds, third, organized anatomical units Of about 70 elements known to chemistry to-day, only 16 are found m that most complex of organisms, the organism of man But these 16 elements combine with one another to form the various liquid, solid and gaseous substances of the organism Oxygen and nitrogen, however, are merely dissolved m the organic fluids , and m living beings, seem to act as elements The inorganic individual compounds (earthy salts, phosphates, chlorides, sulphates, etc) are essential constituents m the composition of living bodies, but are taken ready-made directly from the outer world Organic individual compounds are also constituents of living bodies, but by no means borrowed from the outer world, they are made by the vegetable or animal organism, among such substances are starch, sugar, fat, albumen, etc, etc. When extracted from the body, they preserve their properties because they are not alive, they are organic products, but not organized Anatomical units stand alone as organized liv- ing parts These parts are irritable and, under the influence of various stimulants, exhibit properties exclusively characteristic of living beings They live and nourish themselves, and their nourish- ment creates and preserves their properties, which means that they cannot be cut off from the organism without more or less rapidly losing their vitality

Though very different from one another m respect to their func- tions m the organism, these three classes of bodies all show physico- chemical reactions under the influence of the outer stimuli, — warmth, light, electricity , but living parts also have the power of being irn-

table, i e , reacting under the influence of certain stimuli m a way specially characteristic of living tissues, such as muscular contrac- tion, nervous transmission, glandular secretion, etc. But whatever the variety presented by the three classes of

phenomena, whether the reaction be physico-chemical or vital, it is never m any way spon- taneous The phenomenon always results from the influence exerted on the reacting body by a physico-chemical stimulant outside itself Every definite substance, whether inorganic, organic or organ- ized, is autonomous, that is to say, it has characteristic properties and exhibits independent action Nevertheless, each one of these bodies is inert, that is, it is incapable of putting itself into action, to do this, it must always enter into relation with another body, from which it receives a stimulus Thus every mineral body m the cosmic environment is stable, it changes its state only when the circum- stances m which it is placed are rather seriously changed, either naturally or through experimental interference In any organic environment, the substances created by animals and vegetables are much more changeable and less stable, but still they are inert and exhibit their properties only as they are influenced by agents out- side themselves Finally, anatomical units themselves, which are the most changeable and unstable of substances, are still inert, that is, they never break into vital activity unless some foreign influence invites them A muscle-fibre, for instance, has the vital property peculiar to itself of contracting, but this living fibre is inert m tbe sense that if nothing changes m its environmental or its inner conditions, it cannot bring its functions into play, and it will not contract. For the muscular fibre to contract, a change must neces- sarily be produced m it, by its coming into relation with a stimula- tion from without, which may come either from the blood or from a nerve We may say as much of all the histological units, nerve units, blood units, etc Different living units thus play the part of stimuli, one m relation to another , and the functional manifestations of an organism are merely the expression of their harmonious recipro- cal relations The histological units react either separately or one against another by means of vital properties which are themselves m necessary connection with surrounding physico-chemical conditions, and this relation is so intimate that we may say the intensity of physico-chemical phenomena taking place m an organism may be used

to measure tbe intensity of its vital phenomena Therefore,

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as has already been said, we must not set up an antagonism between vital phenomena and physico-chemical phenomena, hut, on the con- trary, we must note the complete and necessary parallelism between the two classes of phenomena. To sum up, living matter is no more able than inorganic matter to get into activity or movement by itself Every change m matter implies intervention of a new rela- tion, 1 e , an outside condition or influence The role of men of science is to try to define and determine the material conditions pro- ducing the appearance of each phenomenon These conditions once known, experimenters master the phenomenon m this sense, that they can give movement to matter, or take it away, at pleasure

What we have just said is equally true for the phenomena of living bodies and the phenomena of inorganic bodies Only m the case of the complex higher organisms, physiologists and physicians must study the stimuli of vital phenomena, not m the relations of the whole organism with the general cosmic environment, but rather m the organic conditions of the inner environment Considered in the general cosmic environment, the functions of man and of the higher animals seem to us, indeed, free and independent of the physico-chemical conditions of the environment, because its actual stimuli are found m an inner, organic, liquid environment What we see from the outside is merely the result of physico-chemical stimuli from the inner environment, that is where physiologists must build up the real determinism of vital functions

Living machines are therefore created and constructed m such a way that, m perfecting themselves, they become freer and freer in the general cosmic environment But the most absolute determin- ism still obtains, none the less, m the inner environment which is separated more and more from the outer cosmic

environment, by rea- son of the same organic development A living machine keeps up its movement because the inner mechanism of the organism, by acts and forces ceaselessly renewed, repairs the losses involved m the exercise of its functions Machines created by the intelligence of man, though infinitely coarser, are built m just this fashion A steam engine's activity is independent of outer physico-chemical con- ditions, since the machine goes on working through cold, heat, dry- ness and moisture But physicists going down into the inner envi- ronment of the machine, find that this independence is only apparent, and that the movement of its every inner gear is determined by phys-

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ical conditions whose law they know As for physiologists, if they can go down into the inner environment of a living machine, they find likewise absolute determinism that must become the real founda- tion of the science of living bodies

IX The Limits of Oub Knowledge Abe the Same in the Phenomena of Living Bodies and in the Phenomena of Inokganic Bodies

The nature of our mind leads us to seek the essence or the why of things Thus we aim beyond the goal that it is given us to reach , for experience soon teaches us that we cannot get beyond the how,

1 e , beyond the immediate cause or the necessary conditions of phe- nomena, In this respect the limits of our knowledge are the same m biological as m physico-chemical sciences

When, by successive analyses, we find the immediate cause deter- mining the circumstances m which a phenomenon presents itself, we reach a scientific goal beyond which we cannot pass When we know that water, with all its properties, results from combining oxygen and hydrogen m certain proportions, we know everything we can know about it, and that corresponds to the how and not to the

why of things We know how water can be made, but why does the com- bination of one volume of oxygen with two volumes of hydrogen pro- duce water2 We have no idea In medicine it is equally absurd to concern one's self with the question "why " Yet physicians ask it often It was probably to make fun of this tendency, which re- sults from lack of the sense of limits to our learning, that Mohere put the following answer into the mouth of his candidate for the medical degree Asked why opium puts people to sleep, he answered " Quia est m eo vvrius dorrmtiva , cujus est nuiura- sensus assoupire " This answer seems ludicrous and absurd , yet no other answer could be made In the same way, if we wished to answer the question "Why does hydrogen, m combining with oxygen, produce water?" •we should have to answer "Because hydrogen has the quality of being able to beget water " Only the question "why," then, is really absurd, because it necessarily involves a naive or ridiculous answer So we had better recognize that we do not know , and that the limits of our knowledge are precisely here

In physiology, if we prove, for instance, that carbon monoxide

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is deadly •when uniting more firmly than oxygen with the hemoglobin, we know all that we can know about the cause of death Experience teaches us that a part of the mechanism of life is lacking, oxygen can no longer enter the organism, because it cannot displace the carbon monoxide m its union with the hemoglobin But why has carbon monoxide more affinity than oxygen for this substance2 "Why is entrance of oxygen into the organism necessary to life2 Here is the limit of our knowledge m our present state of learning, and even assuming that we succeed m further advancing our experi- mental analysis, we shall reach a blind cause at which we shall be forced to stop, without finding the primal reason for things Let us add that, when the relative determinism of a phenomenon is established, our scientific goal is

reached Experimental analysis of the conditions of the phenomenon, when pushed still further, gives us fresh information, but really teaches us nothing about the nature of the phenomenon originally determined The conditions necessary to a phenomenon teach us nothing about its nature When we know that physical and chemical contact between the blood and the cere- bral nerve cells is necessary to the production of intellectual phe- nomena, that points to conditions, but it cannot teach us anything about the primary nature of intelligence Similarly, when we know that friction and that chemical action produce electricity, we are still ignorant of the primary nature of electricity

We must therefore, m my opinion, stop differentiating the phe- nomena of living bodies from those of inorganic bodies, by a dis- tinction based on our own ability to know the nature of tne former and our inability to know that of the latter The truth is that the nature or very essence of phenomena, whether vital or mineral, will always remain unknown The essence of the simplest mineral phe- nomenon is as completely unknown to chemists and physicists to-day as is the essence of intellectual phenomena or of any other vital phenomenon to physiologists That, moreover, is easy to apprehend , knowledge of the inmost nature or the absolute, in the simplest phenomenon, would demand knowledge of the whole universe, for every phenomenon of the universe is evidently a sort of radiation from that universe to whose harmony it contributes. In living bodies absolute truth would be still harder to attain , because, besides implying knowledge of the universe outside a living body, it would also demand complete knowledge of the oiganism which, as we have

long been saying, is a little world (microcosm) m the great universe (maciocosm) Absolute knowledge could, therefore, leave nothing outside itself , and only on condition of knowing everything could man be granted its attainment Man behaves

as if he were destined to reach this absolute knowledge, and the incessant why which he puts to nature proves it Indeed, this hope, constantly disappointed, constantly reborn, sustains and always will sustain successive gen- erations m the passionate search for truth

Our feelings lead us at first to believe that absolute truth must lie within our realm , but study takes from us, little by little, these chimerical conceits Science has just the privilege of teaching us what we do not know, by replacing feeling with reason and experi- ence and clearly showing us the present boundaries of our knowl- edge But by a marvellous compensation, science, m humbling our pride, pioportionately increases our power Men of science who cany experimental analysis to the point of relatively determining a phenomenon doubtless see clearly their own ignorance of the phe- nomenon m its primary cause, but they have become its master, the instrument at work is unknown, but they can use it This is true of all expenmental sciences in which we can reach only rela- tive or partial truths and know phenomena only m their necessary conditions But this knowledge is enough to bioaden our powei over nature Though we do not know the essence of phenomena, we can produce or prevent their appearance, because we can regulate their physico-chemical conditions We do not know the essence of fire, of electricity, of light, and still we regulate their phenomena to our own advantage We know absolutely nothing of the essence even of life, but we shall nevertheless regulate vital phenomena as soon as we know enough of their necessary conditions Only in liv- ing bodies these conditions are much more complex and more diffi- cult to grasp than m inorganic bodies, that is the whole differenca To sum up, if our feeling constantly puts the question why, our reason shows us that only the question hoio is within our range, for the moment, then, only the question how concerns men of science and experimenters If we cannot know why opium and its alka- loids put us to sleep, we can learn the mechanism of sleep and know how opium or its ingredients puts us to sleep , for sleep takes place only because an active substance enters into contact with

certain organic substances which it changes Learning these changes will

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give us the means of producing or preventing sleep, and we shall he able to act on the phenomenon and regulate it at pleasure

In the knowledge that we acquire, we should distinguish between two sets of notions the first corresponds to the cause of phenomena, the second to the means of producing them By the cause of a phenomenon we mean the constant and definite condition necessary to existence, we call this the relative determinism or the h-ow of things, 1 e , the immediate or determining cause The means of obtaining phenomena are the varied processes by whose aid we may succeed in putting in action the single determining cause which pro- duces the phenomenon. The necessary cause m the formation of water is the combination of two volumes of hydrogen with one of oxygen, this is the single cause which always determines the phe- nomenon We cannot conceive of water apart from this essential condition Subordinate conditions or processes m the formation of water may be extremely varied , only all these processes reach the same result, viz , combination of oxygen and hydrogen in invariable proportions Let us take another example I assume that we wish to transform starch into glucose , we have any number of means or processes for doing this, but fundamentally there will always be the identical cause, and a single determinism will beget the phenomenon. This cause is fixation of one more unit of water m the substance, to bring about its transformation Only we may produce this hydration m any number of conditions and by any number of methods by means of acidulated water, of heat, of animal or vegetable enzymes , but all these processes finally come to a single condition, hydrolysis of the starch The determinism, i e , the cause of the phenomenon, is therefore single, though the means for making it appear may be multiple and apparently very various It is most important to establish this

distinction especially m medicine, where the greatest confusion reigns, precisely because physicians recognize a multitude of causes for the same disease To convince ourselves of what I am urging we have only to open a treatise on pathology By no means all the circumstances enumerated are causes , at most they are means or processes by which a disease can be produced But the leal and effective cause of a disease must be constant and determined, that is unique, anything else would be a denial of science m medicine It is true that determining causes are much harder to recognize and define m the phenomena of living beings , but they exist nevertheless,

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m spite of the seeming diversity of means employed Thus m cer- tain toxic phenomena we see different poisons lead to one cause and to a single determinism for the death of histological units, for example, the coagulation of muscular substance In the same -way, vaned circumstances producing the same disease must all correspond to a single and determined pathogenic action In a word, determinism which insists on identity of effect bound up with identity of cause is an axiom of science which can no more be transgressed m the sci- ences of life than m the sciences of inorganic matter

X. In the Sciences of Living Bodies, as in Those of Inoeganio Bodies, Experimented Create Nothing, They Simply Obey the Laws of Nature

We know the phenomena of nature only through their relations with the causes which produce them Now the law of phenomena is nothing else than this relation numerically established, m such a way as to let us foresee the ratio of cause to effect m any given case Tim ratio, established by observation, enables astronomers to predict celes- tial phenomena , this same ratio, established by observation and ex- periment, again enables physicists, chemists, physiologists, not only to predict the phenomena of nature, but even to modify them at pleasure and to a certainty,

provided they do not swerve from the ratio which experience has pointed out, 1 e , the law In other terms, we can guide natural phenomena only by submitting to laws that govern them

Observers can only observe natural phenomena, experimenters can only modify them , it is not given them to create or to destroy them utterly, because they cannot change natural law We have often repeated that experimenters act, not on phenomena themselves, but on the physico-chemical conditions necessary to their appear- ance Phenomena are just the actual expression of the ratio of these conditions, hence, when conditions are similar, the ratio is constant and the phenomenon identical, and when conditions change, there is another ratio, and a different phenomenon In a word, to make a new phenomenon appear, experimenters merely bring new condi- tions to pass, but they create nothing, either m the way of force or of matter At the end of the last century science proclaimed a great truth, to wit, that with respect to matter, nothing is lost, neither

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is an) thing created m nature , the bodies whose qualities ceaselessly vary under our eyes are all only tiansmutations of aggregations of matter of equal weight In recent times science has proclaimed a second truth which it is still seeking to prove and which m some sense is truly complementary to the first, to w it, that with respect to forces nothing is lost and nothing created m nature , it follows that all the infinitely varied forms of phenomena m the universe are only equivalent transformation of forces, one into another I reserve for treatment elsewhere the question whether differences separate the forces of living bodies from those of inert bodies, let it suffice for the moment to say that the two preceding truths are universal, and that they embrace the phenomena of living bodies as well as those of inert bodies

All phenomena, to whatever order they belong, exist implicitly m the changeless

laws of nature , and they show themselves only when their necessary conditions are actualized The bodies and bemgs on the surface of our earth express the harmonious relation of the cosmic conditions of our planet and our atmosphere with the bemgs and phenomena whose existence the) permit Other cosmic conditions would necessarily make anothei world appear m which all the phe- nomena would occur which found in it their necessary conditions, and from which would disappear all that could not develop m it But no matter what infinite varieties of phenomena we conceive on the earth, by placing ourselves m thought in all the cosmic conditions that our imagination can bring to birth, we are still forced to admit that this would all take place according to the laws of physics, chem- istry and physiology, which have existed without our knowledge from all eternity , and that whatever happens, nothing is created by way either of force or of matter, that only different relations will be produced and through them creation of new bemgs and phenomena

When a chemist makes a new body appear m nature, he cannot flatter himself with having created the law's which brought it to birth, he produced only the conditions which the creative law de- manded for its manifestation The case of organic bodies is the same Chemists and physiologists, m their experiments, can make new' bemgs appear only by obeying the law's of nature which they can- not alter m any way

It is not given to man to alter the cosmic phenomena of the whole universe nor e\en those of the earth, but the advances of science

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enable him to alter the phenomena withm his reach Thus man has already gained a power over mineral nature which is brilliantly revealed m the applications of modem science, still at its dawn The result of experimental science applied to living bodies must also be to alter vital phenomena, by acting solely on the conditions of these phenomena- But here our difficulties are greatly increased by the delicacy of the

conditions of vital phenomena and the complexity and interrelation of all the parts grouped together to form an organized being This is why man can probably never act as easily on animal or vegetable, as on mineral, species His power over living beings will remain more limited, especially where they form higher, i e , more complicated organisms Nevertheless, the difficulties obstruct- ing the power of physiologists do not pertain to the nature of vital phenomena, but merely to their complexity Physiologists will first begin by getting at phenomena of vegetables and of animals m easier relations with the outer cosmic environment It appears, at first sight, as if man and the higher animals must escape from its power to change, because they seem freed from the direct influence of the outer environment But we know that vital phenomena m man, as m the animals nearest him, are connected with the physico-chemical condi- tions of an inner organic environment. This inner environment we must first seek to know, because this must become the real field of action for physiology and experimental medicine

CHAPTER II

EXPERIMENTAL CONSIDERATIONS PECULIAR TO LIVING BEINGS

I The Phenomena or Living Beings Must Be Considered as a Harmonious Whole

So far we have been explaining experimental considerations ap- plicable to both living and inorganic bodies, for living bodies the difference consists merely m the greater complexity of phenomena, making experimental analysis and determination of the conditions incomparably harder But in the behavior of living bodies we must call the reader’s attention to their very special interdependence, m the study of vital functions, if we neglected the physiological point of view, even if we experimented skilfully, we should be led to the most false ideas and the most erroneous deductions

We saw m the last chapter that the object of the expenmental method is to reach the determinism of phenomena, no matter of what nature, whether vital or mineral We know, moreover, that what we call determinism of a phenomenon means nothing else than the determining cause or immediate cause determining the appearance of phenomena Thus we necessarily obtain the conditions m which the phenomena exist, and on which the experimenter must act to make the phenomena vary We therefore consider the various ex- pressions above as equivalents, and the word determinism sums them all up

It is indeed true, as ve have said, that life brings absolutely no difference into the scientific experimental method which must be applied to the study of physiological phenomena, and that m this respect physiological science and physico-chemical science rest on exactly the same principles of investigation But still we must recognize that determinism m the phenomena of life is not only very complex, but that it is at the same time harmoniously graded Thus complex physiological phenomena are made up of a series of simpler phenomena each determining the other by associating together or combining for a common final object Now the physiologist’s prime

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object is to determine tbe elementary conditions of physiological phenomena and to grasp their natural subordination, so as to under- stand and then to follow the different combinations m the varied mechanism of animal organisms The ancient emblem representing life as a closed circle, formed by a serpent biting its own tail, gives a fairly accurate picture of things In complex organisms the organism of life actually forms a closed circle, but a circle which has a head and a tail m this sense, that vital phenomena are not all of equal importance, though each m succession completes the vital cir- cle Thus the muscular and nervous organs sustain the

activity of the organs preparing the blood , but the blood m its turn nourishes the organs which produce it Here is an organic or social inter- dependence which sustains a sort of perpetual motion, until some disorder or stoppage of a necessary vital unit upsets the equilibrium, or leads to disturbance or stoppage m the play of the animal machine The problem for experimenting physicians consists, therefore, m find- ing the simple determinism of an organic disorder, that is to say, in grasping the initial phenomenon which brings all the others m its tram through a complex determinism as necessary m character as the initial determinism This initial determinism is like Ariadne's thread guiding the experimenter m the dark labyrinth of physiologi- cal and pathological phenomena, and enabling him to understand how their varied mechanisms are still bound together by absolute determinisms By examples cited further on, we shall see how a dislocation of the organism or an apparently highly complex disorder may be traced back to an initial simple determinism which later produces more complex determinisms. A case in point is poisoning by carbon monoxide (cf. Part III) I am devoting my whole course at the College de France this year to the study of curare, not for the sake of the substance itself, but because this study shows us how the simplest single determinism, such as the lesion of a terminal motor nerve, re-echoing successively from all the other vital units, leads to secondary determinisms which grow more and more complicated till death ensues. I wish thus to establish experimentally the existence of mtra-organic determinisms to which I shall later return, because I consider stlidy of them the true basis of pathology and of scientific therapeutics.

Physiologists and physicians must never forget that a living being is an organism with its own individuality Since physicists and

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chemists cannot take their stand outside the universe, they study bodies and

phenomena in themselves and separately without neces- sarily having to connect them with nature as a whole But physiol- ogists, finding themselves, on the contrary, outside the animal organ- ism which they see as a whole, must take account of the harmony of this whole, even while trying to get inside, so as to understand the mechanism of its every part The result is that physicists and chem- ists can reject all idea of final causes for the facts that they observe , while physiologists are inclined to acknowledge an harmonious and pre-established unity m an organized body, all of whose partial actions are interdependent and mutually generative We really must learn, then, that if we break up a living organism by isolating its different parts, it is only for the sake of ease in experimental analy- sis, and by no means m order to conceive them separately In- deed when we wish to ascribe to a physiological quality its value and true significance, we must always refer it to this whole, and draw our final conclusion only m relation to its effects m the whole. It is doubtless because he felt this necessary interdependence among all parts of an organism, that Cuvier said that experimentation was not applicable to living bemgs, since it separated organized parts which should remain united For the same reason, other physiologists or physicians, called vitaliBts, have proscribed and still proscribe experi- mentation m medicine These views, which have their conect side, are nevertheless false m their general outcome and have greatly hampered the progress of science It is doubtless correct to say that the constituent parts of an organism are physiologically insepa- rable one from another, and that they all contribute to a common vital result, but we may not conclude from this that the living ma- chine must not be analyzed as we analyze a crude machine whose parts also have their role to play m a whole With the help of experimental analysis we must transfer physiological functions as much as possible outside the organism , segregation allows us to see and to grasp hidden conditions of the phenomena, so as to follow them later inside the organism and to interpret their vital role Thus we establish artificial digestion and fecundation, so as to know natural digestion and fecundation

better Thanks to their organic self-regulation, we can also detach living tissues, and by means of artificial circulation or otherwise, we can place them in conditions where we can better study their characteristics We occasionally

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isolate an organ by using anesthetics to destroy the reactions of its general group, we reach the same result by cutting the nerves leading to a part, but preserving the blood vessels By means of experimental analysis, I have even transformed warm-blooded ani- mals, as it were, into cold-blooded animals, so as to study better the characteristics of their histological units; I have succeeded m poison- ing glands separately and m making them work, by means of dis- sected nerves, quite apart from the organism In this last case we can have a gland, at will, m a state, first, of absolute rest, then, of exaggerated action, when both extremes of the phenomenon are known we can later easily grasp all the intervening stages, and we then understand how a completely chemical function can be regulated by a nervous system, so as to supply organic fluids m conditions that are always the same We will not further amplify these suggestions about experimental analysis, we sum up by saying that proscribing experimental analysis of organs means arresting science and deny- ing the experimental method , but, on the other hand, that practising physiological analysis, while losing sight of the harmonious unity of an organism, means misunderstanding the science of life and indi- viduality, and leaving it characterless.

After carrying out an analysis of phenomena, we must therefore always reconstruct our physiological synthesis, so as to see the joint action of all the parts we have isolated A propos of the phrase physiological synthesis, we must further explain our thought It is generally agreed that synthesis reunites what analysis has divided, and that synthesis therefore verifies analysis, of which it is merely the counterproof or

necessary complement This definition is en- tirely true for analysis and synthesis of matter In chemistry, syn- thesis produces, weight for weight, the same body made up of identical elements combined m the same proportions , but m the case of analyzing and synthesizing the properties of bodies, i.e, synthesizing phenomena, it is much harder Indeed, the properties of bodies result not merely from the nature and proportions of matter, but also from the arrangement of matter Moreover, as we know, it happens that properties, which appear and disappear m synthesis and analysis, can- not be considered as simple addition or pure subtraction of proper- ties of the constituent bodies Thus, for example, the properties of oxygen and hydrogen do not account for the properties of water, which result nevertheless from combining them

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1 do not intend to go into these difficult yet fundamental problems about the relative properties of combined or combining bodies, they will find their proper place elsewhere I shall here only repeat that phenomena merely express the relations of bodies, whence it follows that, by dissociating the parts of a whole, we must make phe- nomena cease if only because we destroy the relations It follows also, in. physiology, that analysis, which teaches us the properties of isolated elementary parts, can never give us more than a most incom- plete ideal synthesis, just as knowing a solitary man would not bring us knowledge of all the institutions which result from man’s associa- tion, and which can reveal themselves only through social life In a word, when we unite physiological elements, properties appear which were imperceptible m the separate elements We must there- fore always proceed experimentally m vital synthesis, because quite characteristic phenomena may result from more and more complex union or association of organized elements All this proves that these elements, though distinct and self-dependent, do not therefore play

the part of simple associates , their union expresses more than addition of their separate properties I am persuaded that the obstacles surrounding the experimental study of psychological phe- nomena are largely due to difficulties of this kind , for despite their marvellous character and the delicacy of their manifestations, I find it impossible not to include cerebral phenomena, like all other phe- nomena of living bodies, in the laws of scientific determinism.

Physiologists and physicians must therefore always consider organisms as a whole and in detail at one and the same time, without ever losing sight of the peculiar conditions of all the special phe- nomena whose resultant is the individual Yet particular facts are never scientific, only generalization can establish science But here we must avoid a double stumbling block, for if excess of detail is anti-scientific, excessive generalization creates an ideal science no longer connected with reality This stumbling block, unimportant to a contemplative naturalist, is large for physicians who must first of all seek objective, practical truths We must doubless admire those great horizons dimly seen by the genius of a Goethe, an Oken, a Carus, a Geoffroy Samt-Hilaire, a Darwin, m which a general con- ception shows us all living beings as the expression of types ceaselessly transformed m the evolution of organisms and species, — types m which every living being individually disappears like a reflection of

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tlie whole to which it belongs In medicine we can also rise to the most abstract generalizations, whether we take the naturalist’s point of view and conceive diseases as morbid species to be classified nosologically, or whether we start from the physiological point of view and consider that disease does not exist, m the sense that it is only a special case of a general physiological state Doubtless all these brilliant views do, after a fashion, guide and serve us But if we gave ourselves up exclusively

to hypothetical contemplation, we should soon turn our backs on reality, and m my opinion, we should misunderstand true scientific philosophy, by setting up a sort of opposition or exclusion between practice, which requires knowl- edge of particulars, and generalizations which tend to mingle all m all

A physician, m fact, is by no means physician to living beings m general, not even physician to the human race, but rather, phy- sician to a human individual, and still more physician to an indi- vidual m certain morbid conditions peculiar to himself and forming what is called his idiosyncrasy Hence it seems to follow that medi- cine, m contrast with other sciences, should be established more and more on particulars This opinion is incorrect and based only on appearances , for m all sciences, generalization leads to the law of phe- nomena and the true scientific goal Only we must recognize that all the morphological generalizations to which we alluded above are too superficial and are therefore insufficient for physiologists and physicians Naturalists, physiologists and physicians have wholly different problems m view , their investigations advance m far from parallel lines, hence we cannot, for instance, exactly superpose a physiological scale on the geological scale Physiologists and phy- sicians delve much more deeply than zoologists into the problem of biology, physiologists consider the general conditions necessary to vital phenomena as well as the various changes to which they may be subject But physicians cannot content themselves with knowing that all vital phenomena occur in identical conditions among all human beings , they must go still further by studying the details of these conditions m each individual considered m given morbid condi- tions Only after delving, then, as deeply as possible into the secrets of vital phenomena m the normal and pathological states can physiol- ogists and physicians attain illuminating and fertile generalizations

The primary essence of life is a developing organic force, tho

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force which constituted the mediating nature of Hippocrates and the archeus faber of Van Helmont. But whatever our idea of the nature of this foice, it is always exhibited concurrently and parallel with the physico-chemical conditions proper to vital phenomena Through study, then, of physico-chemical details, physicians will learn to un- derstand individualities as special cases mcluded m a general law, and will discover there, as everywhere, an harmonious generalization of variety m unity But since physicians deal with variety, they must always seek to define it m their studies and to comprehend it in their generalizations

If I had to define life in a single phrase, I should clearly express my thought by throwing into relief the one characteristic which, m my opinion, sharply diffeientiates biological science I should say life is creation In fact, a created organism is a machine which necessarily works by vntue of the physico-chemical properties of its constituent elements To-day we differentiate three kinds of prop- erties exhibited m the phenomena of living beings physical prop- erties, chemical properties and vital properties But the term “vital properties” is itself only provisional, because we call properties vital which we have not yet been able to reduce to physico-chemical terms, but m that we shall doubtless succeed some day So that what distinguishes a living machine is not the nature of its physico- chemical properties, complex as they may be, but rather the creation of the machine which develops under our eyes in conditions proper to itself and according to a definite idea which expresses the living being’s nature and the very essence of life

When a chicken develops in an egg, the formation of the ani- mal body as a grouping of chemical elements is not what essentially distinguishes the vital force This grouping takes place only accord- ing to laws which govern the chemico-physical properties of matter, but the guiding idea of the vital evolution is essentially of the domain of life and belongs neither to chemistry nor to physics nor

to any- thing else In every living germ is a creative idea which develops and exhibits itself through organization As long as a living being persists, it remains under the influence of this same creative vital force, and death comes when it can no longer express itself, here as everywhere, everything is derived from the idea which alone creates and guides, ply sico-chemical means of expression are com- mon to all natural phenomena and remain mingled, pell-mell, like the

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letters of the alphabet m a box, till a force goes to fetch them, to express the most varied thoughts and mechanisms This same vital idea preserves beings, by reconstructing the living parts disorgan- ized by exercise or destroyed by accidents or diseases. To the physico-chemical conditions of this primal development, then, we must always refer our explanation of life, whether m the normal or the pathological state We shall see, indeed, that physiologists and physicians can really act only indirectly through animal physieo- chemistry, that is to say, through physics and chemistry worked out m the special field of life, where the necessary conditions of all phenomena of living organisms develop, create and support each other according to a definite idea and obedient to rigorous determinisms

II Experimental Practice with Living Beings

As we have said, the experimental method and the principles of experimentation are identical for the phenomena of inorganic bodies and the phenomena of living bodies But it cannot be the same with experimental practice, and it is easy to conceive that the peculiar organization of living bodies requires special processes for its analysis and must offer difficulties sui generis. However, the considerations and special precepts, which we shall present to physiologists, to fore- arm them against sources of error m experimental practice, have to do only with the delicacy, mobility and fugitiveness of vital qualities and the complexity of the phenomena of life

Physiologists, indeed, have only to take apart the living machine, and with the help of tools and processes borrowed from physics and ekemistiy, to study and measure the various vital phenomena whose law they seek to discover

Each of the sciences possesses, if not an individual method, at least particular processes, and the sciences, moreover, serve as in- struments one for another. Mathematics serves as an instrument for physics, chemistry and biology m different degrees, physics and chemistry serve as powerful instruments for physiology and medicine In the mutual service which sciences render one another, we must of course distinguish between the men of science, who use, and those who carry forward each science Physicists and chemists are not mathematicians because they make calculations, physiologists are not chemists or physicists because they make use of chemical reagents

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or physical instruments, any moTe than chemists and physicists are physiologists because they study the composition or properties of certain animal or vegetable fluids or tissues Each science has its problem and its point of view which we may not confuse without risk of leading scientific investigation astray Yet this confusion has often occurred m biological science which, because of its com- plexity, needs the help of all the other sciences We have seen, and we still often see chemists and physicists who, instead of confining themselves to the demand that living bodies furnish them suitable means and arguments to establish certain principles of their own sciences, try to absorb physiology and reduce it to simple physico- chemical phenomena They offer explanations or systems of life which tempt us at times by their false simplicity, hut which harm biological science m every case, by bringing m false guidance and inaccuracy which it then takes long to dispel In a word, biology has its own problem and its definite point of view , it borrows from other

sciences only their help and their methods, not their theories This help from other sciences is so powerful that, without it, the development of the science of vital phenomena would be impossible Previous knowledge of the physico-chemical sciences is therefore decidedly not, as is often said, an accessory to biology, but, on the contrary, is essential to it and fundamental That is why I think it proper to call the physico-chemical sciences allied sciences, and not sciences accessory to physiology We shall see that anatomy is also a science allied to physiology, just as physiology itself, which requires the help of anatomy and of all the physico-chemical sciences, is the science most closely allied to medicine and forms its true scien- tific foundation

The application of physico-chemical sciences to physiology and the use of their processes as instruments, suited to the analysis of the phenomena of life, present a great many difficulties inherent, as we have said, m the mobility and fugitiveness of vital phenomena The spontaneity and mobility enjoyed by living beings make the properties of organized bodies very hard to fix and to study We must return for an instant here to the nature of these difficulties, as I have already had occasion to do m my lectures 1

'Claude Bernard, Logons sur leg propnitis phytnologxquce doe alterations pathologiqucs des liquids de Vorgamsme Pans, 1859, Vol I Logon d’ouver turc, Dec 9, 1857

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A living body differs essentially from an inorganic body from the point of view of the experimenter An inorganic body has no sort of spontaneity, as its properties are m equilibrium with outside conditions, it soon settles into physico-chemical indifference, 1 e , into stable equilibrium with its surroundings Hence, all the phenom- enal changes that it experiences will necessarily come from altera- tions

occurring in surrounding circumstances, and we can easily see that by taking strict account of these circumstances, we can be sure of having the experimental conditions necessary to a good experiment A living body, especially m the higher animals, never falls into chemico-physical indifference to the outer environment, it has ceaseless motions, an organic evolution apparently spontaneous and constant, and though this evolution requires outer circumstances for its manifestation, it is nevertheless independent m its advance and modality As proof of this, we see living beings bom, develop, fall ill and die, without the conditions of the outer world changing for the observer

It follows that, in experimenting on inorganic bodies with the help of such instruments as the barometer, thermometer and hygrometer, we can put ourselves m identical conditions and consequently carry on well-defined and similar experiments. Physiologists and physicians have rightly imitated the physicists and have sought to make their experiments more accurate by using the same instruments But we can see at once that outer conditions whose changes are of such importance to physicists and chemists are of much less value to physicians Alterations m the phenomena of inorganic bodies are, m fact, always brought about by an outer cosmic change, and it happens at times that a very Blight alteration m the surrounding temperature or m barometric pressure leads to important changes m the phenomena of inor- ganic bodies But m man and m the higher animals the phe- nomena of life may alter without any appreciable outer cosmic change, and slight thermometnc or barometric changes often exert no real influence on vital manifestations, and though we cannot say that these outer cosmic influences are essentially nil, circum- stances occur where it would be almost ludicrous to take account of them Such was the experimenter's case who repeated my ex- periments on puncture of the floor of the fourth ventricle, to cause artificial diabetes he thought that he exhibited greater accuracy w

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carefully noting the barometric pressure at the moment of making the experiment.

However, instead of experimenting on man and the higher ani- mals, if we experiment on lower living beings, whether animal or vegetable, we shall see that the thermometric, barometric and hygro- metnc data, which were so unimportant in the first case, must on the contrary be kept very seriously under consideration in the second Indeed, if we vary the conditions of humidity, heat and atmospheric pressure for infusoria, the vital manifestations m these beings are altered or annihilated according to the more or less significant varia- tions that we make m the cosmic influences cited above In vege- tables and in cold-blooded animals, the conditions of temperature and humidity m the cosmic environment again play a very large part m the manifestations of life This is what is called the influence of the seasons, which is familiar to everyone In fine, then, only the warm-blooded animals and man seem to escape cosmic influences and to have free and independent manifestations. We have already said elsewhere that this kind of independence of vital manifestations m man and the higher animals results from greater perfection of their organism, but does not prove that manifestations of life m these physiologically more perfect bemgs are subject to other laws or other causes We know, in fact, that the histological units of our organs express the phenomena of life, now if the functions of these units show no variations under the influence of variations m the tempera- ture, humidity and pressure of the outer atmosphere, it is because they are immersed m an organic environment whose degrees of tem- perature, humidity and pressure do not change with variations m the cosmic environment. Hence, we must conclude that funda- mentally manifestations of life m warm-blooded animals and m man are equally subject to exact and definite physico-chemical conditions In recapitulating all that we have already said, we see that con- ditions of environment m all natural phenomena govern their phe- nomenal manifestations The conditions of our cosmic

environment generally govern the mineral phenomena occurring on the surface of the earth , but organized beings include withm themselves the con- dition peculiar to their vital manifestations, and m proportion as the organism, l e , the living machine, perfects itself, and its organized units grow more delicate, it creates conditions peculiar to an organic environment which becomes more and more isolated from the cosmic

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environment We thus come back to the distinction which I estab- lished long since, and which I believe very fruitful, to wit, that two environments must be considered m physiology, the general maerocosmic environment and the microcosmic environment pe- culiar to living beings, the latter is more or less independent of the former, according to the degree of perfection of the organism. More- over, we easily understand what we see here m the living machine, since the same thing is true of the inanimate machines created by man Thus, climatic changes have no influence at all on the action of a steam engine, though everyone knows that exact conditions of temperature, pressure and humidity inside the machine govern all its movements For inanimate machines we could therefore also distinguish between a maerocosmic environment and a microcosmic environment In any case, the perfection of the machine consists m being more and more free and independent, so as to be less and less subject to the influence of the outer environment The human machine is the more perfect, the better it defends itself from pene- tration by the influences of the outer environment, as the organism grows old and enfeebled, it becomes more sensitive to the outer influ- ences of cold, heat, humidity, and m general to all other climatic influences

To sum up, if we wish to find the exact conditions of vital mani- festations m man and the higher animals, we must really look, not at the outer cosmic environment,

but rather at the inner organic en- vironment Indeed, as we have often said, it is in the study of these inner organic conditions that direct and true explanations are to be found for the phenomena of the life, health, sickness and death of the organism From the outside, we see only the resultant of all the inner activities of the body, which therefore seem like the result of a distinct vital force m only the most distant relations with the physico-chemical conditions of the outer environment, and mani- festing itself always as a sort of organic peisonahty endowed with specific tendencies. We have elsewhere said that ancient medicine considered the influence of the cosmic environment, of water, air and locality, we may indeed find useful suggestions here as to hygienic and as to morbid changes But modem experimental medi- cine will be distinguished for being especially founded on knowledge of the inner environment where normal and morbid as well as medic- inal influences take action But how are we to know this inner

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environment of the organism, so complex m man and m the higher animals, unless we go down and, as it were, penetrate into it, by means of experimentation applied to living bodies 2 That is to say, to analyze the phenomena of life, we must necessarily penetrate into living organisms with the help of the methods of vivisection.

To sum up, only m the physico-chemical conditions of the inner environment can we find the causation of the external phenomena of life The life of an organism is simply the resultant of all its in- most workings , it may appear more or less lively, or more or less enfeebled and languishing, without possible explanation by anything m the outer environment, because it is governed by the conditions of the inner environment We must therefore seek the true foundation of animal physics and chemistry m the physico-chemical properties of the inner environment However, as

we shall see further on, it is necessary to consider not only the physico-chemical conditions indis- pensable to life, but also the peculiar, evolutionary, physiological conditions which are the quid propnum of biological science I have always greatly emphasized this distinction because I believe that it is basic, and that physiological considerations must predominate m a treatise on experimentation applied to medicine Here indeed we shall find the differences due to influences of age, sex, species, race, or to state of fasting or digestion, etc That will lead us to con- sider, m the organism, reciprocal and simultaneous reactions of the inner environment on the organs, and of the organs on the inner environment

III Vivisection

We have succeeded m discovering the laws of inorganic matter only by penetrating into inanimate bodies and machines, similarly we shall succeed m learning the laws and properties of living matter only by displacing living organs m order to get into their inner environment After dissecting cadavers, then, we must necessarily dissect living beings, to uncover the inner or hidden parts of the organisms and see them work, to this sort of operation we give the name of vivisection, and without this mode of investigation, neither physiology nor scientific medicine is possible , to learn how man and animals live, we cannot avoid seeing great numbers of them die, because the mechanisms of life can be unveiled and proved only by knowledge of the mechanisms of death.

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Men have felt this truth m all ages, and m medicine, from the earliest times, men have performed not only therapeutic experiments hut even vivisection We are told that the kings of Persia delivered men condemned to death to their physicians, so that they might perform on them vivisections useful to science According to Galen, Attalus III (Philometor), who reigned at Pergamum, one hundred thirty-seven years

before Jesus Christ, experimented with poisons and antidotes on criminals condemned to death 2 Celsus recalls and approves the vivisection which Herophilus and Erasistratus per- formed on criminals with the Ptolemies' consent It is not cruel, he says, to inflict on a few criminals, sufferings which may benefit multitudes of innocent people throughout all centuries 3 The Grand Duke of Tuscany had a criminal given over to the professor of anatomy, Fallopius, at Pisa, with permission to kill or dissect him at pleasure As the criminal had a quartan fever, Fallopius wished to investigate the effects of opium on the paroxysms He administered two drams of opium during an intermission , death occurred alter the second experiment 4 Similar instances have occasionally recurred, and the story is well known of the archer of Meudon 5 who was par- doned because a nephrotomy was successfully performed on hun. Vivisection of animals also goes very far back Galen may be consid- ered its founder He performed his experiments especially on monkeys and on young pigs and described the instruments and methods used m experimenting Galen performed almost no other kind of experiment than that which we call disturbing experiments, which consist m wounding, destroying or removing a part, so as to judge its function by the disturbance caused by its removal He sum- marized earlier experiments and studied for himself the effects of de- stroying the spinal cord at different heights, of perforating the chest on one side or both sides at once , the effects of section of the nerves leading to the intercostal muscles and of section of the recurrent nerve He tied arteries and performed experiments on the mecha- nism of deglutition 6 Since Galen, at long intervals m the midst of

1 Daniel Leclerc, Eutoire de la mddecine, p 338

* CelBUB, De Medxcina

* Astrue, De Morbis Verier ex s Vol II, pp 748 and 749

* Payer, Traiti des maladies des reins Vol III, p 213 Paris, 1841

' Dezeimens, Djcftonnaire hxstonque, Vol II, p 444 Daremberg Exposition des

connaxssances de Oahen sur I’anatomie pathologique et la pathologic du systime ncrieux Ihesis, 1841, pp 13 and 80

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medical systems, eminent vmsectors have always appeared As such, the names of Graaf, Harvey, Aselli, Pecquet, Haller, etc , have been handed down to us In our time, and especially under the influence of Magendie, vivisection has entered physiology and medicine once for all, as an habitual or indispensable method of study

The prejudices clinging to respect for corpses long halted the progress of anatomy In the same way, vivisection in all ages has met with prejudices and detractors We cannot aspire to destroy all the prejudice m the world, neither shall we allow ourselves here to answer the arguments of detractors of vivisection, since they thereby deny experimental medicine, 1 e , scientific medicine How- ever, we shall consider a few general questions, and then we shall set up the scientific goal which vivisection has m view

First, have we a right to perform experiments and vivisections on man ? Physicians make therapeutic experiments daily on their patients, and surgeons perform vivisections daily on their subjects Experiments, then, may be performed on man, but within what lim- its ? It is our duty and our right to perform an experiment on man whenever it can save his life, cure him or gam him some personal benefit The principle of medical and surgical morality, therefore, consists m never performing on man an experiment which might be harmful to him to any extent, even though the result might be highly advantageous to science, 1 e , to the health of others But performing experiments and operations exclusively from the point of view of the patient’s own advantage does not prevent their turning out profitably to science It cannot indeed be otherwise, an old phy- sician who has often administered drugs and

treated many patients is more experienced, that is, he will experiment better on new pa- tients, because he has learned from experiments made on others A surgeon who has performed operations on different kinds of pa- tients learns and perfects himself experimentally Instruction comes only through experience , and that fits perfectly into the definitions given at the beginning of this introduction

May we make experiments on men condemned to death or vivi- sect them ? Instances have been cited, analogous to the one recalled above, m which men have permitted themselves to perform dangerous operations on condemned criminals, granting them pardon m ex- change Modem ideas of morals condemn such actions, I com- pletely agree with these ideas , I consider it wholly permissible, how-

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ever, and useful to science, to make investigations on the properties of tissues immediately after the decapitations of criminals A helminthologist had a condemned woman without her knowledge swallow larvae of intestinal worms, so as to see whether the worms developed m the intestines 7 after her death. Others have made analogous experiments on patients with phthisis doomed to an early death , some men have made experiments on themselves As experi- ments of this kind are of great interest to science and can he con- clusive only on man, they seem to be wholly permissible when they involve no suffering or harm to the subject of the experiment For we must not deceive ourselves, morals do not forbid making experi- ments on one’s neighbor or on one’s self, m everyday life men do nothing but experiment on one another Christian morals forbid only one thing, doing ill to one’s neighbor. So, among the experi- ments that may be tried on man, those that can only harm are for- bidden, those that are innocent are permissible, and those that may do good are obligatory

Another question presents itself Have we the right to make experiments on animals

and vivisect them2 As for me, I think we have this right, wholly and absolutely It would be strange in- deed if we recognized man's right to make use of animals m every walk of life, for domestic service, for food, and then forbade him to make use of them for his own instruction m one of the sciences most useful to humanity No hesitation is possible, the science of life can be established only through experiment, and we can save living beings from death only after sacrificing others Experiments must be made either on man or on animals Now I think that pby- Bicians already make too many dangerous experiments on man, before carefully studying them on animals I do not admit that it-is moral to try more or less dangerous or active remedies on patients m hos- pitals, without first experimenting with them on dogs, for I shall prove, further on, that results obtained on animals may all be con- clusive for man when we know how to experiment properly If it is immoral, then, to make an experiment on man when it is dangerous to him, even though the result may be useful to others, it is essen- tially moral to make experiments on an animal, even though painful and dangerous to him, if they may be useful to man

After all this, should we let ourselves be moved by the sensitive ' Davame, Tra\t6 ties cntosoairca Paris, 1800 Synopsis, xxvii

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cries of people of fashion or by the objections of men unfamiliar -with scientific ideas ? All feelings deserve respect, and I shall be very careful never to offend anyone's I easily explain them to m3 self, and that is why they cannot stop me I undei stand perfectly how physicians under the influence of false ideas, and lacking the scien- tific sense, fail to appreciate the necessity of experiment and vivisec- tion m establishing biological science I also understand perfectly how people of fashion, moved by ideas wholly different from those that animate physiologists, judge vivisection quite different!} It cannot be otherwise Somewhere m this introduction

we said that, m science, ideas are what give facts their value and meaning It is the same m morals, it is everywhere the same Facts materially alike may have opposite scientific meanings, according to the ideas with which they are connected A cowaidly assassin, a hero and a warrior each plunges a dagger into the breast of his fellow What differentiates them, unless it be the ideas which guide their hands ? A surgeon, a physiologist and Hero give themselves up alike to muti- lation of living hemgs What differentiates them also, if not ideas ? I therefore shall not follow the example of LeGallois,8 m trying to justify physiologists in the eyes of strangers to science who re- proach them with cruelty , the difference m ideas explains everything A physiologist is not a man of fashion, he is a man of science, absorbed by the scientific idea which he pursues he no longer hears the cry of animals, he no longer sees the blood that flows, he sees only his idea and perceives only organisms concealing problems which he intends to solve Similarly, no surgeon is stopped by the most moving cries and sobs, because he sees only his idea and the purpose of his operation Similarly again, no anatomist feels himself m a horrible slaughter house , under the influence of a scientific idea, he delightedly follows a nervous filament through stinking livid flesh, which to any other man would be an object of disgust and horror After what has gone before we shall deem all discussion of vivisec- tion futile or absurd It is impossible for men, judging facts by such different ideas, ever to agree , and as it is impossible to satisf3 everybody, a man of science should attend only to the opinion of men of science who understand him, and should derive rules of conduct only from his own conscience

The scientific principle of vivisection is easy, moreover, to grasp •LeGallois, CEuvres Paris, 1824 Preface, p XXX

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It is always a question of separating or altering certain parts of the living machine,

so as to study them and thus to decide how they func- tion and for what Vivisection, considered as an analytic method of investigation of the living, includes many successive steps, for we may need to act either on organic apparatus, or on organs, or on tissue, or on the histological units themselves. In extemporized and other vivisections, we produce mutilations whose results we study by preserving the animals At other times, vivisection is only an autopsy on the living, or a study of properties of tissues immediately after death The various processes of analytic study of the mecha- nisms of life m living animals are indispensable, as we shall see, to physiology, to pathology and to therapeutics However, it would not do to believe that vivisection m itself can constitute the whole experimental method as applied to the study of vital phenomena. Vivisection is only anatomical dissection of the living, it is neces- sarily combined with all the other physico-chemical means of investi- gation which must be carried into the organism Reduced to itself, vivisection would have only a limited range and m certain cases must even mislead us as to the actual role of organs By these reservations I do not deny the usefulness or even the necessity of vivisection m the study of vital phenomena I merely declare it insufficient Our instruments for vivisection are indeed so coarse and our senses so imperfect that we can reach only the coarse and complex parts of an oigamsm. Vivisection under the microscope would make much finer analysis possible, but it presents much greater difficulties and is applicable only to very small animals

But when we reach the limits of vivisection we have other means of going deeper and dealing with the elementary parts of organisms where the elementary properties of vital phenomena have their seat We may introduce poisons into the circulation, which carry their spe- cific action to one or another histological unit. Localized poisonings, as Fontana and J Muller have already used them, are valuable means of physiological analysis Poisons are veritable reagents of life, ex- tremely delicate instruments which dissect vital units I believe myself the first to consider the study of poisons from this point of view, for I am of the opinion that studious attention to

agents which alter histological units should form the common foundation of general physiology, pathology and therapeutics We must always, indeed, go back to the organs to find the simplest explanations of life

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To sum up, dissection is a displacing of a living organism by means of instruments and methods capable of isolating its different parts It is easy to understand that such dissection of the living presupposes dissection of the dead

IV Nobmal Anatomy in Its Relations -with Vivisection

Anatomy is the basis necessary to all medical investigation, whether theoretical or practical A corpse is an organism deprived of living motion, and the earliest explanation of vital phenomena was naturally sought m dead organs, just as we seek explanation of the action of a machine m motion by studying the parts of the machine at rest It seems, therefore, that the anatomy of man ought to be the basis of physiology and human medicine Prejudice, however, op- posed dissection of corpses, and m default of the human body, men dissected corpses of animals, m organization as close as possible to man Thus Galen’s anatomy and physiology were done mainly on monkeys At the same time, Galen also performed dissections of cadavers and experiments on living animals, thus proving that he understood perfectly that dissection of cadavers is significant only m so far as it is compared with dissection of living bodies In this way, anatomy is indeed only the first step m physiology Anatomy m itself is a sterile science, its existence is justified only by the presence of living men and animals, well and sick, and by its own possible usefulness to physiology and pathology

We shall limit ourselves here to considering the kinds of service which anatomy, whether of man or of animals, m our present state of knowledge, can render physiology and medicine This seems to me the more necessary, because different

ideas on this subject hold sway m science, m judging these questions it is, of course, understood that I take the point of view of experimental physiology and medicine, which together make up the truly active science of medicine In biology we may accept various points of view which establish, as it were, just so many distinct sub-sciences One science, in fact, is sep- arate from another science only because it has a special pomt of view and a particular problem In normal biology, we may distin- guish the zoological point of view, the direct and comparative ana- tomical points of view, the special and the general physiological points of view Zoology, describing and classifying species, is only

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a science of observation used as a vestibule to the true science of ani- mals The zoologist merely catalogues animals by outward or inner characteristics of form, according to the types and the laws which nature offers him m the formation of these types The zoologist's object is classification of beings according to a sort of plan of crea- tion, and for him the problem is summed up m finding the precise place that an animal should fill m a given classification

Anatomy, or the science of animal organization, is more closely and necessarily related to physiology The anatomical point of view differs, however, from the physiological m this, that anatomists wish to explain anatomy by physiology, while physiologists seek to explam physiology by anatomy, which is quite another matter The anatom- ical point of view has dominated science from the beginning up to the present, and it still has many partisans The great anatomists who took this point of view all contributed valiantly, nevertheless, to the development of physiological science , and Haller summed up the idea of the subordination of physiology to anatomy m defining physi- ology as anatomia ammata. I can easily understand that the ana- tomical principle was destined necessarily to present itself first, but I

believe that it is false m its limitations, and that it has to-day grown harmful to physiology, after having rendered great service, which I should be the last to deny Anatomy, m fact, is a simpler science than physiology and consequently should be subordinate to it, in- stead of dominating it Every explanation of vital phenomena, based exclusively on anatomical considerations, is necessarily incomplete The great Haller, who summed up the anatomical period of physi- ology m his immense and admirable writings, restricted himself so far that his physiology is reduced to an irritable fibre and a sensitive fibre The whole humoral or physico-chemical side of physiology, which cannot he approached by dissection and which treats of what we call our inner environment, was neglected The reproach which I am making here against the anatomists who wished to subordinate physiology to their point of view, I make in the same way against chemists and physicists who wish to do the same thing They are also wrong m endeavoring to subordinate physiology, a more complex science, to chemistry or physics, which are simpler sciences This has not prevented great service being rendered to physiology by much work m physiological chemistry and physics, even though conceived from a false point of view

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In a word, I consider that the most complex of all sciences, physi- ology, cannot be completely explained by anatomy To physiology, anatomy is only an auxiliary science, the most immediately necessary, I agree, but insufficient alone, unless we wish to assume that anatomy includes everything, and that the oxygen, chloride of sodium and iron found m the body are anatomical units of the body Attempts of this kind have been revived m our day by eminent anatomists and his- tologists I do not share these views, because they seem to me to create confusion in the sciences and to lead to darkness instead of light

Anatomists, we said above, try to invert, the true method of ex- planation, 1 e , they

take anatomy as an exclusive starting point, and propose to deduce directly from it all the functions solely by logic and without experiments I have already protested against the pre- tentiousness of anatomical deductions,9 by showing that they rest on an illusion of which anatomists are unaware In anatomy, we must m fact distinguish between two classes of things (1) The passive mechanical arrangements of various organs and apparatus which, from this point of view, are really nothing but instruments of animal mechanics, (2) the activity of vital units which put m play this diverse apparatus The anatomy of corpses can certainly take ac- count of the mechanical arrangements of the animal organism, inspection of the skeleton certainly shows a combination of levers whose action we understand solely through their arrangement So with the system of canals or of tubes conducting fluids, and thus the valves m the veins have mechanical functions which put Harvey on the track leading to the discovery of the circulation of the blood The reservoirs, the bladders, the various pockets m which secreted and excreted fluids reside, offer mechanical arrangements which more or less clearly indicate the functions which they must fulfill, without our necessarily having recourse to experiment on the living to learn it But we should notice that these mechanical deductions are by no means absolutely restricted to the functions of living beings, we deduce everywhere, ra the same way, that pipes are meant to conduct, reservoirs meant to hold and levers meant to move

When we come to the active or vital elements which put all the passive instruments of the organism m play, then anatomy of corpses

* Cf Claude Bernard, Logons dc physiologic exptnmeniale, Pans, 1850, Vol II Logon d’owcrture, May 2, 1855

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cannot and does not teach anything All our knowledge on this subject must

necessarily come from experiment or from observation of the living , when, therefore, anatomists believe that they are making deductions solely from anatomy and without experiments, they forget that their starting point was the same experimental physiology which they seem to disdain When anatomists deduce the functions of an organism, as they say, from their texture, they merely use knowledge gained on the living, to interpret what they see m the dead, hut anatomy really teaches them nothing, it merely supplies them with the quality of a tissue

So when anatomists meet with muscular fibres m some part of the body, they infer contractile motion , when they meet gland cells, they infer secretion , when they meet with nerve fibres, they infer sensa- tion or movement But what taught them that muscular fibre contracts, that gland cells secrete, that a nerve is sensory or motor, unless it was observation of the living, or, m other words, vivisection 2 Only, noting that these contractile, secreting or nerve tissues have definite anatomical forms, they establish a relation between the form of the anatomical unit and its functions, so that when they meet one, they infer the other But, I repeat, dead anatomy teaches nothing, it merely leans on what experimental physiology teaches , and a clear proof of this is that, where experimental physiology has learned noth- ing as yet, anatomists can interpret nothing by anatomy alone Thus, the anatomy of the spleen, the suprarenal glands and the thyroid is as well known as the anatomy of a muscle or of a nerve, and neverthe- less anatomists are silent as to the uses of these parts But as soon as physiologists have discovered something about the functions of these organs, anatomists will put the physiological properties noted into relation with their anatomical observations I must also point out that anatomists, m their localizations, can never go beyond the teachings of physiology, except under penalty of falling into error Thus, if anatomists, on the basis of physiological teaching, suggest that, where muscular fibres are present, there are contraction and movement also, they may not infer that, where they see no muscular fibre, there is never contraction or movement Experimental physi- ology has proved, m fact, that

contracting units are of various forms, among them some which anatomists have not yet been able to define In a word, to know something about the functions of life, you must study them in the living Anatomy yields only characteristics

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by winch to recognize tissues, but itself teaches nothing about their vital properties How indeed could the form of the nerve cell show us the nervous properties which it transmits 2 How could the lorm of a liver cell show us that sugar is made m it2 How could the form of a muscle fibre teach us about muscular contraction2 We have here only an empirical relation established by comparative observa- tion of the living and the dead I remember having often heard de Blamville try to differentiate m his lectures betw een what should be called, according to him, a substratum , and what should be called, on the other hand, an organ In an organ, according to de Blamville, we should be able to understand the necessary mechanical relation between a structure and its function Thus, from the form of bony levers, he said, we conceive a definite motion , from the disposal of the blood of the reservoirs for liquids, and of the excretory ducts of glands, we understand that liquids are put m circulation or retained by mechanical arrangements that we can explain But as for the encephalon, he added, no material relations can be established between the structure of the brain and the nature of intellectual phenomena Therefore, concluded de Blamville, the bram is not the organ of thought, it is merely a substratum We may accept, if we like, de Blamville’s distinction, but if so, it will be general and not limited to the bram Indeed, if we understand that a muscle inserted be- tween two bones may act mechanically as a power drawing them to- gether, we by no means understand how the muscle contracts, and we can just as well say that the muscle is the substratum of contraction Though we understand that a fluid secreted by a gland flows out of its tubes, we cannot thereby conceive any idea of the essence of secretory phenomena

And we may just as well say that the gland is a sub- stratum of secretion To sum up, the anatomical point of view is wholly subordinate to the point of view of experimental physiology, as an explanation of vital phenomena But, as we said above, there are two things m anatomy the tools of the organism and the essen- tial agents of life The essential agents of life depend upon the vital properties of our tissues, which can be defined only by observation or by experiment on the living These agents are the same in all animals, without distinction of class, genus or species Here is the domain of general anatomy and physiology Next come tools of life, which are nothing but mechanical tools or weapons with which nature especially provides each organism according to its class, its genus

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or its species We may even say that the special tools constitute the species , for a rabbit differs from a dog only because one has organs that make it eat grass, and the other organs that force it to eat flesh But as to the inmost phenomena of life, the two animals are identical A rabbit is carnivorous if we give him meat ready prepared, and I long ago proved that all fasting animals are carnivorous

Comparative anatomy is merely an inner zoology, its mm ib to classify the apparatus or tools of life These classifications should corroborate or rectify the characteristics suggested by outer forms Thus the whale, which might be put with the fishes by reason of its outer form, is placed with the mammals because of its interior organization Comparative anatomy shows us also that the tools of life are arranged m necessary and harmonious relations with the whole organism Thus, an animal with claws should have the jaws, teeth and the articulations of the limbs disposed m a definite way The genius of Cuvier amplified these views and derived from them a new science, paleontology, which reconstructs an entire animal from a fragment of his skeleton. The object of comparative anatomy, then, is to show the functional

harmony of the tools with which na- ture has endowed an animal and to teach us the changes necessary m these tools according to various circumstances of animal life But beneath all these changes comparative anatomy always shows us the uniform plan of creation, thus any number of organs exist, not as aids to life (they are often actually harmful), hut as characteristics of the species or as vestiges of a single plan of organic composition The stag's antlers have no use favorable to the animal's life, the shoulder blade of a slow-wonn and the mammas m males are ves- tiges of organs that have lost their functions Nature, as Goethe said, is a great artist, to ornament forms, she often adds organs that are useless to life m itself, as an architect makes ornaments for his building, such as friezes, cornices and volutes which are useless for habitation

The object of comparative anatomy and physiology is, therefore, to find the morphological laws of the tools and the organs which together make up organisms Comparative physiology, m so far as it infers functions by comparing organs, would be an insufficient and false science if it rejected experimentation Comparing the forms of limbs or of the mechanical apparatus of life may suggest the uses of these parts But what can the form of the liver or the pancreas tell

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us about the function of these organs2 Has not experiment shown the mistake of likening the pancreas to a salivary gland 2 10 What can the form of the brain or the nerves teach us about their func- tions 2 All that we know has been learned by the observation of the lmng, or by experiment What can we say about fishes' brains, for instance, until experiment has clarified the question2 In a word, anatomical deduction has yielded what it can To linger in this path means lagging behind the progress of science and believing that we can impose scientific principles without experimental verification That, in a word, is a relic of the scholasticism of the

Middle Ages But, on the other hand, comparative physiology, m so far as it relies on experiment and seeks the properties of tissues and organs m ani- mals, does not seem to me to have separate existence as a science It falls back necessarily into special or general physiology, since its object is the same

We distinguish between the various biological sciences only by the goal which we set ourselves or the idea which we pursue m studying them Zoologists and comparative anatomists see all living beings as a whole, and by studying the outer and inner characteristics of beings, they seek to discover the morphological laws of their evolu- tion and their transformation Physiologists take a quite different point of view they deal with just one thing, the properties of living matter and the mechanism of life, m whatever form it shows itself For them, genus, species and class no longer exist There are only living beings , and if they choose one of them for study, that is usually for convenience m experimentation Physiologists also follow a different idea from the anatomists The latter, as we have seen, try to infer the source of life exclusively from anatomy , they therefore adopt an anatomical plan Physiologists adopt another plan and follow a different conception , instead of proceeding from the organ to the function, they start from the physiological phenomenon and seek its explanation m the organism To solve the problem of life, physiologists therefore call to their aid all the sciences, — anatomy physics, chemistry, which are all allies serving as indispensable tools for investigation We must, therefore, necessarily be familiar enough with these various sciences to know all the resources which may be drawn from them Let us add, m ending, that from every

"Claude Bernard, Mimrnrc sur le pancreas {Supplement aux Comptcs rendus dc VAcaddmic des sciences 1856 Vol I)

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biological point of view, experimental physiology is m itself the one active science

of life, because by defining tbe necessary conditions of vital phenomena it will succeed m mastering them and m governing them through knowledge of their peculiar laws

V Pathological Anatomy and Dissection in Relation to Vivisection

What we said m the last paragraph about normal anatomy and physiology may be repeated for pathological anatomy and physiology We find similarly three points of view appearing one after another, the taxonomical or nosological point of view, the anatomical point of view and the physiological point of view We cannot here go into de- tailed study of these questions, which would include neither more nor less than the entire history of medical science We shall limit ourselves to suggesting oui idea m a few words

While observing and describing diseases, men must have sought at the same time to classify them, as they sought to classify animals, and according to precisely the same principles, by artificial or nat- ural methods Pmel applied to pathology the natural classification introduced into botany by de Jussieu, and into zoology by Cuvier It is sufficient to quote the first sentence of Pmel's Nosogmphy "Given a disease, to find its place m a nosological scheme " 11 No one, I think, will consider this the goal of all medicine, it is merely a partial point of view, the taxonomic point of view

After nosology came the anatomical point of view , that is, after considering diseases as morbid species, men try to place them ana- tomically It was thought that, just as there is a normal organiza- tion to take account of vital phenomena m the normal state, so there must he an abnormal organization to take account of morbid phe- nomena Though the point of view of pathological anatomy can al- ready be recognized in Morgagni and Bonnet, still it is especially m this century, under the influence of Broussais and Laennec, that pathological anatomy has been

systematically built up Men compared the anatomy of diseases, they classified changes m tissues, hut they also tried to bring these changes into relation with the morbid phenomena and, as it were, to deduce the second from the first The same problems presented themselves as m comparative, normal 11 Pmel, NosograpJne plnlosophiqtie 1800

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anatomy In the case of morbid changes producing physical or me- chanical alteration m a function, as for instance a vascular compres- sion or mechanical lesion of a limb, men could understand the rela- tion connecting the morbid symptom with its cause and could make what is called a rational diagnosis Laennec, one of my predecessors m the chair of medicine at the College de France, immortalized him- self m this field by the precision which he gave to physical diagnosis of diseases of the heart and lungs But diagnosis became impossible m the case of diseases where changes were imperceptible with our piesent means of investigation No longer able to find an anatomical relation, men said then that the disease was essential, i e , without any lesion, which is absurd, for it amounts to acknowledging an effect without a cause Men came to understand that, to find the explanation of such diseases, they must carry their investigations into the minutest parts of the organism where life has its seat The new era of microscopic pathological anatomy was inaugurated m Germany by Johannes Muller, 12 and an illustrious professor m Ber- lin, Virchow, recently systematized micioscopie pathology 13 So in changes of the tissues, they found proper characteristics for defining diseases A propos of this, they invented the name pathological physi- ology, to designate pathological function in relation to abnormal anatomy I shall not have to consider whether these expressions, pathological anatomy and physiological pathology, are well chosen I shall simply say that the pathological anatomy, whose pathological

phenomena they define, is subject to the same objection of insuffi- ciency that I have already made to normal anatomy First, the pathological anatomists assume it proved that anatomical changes are always primary, which I do not admit, believing the contrary, that a pathological change is very often secondary and is the con- sequence or fruit of toe disease instead of its germ , which does not prevent this product from later becoming a morbid germ of other symptoms I shall therefore not admit that cells or fibres of tissues are always primarily attacked , a morbid physico-chemical change m the organic environment being able, m itself, to lead to the morbid phenomena, m the manner of a toxic symptom which occurs, without

u Muller, Dc Olandularum scccrncnUum structura pcnttion carumque pnma formaixonc tn ftcmtnc atque ammalibus Leipzig, 1830

“ Virchow, La Pathologic cellulatrc basic sur Vitudc physiologique et pathu logique dcs tissue, translated by P Picard Pans, 1860

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primary lesion of the tissues, through mere change m the environ- ment.

The anatomical point of view is therefore insufficient, and the changes noted m cadavers after death really show characteristics by which to recognize and classify diseases, rather than lesions capable of explaining death It is indeed strange to see how little attention most physicians pay to this latter point of view, which is the true point of view of physiology When a physician, for example, makes a typhoid autopsy, he notes the intestinal lesions and is satisfied. But m reality that explains absolutely nothing about either the cause of the disease, or the action of drugs, or the reason for death Micro- scopic anatomy teaches us no more about it, for when a person dies of tuberculosis or pneumonia or typhoid fever, the microscopic lesions found after death existed before, and often long before, death is not explained by the particles either of the tubercle or of Beyer’s patches m the intestines or of other

morbid products , death, m fact, can be understood only because some histological unit has lost its physiological properties, a loss which has brought on the disruption of vital phenomena But to grasp the physiological lesions m their relations with the mechanism of death, we should have to make autopsies on cadavers immediately after death, which is impossible This, then, is why we must perform experiments on animals and must necessarily give medicine the experimental point of view, if we mean to found a truly scientific medicine which shall logically embrace physiology, pathology and therapeutics Bor many years I have done my best to advance m this direction 14 But the point of view of experimental medicine is most complex, in that it is physio- logical and also includes explanation of pathological phenomena by anatomy A propos of pathological anatomy, I shall repeat what I said about normal anatomy, to wit, that anatomy m itself teaches nothing without observation of the living For pathology we must therefore establish pathological vivisection, that is to say, we must create diseases m animals and sacrifice them at various stages of these diseases We may also study in the living the changes m the physiological properties of tissues as well as the changes m the cells or the environments When the animal dies, we must make an au- topsy immediately after death, 3ust as if we were dealing with one of those instantaneous diseases called poisoning, for fundamentally a Claude Bernard, Cours de pathologie expinmentdle (Medical Times, I860)

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there is no difference in the study of physiological activities, whether morbid, toxic or medicinal In a word, a physician should not bold to anatomical pathology alone, to explain the disease, be starts from observation of the patient and later explains the disease by physi- ology with the help of pathological anatomy and all the allied sciences used by investigators of biological phenomena

VI The Variety of Animals Subjected to Experimentation , the Variability of

Organic Conditions Which They Present to Experimenters

All animals may be used for physiological investigations, because, with the same properties and lesions m life and disease, the same result everywhere recurs, though m mechanism the vital manifesta- tions vary greatly However, the animals most used by physiologists are those procured most easily, and here we must set m the front rank domestic animals such as dogs, cats, horses, rabbits, oxen, sheep, pigs, barnyard fowl, etc , hut if we had to reckon up the services rendered to science, frogs would deserve the first place No other animal has been used for greater or more numerous discoveries, at all points m science , and even to-day, physiology without frogs would he impossible If the frog, as has been said, is the Job of physiology, that is to say, the animal most maltreated by experimenters, it is certainly the animal most closely associated with their labors and their scientific glory 15 To the list of animals cited above, we must add many others, warm-blooded and cold-blooded, vertebrates and invertebrates, and even infusoria which may he used for special investigations But specific diversity is not the sole difference be- tween the animals which physiologists subject to experimentation, in the condition m which they are found, they present many differ- ences which at this point require consideration, for without knowl- edge or appreciation of their individual characteristics, we can have neither biological exactness nor precision m experimentation

The first condition for making an experiment is that its cir- cumstances must he so well known and so precisely defined that we can always reconstruct them and reproduce the same phenomena at will We have said elsewhere that this fundamental condition of

“ C Dum6nl, Notice histonquc stir les dicouvcrtcs faites dans les sciences d'obscrvation par Vdtude de I’organtsme des grenouilles 1840

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experimentation is relatively easy to fulfill in inorganic beings and is surrounded with great difficulties m living beings, particularly m warm-blooded animals In fact, we must not only reckon with variations in. the surrounding cosmic environment, but must also reckon with variations m the organic environment, — that is to say, the present state of the animal organism We should therefore be greatly m the wrong if we believed it enough, m making an experiment on two animals of the same species, to place them m exactly the same experimental conditions In every animal, certain physiological conditions of the inner environment have an extreme variability, which, at a given moment, produces appreciable differences, from the experimental point of view, between animals of the same species whose outward appearance is identical I believe that, more than anyone else, I have emphasized how necessary it is to study physio- logical conditions, and have shown that knowledge of them is the necessary foundation of experimental physiology

We must indeed admit that vital phenomena m an animal vary only with precise and definite conditions of the inner environment We shall therefore try to find these experimental, physiological con- ditions, instead of tabulating the variations m phenomena and taking averages as expressions of reality , we should thus reach conclusions based on correct statistics, but with no more scientific reality than if they were wholly arbitrary If we wish to wipe out the diversity evident m organic fluids by taking the averages of all the analyses of urine or blood, even from an animal of the same species, we should thus have a mere combination of these humors corresponding to no definite physiological state of the animal I have indeed shown that, m lasting, urine always has the same definite com- position , I have shown that the blood coming out of an organ is quite different, according to whether the organ is in a state of activity or rest If we look for sugar m the liver, for instance, and make tabu- lations of its absence or presence, and take averages to find out how many

times per hundred there is sugar or glycogen m that organ, we shall find a number which, whatever it is, means nothing, because, as I have shown, m certain physiological conditions there is always sugar, and m other conditions there is never any Now taking an- other point of view, if we meant to consider all the experiments suc- cessful m which there was hepatic sugar and consider all those unsuc- cessful m which there was none, we should fall into another but no

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less reprehensible kind of error In fact, I have posited this prin- ciple there never are any unsuccessful experiments , they are all successful in their own definite conditions, so that negative cannot nullify positive results I shall return elsewhere, however, to this important subject For the moment, I wish merely to call to the attention of experimenters the importance of defining organic con- ditions, because, as I have already said, they are the one foundation of experimental physiology and medicine In what follows, a few indications will suffice, since those conditions will be studied later, a propos of each particular experiment, from the three points of view physiological, pathological and therapeutic

In every experiment on living animals, three kinds of physio- logical conditions peculiar to the animal must be considered, apart from general cosmic conditions, to wit anatomical operative condi- tions, physico-chemical conditions of the inner environment and or- ganic conditions of units in the tissues

1 Operative Anatomical Conditions — Anatomy is the neces- sary foundation of physiology, and never can we become good physi ologists if we are not first deeply versed m anatomical studies and trained m delicate dissections, so as to be able to make the prepara- tions which are often required for physiological experiments In fact, operative anatomical physiology has not yet been founded, the zoologists' comparative anatomy is too vaguely superficial for physiologists to find m it the

exact topographical knowledge that they need , the anatomy of domestic animals is done by veterinarians from too special and restricted a point of view to be of great use to experimenters, and thus physiologists are ordinarily reduced to mak- ing for themselves the anatomical investigations which they need to devise their experiments It is evident that, m severing a nerve, ty- ing a duct or injecting a vessel, knowledge of the anatomical arrange- ment of parts, m the animal operated on, is absolutely indispensable to understanding and defining the physiological results of the experi- ment Some experiments would be impossible with certain species of animals, and intelligent choice of an animal offering a happy anatomical arrangement is often a condition essential to the success of an experiment and to the solution of an important physiological problem Anatomical arrangements may sometimes present anom- alies which must also be thoroughly known, as well as the variations observed between one animal and another In the sequel of this

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work, I shall therefore be careful always to describe experimental methods, including the anatomical arrangement, and I shall show that divergencies of opinion among physiologists have been caused, more than once, by anatomical differences which they failed to reckon with, when interpreting the results of experiments As life is merely a mechanism, anatomical arrangements peculiar to certain animals may seem insignificant at first sight , yet these seemingly futile mi- nutise are often enough to change the physiological manifestations completely and to form what we call a highly important idiosyncrasy. A case m point is section of the two facial nerves, which is mortal m horses, but not mortal m other closely related animals

2. Physico-chemical Conditions of the Inner Environment — Life is made manifest by the action of outer stimuli on irritable living tissues which react by manifesting their special properties The physiological conditions of life are therefore nothing but

the special physico-chemical stimuli which set in action the tissues of the or- ganism These stimuli are found m the atmosphere or the environ- ment which the animal inhabits , but we know that the properties of the general outer atmosphere pass into the organic atmosphere m which all the physiological conditions of the outer atmosphere are found, plus a certain number of others peculiar to the inner environ- ment We shall content ourselves here with naming the principal physico-chemical conditions of the inner environment to which ex- perimenters should direct their attention These, moreover, are only the conditions offered by every environment in winch life manifests itself

Water is the first indispensable condition of every vital manifes- tation, as of every manifestation of physico-chemical phenomena In the outer cosmic environment we may distinguish between aquatic and aenal animals, but this distinction can no longer be made be- tween histological units , plunged m the inner environment, they are aquatic m all living beings, that is to say, they are bathed in organic fluids, including very large quantities of water The proportion of water at times reaches 90 to 99 per cent m the organic fluids, and when this proportion of water is notably diminished, peculiar physio- logical troubles result Thus, if we remove water from frogs by prolonged exposure to dry air, and if we reduce the quantity of water m the blood by introducing into the body substances with a very high endosmotie equivalent, we witness convulsive phenomena, which

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cease as soon as -we restore the normal proportion of -water Com- plete removal of water from living bodies invariably leads to death m large organisms provided with delicate histological units , but it is well known that in small inferior organisms, removal of water invari- ably suspends life Cases m point are the return to life of rotifera, of tardigrades and the small eels m mildewed wheat There are num- berless

cases of latent life m vegetables and animals, due to removal of the organism's water

Temperature has a considerable influence on life Raising the temperature makes vital phenomena as well as the manifestation of physico-chemical phenomena more active In the outer cosmic en- vironment, variations of temperature create the seasons which are characterized only by variations m the behavior of animal and vege- table life on the surface of the earth These variations take place only because the inner environment or organic atmosphere of plants and certain animals remams m equilibrium with the outer atmosphere If we put plants m hothouses, the influence of winter no longer makes itself felt , the case of cold-blooded and hibernating animals is the same But warm-blooded animals keep their organic units, as it were, in a hothouse , so they do not feel the influence of hibernation However, since this is only a special resistance of the inner environ- ment to falling into heat equilibrium with the outer environment, this resistance can be overcome m certain cases, and in some circum- stances warm-blooded animals can warm or cool themselves The maximum temperatuie compatible with life does not generally rise above 15 degiees The minimum does not go below the freezing point of the organic animal or vegetable fluids Howevei, these extremes may vary In warm-blooded animals the temperature of the inner atmosphere is normally from 38 to 40 degrees it cannot go above 45 to 50 degrees nor below 15 to 20 degrees, without causing pbv Biolog- ical disturbance or even death if the variations are rapid In hiber- nating animals, the gradual change of temperature which occurs may go much lower, causing the progressive disappearance of manifes- tation of life, to the point of lethargy or latent life, which may some- times last a very long time, if the temperature does not vary

Air is necessarj to the life of all vegetable and animal beings, air therefore exists m the inner organic atmosphere The three gases of the outer air, oxygen, nitrogen and carbonic acid gas, are m solu- tion in the organic fluids m which the histological units breathe di-

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rectly, like fish m water. Cessation of life through removal of these gases, especially oxygen, is what we call death by asphyxiation In living beings, there is a constant interchange of gases between the inner and the outer environment, yet vegetables and animals, as we know, differ m respect to the changes which they cause m the sur- rounding air.

Pressure exists m the outer atmosphere, we know that on the surface of the earth the air exerts on living beings a pressure that lifts a column of mercury to a height of about 76 centimeters In the inner atmosphere of warm-blooded animals, the nutritive fluids circulate under the influence of a pressure greater by about 150 mm. than the outer atmospheric pressure, but this does not necessarily indicate that the histological units really support such pressure The influence of variations of pressure on the manifestations of life of organic units, moreover, is little known We learn, however, that life cannot appear m too highly rarefied air, not only because the gases of the outer air cannot then dissolve m the alimentary fluid, but also because the gases dissolved in it escape This is what we observe when we place a small animal under an air pump, its lungs are obstructed by the gases liberated m the blood The articulates bear this removal of air much better, as various experiments have shown Fishes m the depths of the sea sometimes live under considerable pressure

The chemical composition of the cosmic or outer environment is constant and very simple Its composition is that of the air, which remains the same, except for the proportions of water vapor and a few electric and other conditions which vary The chemical conditions of the inner or organic environments are much more complex, and complication increases as the animal itself becomes higher and more complex Organic environments, as we have said, are always aque- ous, they hold in solution definite saline and organic substances, they show fixed reactions , the lowest animal

has its own organic environ- ment, infusoria have an environment belonging to them, m this sense that they are more permeated than is a fish with the water m which he swims In the organic environments of the higher animals, the histological units are like veritable infusoria, that is to say, they are provided with an environment proper to themselves which is not the general organic environment Thus a corpuscle of blood is per- meated with a fluid different from the serum m which it floats

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3 Organic Conditions — Organic conditions are those -which cor- respond to the evolution or change of the vital properties of organic units Variation of these conditions necessarily leads to changes whose principal features we must recall here Manifestations of life grow more varied, delicate and active m proportion as hemgs rise m the scale of organization But susceptibility to disease also in- creases at the same time Experimentation, as we have already said, is necessarily more difficult as organization becomes more complex

Animal and vegetable species are separated by peculiar condi- tions which prevent them from mingling, so that fecundation, graft- ing and transfusion cannot be performed between beings of different species These are problems of the greatest interest, which I be- lieve may be attacked and reduced to differences m the physico-chemical properties of environment

In the same species of animals, breeds may still show a certain number of very interesting differences In different breeds of dogs and horses I have noted very peculiar physiological characteristics related, m different degrees, to the properties of certain histological units, particularly of the nervous system Finally, among indi- viduals of the same breed we find physiological peculiarities which are also connected with special variations m the properties of certain histological units

These, therefore, are what we call idiosyncrasies

The same individual is unlike himself at some periods m his evo- lution, this leads to differences connected with age After birth, the phenomena of life are of slight intensity , soon they become very active, to slow down again toward old age

Sex and the physiological state of the genital organs maj lead to changes which are sometimes very profound, especially m the lower animals, among which the physiological characteristics of the larvse, in certain cases, completely differ from the characteristics of the animal when full grown and endowed with genital organs

Molting at times leads to such profound organic changes that experiments performed on animals m different stages yield by no means the same results 16

Hibernation also leads to great differences in the phenomena of ” Sw L Ziegler, Vcbcr d\e Brunet und den Embryo der Rehc Hanover, 1843

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life, and operating on a frog or a toad is by no means the same thing m summer as m winter 17

States of digestion or fasting, of health or disease, also cause great changes m the intensity of vital phenomena and so m the resist- ance of animals to the influence of certain toxic substances and m their susceptibility to one or another parasitic or virulent disease

Habit is yet another condition potent m changing organisms This condition is one of the most important to keep in mind, espe- cially when we intend to experiment on the action of toxic or me- dicinal materials

The size of animals also involves important changes m the in- tensity of vital phenomena In general, vital phenomena are more intense m small animals than m large, which means, as we shall see further on, that we cannot rigorously measure

physiological phe- nomena m proportion to weight

To sum up, after all that we have previously said, we see what huge complexity inheres m animal experimentation because of the numberless factors with which the physiologist must reckon Never- theless, we may succeed if we make proper distinctions and subordi- nations, as we have just said, among the various factors, and if we seek to connect the factors m question with definite physico-chem- ical conditions

VII The Choice of Animals , the Usefulness to Medicine of Experiments on Various Species of Animals

Among the objections that physicians have offered to experimen- tation is one which must be seriously considered because it throws doubt on the usefulness of animal experiments to human physiology and medicine It has been said, indeed, that experiments performed on a dog or a frog may be conclusive in their application to dogs and frogs, but never to man, because man has a physiological and patho- logical nature proper to himself and different from all other animals It has been further stated that to be really conclusive for man, experi- ments would have to be made on man or on animals as near to him as possible It was surely with this idea that Galen chose a monkey for his experiments, and Vesalius a pig, as subjects more closely

»See Stanmus, Beobachtungen tiler Verjungungsvorgange m ihiertschen Orgamsmue Roatoch and Schwerin, 1853

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resembling man in his omnivorous capacity Even to-day, many people choose dogs for experiments, not only because it is easier to procure this animal, but also because they think that experiments performed on dogs can more properly be applied to man than those performed on frogs How well founded are these opinions 2 How much

importance should we ascribe to the choice of animals m rela- tion to the usefulness of the experiment to physicians 2

As far as direct applicability to medical practice is concerned, it is quite certain that experiments made on man are always the most conclusive No one has ever denied it. Only, as neither the moral law nor that of the state permits making on man the experiments which the interests of science imperatively demand, we frankly ac- claim experimentation on animals from the theoretic point of view, experiments on all sorts of animals are indispensable, while from the immediately practical point of view, they are highly useful to medicine In fact, as we have already often expressed it, two things must be considered m the phenomena of life first the fundamental properties of vital units which are general, then arrangements and mechanisms m organizations, which give each animal species its peculiar anatomical and physiological form Now, among all the animals on which physiologists and physicians may experiment, some are better suited than others to the studies depending on these two points of view Here we shall merely say m general that, for the study of tissues, cold-blooded animals or young mammals are more appropriate, because the properties of their living tissues vanish more slowly and so can better be studied There aTe also experi- ments m which it is proper to choose certain animals which offer fa- vorable anatomical arrangements or special susceptibility to certain influences For each kind of investigation we shall be careful to point out the proper choice of animals This is so important that the solution of a physiological or pathological problem often depends solely on the appropriate choice of the animal for the experiment so as to make the result clear and searching

General physiology and pathology are necessarily based on the study of tissues m all animals, for a general pathology that did not ultimately rest on considerations drawn from the comparative pa- thology of animals at all stages of organization could build, up a collec- tion of generalities about human pathology, but never a general pathology m the scientific sense of the word lust as an organism

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cm live only by the normal manifestation of its properties or the' help of one or more of its vital units, so the organism can become diseased only by abnormal manifestation of the properties of one or more of its vital units Now the vital units, being of like nature m all living beings, are subject to the same organic laws They de- velop, live, become diseased and die under influences necessarily of like nature, though manifested by infinitely varying mechanisms A poison or a morbid condition, acting on a definite histological unit, should attack it m like circumstances m all animals furnished with it, otherwise these units would cease to be of like nature, and if we went on considering as of like nature units reacting m different or opposite ways under the influence of normal or pathological vital reagents, we should not only deny science m general, but also bring into zoology confusion and darkness that would absolutely block its advance, for the quality which should be placed m the front rank of the science of life and should dominate all the rest is vitality The vital quality may doubtless offer great diversities in degree and kind of manifestation, according to peculiar circumstances of environ- ment or mechanism shown by healthy or diseased organisms The lower organisms have fewer distinct vital units than do the higher organisms, whence it follows that these beings are less easily attacked by morbid or mortal influences But m animals of the same class, order or species there are also constant or variable differences which medical physiologists must absolutely know and explain, because these differences, though resting on delicate distinctions, give phe- nomena an essentially different aspect The problem of science will consist precisely m this, to seek the unitary character of physio- logical and pathological phenomena m the midst of the infinite va- riety of their particular manifestations Experimentation on ani- mals is therefore one foundation of comparative physiology and pathology , and we shall later quote examples to prove how important it is not to lose sight of the above ideas

In special questions of physiology and pathology, experimentation on the higher animals yields daily results, which are applicable m practice, that is, m hygiene or m medicine , studies of digestion made on animals are evidently comparable with the same phenomena in man, as W Beaumont’s observations on his Canadian, compared with those he made by means of a gastric fistula m a dog, have super- abundantly proved Experiments made with animals, whether on the

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cerebrospinal nerves or on the vasomotor and secretory nerves of the large sympathetic (like experiments on circulation), are appli- cable at every point to the physiology and pathology of man Ex- periments on animals, with deleterious Bubstances or m harmful cir- cumstances, are very useful and entirely conclusive for the toxicology and hygiene of man Investigations of medicinal or of toxic sub- stances also are wholly applicable to man from the therapeutic point of view, for, as I have shown,19 the effects of these substances are the same on man as on animals, save for differences in degree In pathological physiology, investigations of the formation of callus, the production of pus, etc, m animals are incontestably useful to human medicine

But aside from all the connections to be found between man and animals we must recognize that there are differences also Thus from a physiological point of view, experimental study of sense organs and cerebral functions must be made on man, on the one hand, because man is made higher than the animals by faculties which animals lack, and, on the other hand, because animals cannot di- rectly account to us for the sensations which they experience From the pathological point of view, we also note differences between man and animals, thus animals have parasitic and other diseases un- known to man, and vice versa Among these diseases some are trans- missible from man to animals and from animals to man, others, not Finally,

certain susceptibilities to inflammation of the perito- neum and other organs are not developed to the same degree m man as m animals of various classes or species But, far from being motives to hold us back from experimenting and from applying conclusions from pathological investigation made on animals to differ- ences observed in man, these differences provide convincing reasons to the contrary Different species of animals show numerous and important differences m pathological tendencies I have already said that there are breeds and varieties among domestic animals, such as asses, dogs and horses, which present wholly individual physiological and pathological susceptibilities, I have even noted individual differences that were often rather marked Only experimental studies of these diversities can furnish an explanation of the individual dif- ferences observed in man, either m different races or in different m-

n Claude Bernard, Rcchcrches sur Vopium et see alcaloides (Comptes rendwt dc VAcadimxc dee sciences, 1864)

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dmduals of the same race, differences -which physicians call predis- positions or idiosyncrasies Instead of persisting as indeterminate states of the organism, predispositions, -when studied experimentally, will be classed in due time as particular cases of a general physio- logical law, which will thus become the scientific foundation of prac- tical medicine.

To sum up, I not only conclude that experiments made on animals from the physiological, pathological and therapeutic points of new have results that are applicable to theoretic medicine, but I think that without such comparative study of animals, practical medicine can never acquire a scientific character. In this connection I shall finish with the words of Buffon, to which we might ascribe a different philosophic meaning, but which are scientifically very true for this

occasion • “If animals did not exist, man’s nature would be still more incomprehensible ”

VIII. Comparison between Animats and Comparative Experimentation

In animals, and especially the higher animals, experimentation is so complex and liable to so many sources of error, both foreseen and unforeseen, that we must proceed most circumspectly to avoid them To bring experimentation to bear on parts of the organism that we wish to explore, we must often do considerable tearing down and produce direct or indirect disturbances which must change or destroy our experimental results These very real difficulties have often vitiated experimental investigations on living beings and fur- nished arguments to the detractors of experimentation But science would never progress if we thought ourselves justified m renouncing scientific methods because they were imperfect, m this case, the one thing to do is to perfect the methods Now perfecting physiological experimentation consists not only m improving instruments and op- erative methods, but above all and still more m study and well-regu- lated use of comparative experimentation

We have elsewhere said (p 55) that experimental counterproof must not be mistaken for comparative experimentation Counter- proof has not the slightest reference to sources of error that may be met m observing facts, it assumes that they are all avoided and is concerned only with experimental reasoning, it has m view only

judging whether the relation established between a phenomenon and its immediate cause is correct and rational Counterproof is there- fore only a synthesis verifying an analysis or an analysis controlling a synthesis

Comparative experimentation, on the contrary, bears solely on notation of fact and on the art of disengaging it from circumstances or from other phenomena with which it may he entangled Compara- tive experimentation, however, is not exactly

what philosophers call the method of differences When an experimenter is confronted with complex phenomena due to the combined properties of various bodies, he proceeds by differentiation, that is to say, he separates each of these bodies, one by one in succession, and sees by the difference what part of the total phenomenon belongs to each of them But this method of exploration implies two things it implies, first of all, that we know how many bodies are concerned in expressing the whole phenomenon, and then it admits that these bodies do not combine m any such way as to confuse their action m a final harmonious result In physiology the method of differences is rarely applicable, because we can never flatter ourselves that we know all the bodies and all the conditions combining to express a collection of phenomena, and m numberless cases because various organs of the body may take each other's place m phenomena, that are partly common to them all, and may more or less obscure the results of ablation of a limited part. Suppose, for instance, that we paralyze the whole body, a single muscle at a time The disturbance produced by each paralyzed muscle will be more 01; less compensated and replaced by neighboring muscles, and we should finally come to the conclusion that each particular muscle contributed little to the movements of the body The nature of this source of error has been very well expressed by comparing it with what would happen to an experimenter who removed, one after another, every brick m the foundation of a column He would see, indeed, that re- moving m succession one brick at a time does not make the column totter, and he would come to the logical but false conclusion that not one of these bncks helps to support the column In physiology, comparative experimentation depends upon quite another idea, for its object is to reduce the most complex investigation to unity, and its result is to eliminate by a single stroke all known and unknown sources of error

Physiological phenomena are so complex that we could never ex-

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periment at all rigorously on living animals if we necessarily had to define all the other changes we might cause in the organism on which we were operating But fortunately it is enough for us completely to isolate the one phenomenon on which our studies are brought to bear, separating it by means of comparative experimentation from all surrounding complications Comparative experimentation reaches this goal by adding to a similar organism, used for comparison, all our experimental changes save one, the very one which we intend to disengage

If, for instance, we wish to know the result of section or ablation of a deep-seated organ which cannot be reached without injuring many neighboring organs, we necessarily risk confusion m the total result between the effects of lesions caused by our operative procedure and the particular effects of section or ablation of the organ whose physiological role we wish to decide The only way to avoid this mistake is to perform the same operation on a similar animal, but without making the section or ablation of the organ on which we are experimenting We thus have two animals m which all the experi- mental conditions are the same, save one, — ablation of an organ whose action is thus disengaged and expressed m the difference observed between the two animals Comparative experimentation m experi- mental medicine is an absolute and general rule applicable to all kinds of investigation, whether we wish to learn the effects of vari- ous agents influencing the bodily economy or to verify the physiolog- ical role of various parts of the body by experiments m vivisection

At times comparative experimentation may be done on two ani- mals of the same species m condition as closely comparable as possi- ble, again the experiment must be made on the same animal When working on two animals, as we have just said, we must place them m the same conditions, save one, the one that we wish to compare This implies that the two animals compared are so much alike that differences noted in them after the experiment cannot be attributed to a difference depending on the individuals themselves For experi- menting on organs or tissues

whose properties are definite and easily perceived, comparison of two animals of the same species will suffice , but, on the other hand, when we wish to compare delicate and fugi- tive qualities, we must make our comparison on the same animal, whether the nature of the experiment permits experimenting on him repeatedly at different times, or whether we have to act at one and

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the same time on similar parts of the same specimen Differences, m fact, are harder to grasp m proportion as the phenomena that ire rush to study grow more fugitive or more delicate, m this respect no animal is ever absolutely comparable ruth another, and, as we have already said, neither is the same animal comparable with him- self at different times when we examine him, whether because he is in diffeient conditions, 01 because his oigamsm has grown less sensitive, b\ getting used to the substance given him or to the operation to which he is subjected

IX The Use of Calculation in Study of Living Beings, Averages and Statistics

Finally, it sometimes becomes necessary to extend comparative experimentation outside of the animal, since sources of error may also be met m the instruments used for experimentation I shall limit myself here to pointing out and defining the principle of com- parative experimentation, it will be explained, a propos of special cases, m the couise of this work In the third part of this Intro- duction I shall cite examples chosen to show the importance of com- parative experimentation, which is the true foundation of experi- mental medicine , it would be easy, m fact, to prove that almost all expel imental errors come from neglecting comparative judgment of facts or from thinking cases comparable which are not so

In the experimental sciences, measurement of phenomena is fun- damental, since their law can be established by quantitatively deter- mining an effect m relation to a given cause In biology, if we wish to learn the laws of life, v e must therefore not only observe and note vital phenomena, but moreover must also define numerically

the ratios of their relative intensity one to another

The application of mathematics to natural phenomena is the aim of all science, because phenomenal law should always be mathemat- ically expressed To this end, data used m calculations should be results of well-analyzed facts, so that we may be sure that we fully know the conditions of the phenomena between which we wish to establish an equation Now, I think that efforts of this kind are piemature m most vital phenomena, precisely because these phe- nomena are so complex that we must not only assume, but are m fact certain that, beside the few among their conditions which we know,

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there are numberless others ’which are still totally unknown I be- lieve that the most useful path for physiology and medicine to follow now is to seek to discover new facts instead of trying to reduce to equations the facts which science already possesses This does not mean that I condemn the application of mathematics to biological phenomena, because the science will later he established by this alone , only I am convinced that, since a complete equation is impossible for the moment, qualitative must necessarily precede quantitative study of phenomena.

Physicists and chemists have already often tried to reduce the physico-chemical phenomena of living beings to figures Among the ancients, as well as among the moderns, the most eminent physicists and chemists wished to establish principles of animal mechanics and laws for chemical statistics of animals Though the progress of physico-chemical science has made these problems more accessible to-day than m the past, it seems to me impossible to reach accurate conclusions at present, because foundations are lacking on which to base our calculations We may, of course, stuke a balance between what a living organism takes m as nourishment and what it gives out m excretions, but the results would be mere statistics incapable of throwing light

on the inmost phenomena of nutrition m living beings According to a Dutch chemist's phrase, this would be like trying to tell what happens inside a house by watching what goes m by the door and what comes out by the chimney We can accurately fix the ex- treme terms of nutrition , but if we afterward try to interpret the in- termediary between them, we find ourselves m an unknown region the greater part of which is created by the imagination, and this the more easily because figuies often lend themselves marvellously to demonstrating the most diverse hypotheses Twenty-five years ago, at the outset of my career as a physiologist, I was one of the first, I think, to carry experimentation into the inner environment of the organism, so as to follow experimentally, step by step, all the trans- formations of substances that chemists explained theoretically I therefore devised experiments to investigate how sugar, one of the best defined of alimentary substances, is broken down m living be- ings But instead of informing myself about the breaking down of sugar, my experiments led me to discover 10 that sugar is continually produced m animals, no matter what they eat Moreover, these m- u See the third part of this Introduction

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vestigations convinced me that numberless very complex physico- chemical phenomena take place, in the organic environment, which give rise to many other products, still unknown to us, with which the chemists do not at all reckon m their static equations In the chemical statics of life, as well as m the various quantitative esti- mates of physiological phenomena, certainly neither chemical think- ing nor rigor m calculation is lacking , but physiological foundations, which most of the time are false, simply because they are incomplete We are afterwards led astray all the more easily because we start from an incomplete experimental result and reason without verify- ing our deductions at every step Let me cite examples of calcula-

tions which I condemn, taking them from works which I neverthe- less hold m the highest esteem In 1852 Bidder and Schmidt of Dorpat published highly important works on digestion and nutri- tion Their investigations include excellent and very numerous raw data, hut m my opmion the deductions from their calculations are often risky or erroneous Thus, for example, they took a dog weigh- ing 16 kilograms, m the duct of the submaxillary gland they placed a tube through which the secretion flowed , and m one hour they ob- tained 5 640 grams of saliva, from which they concluded that for both glands this should make 11 280 grams They afterward placed another tube m the duct of the same animal's parotid gland, and m an hour they obtained 8 790 grams of saliva which for both parotid glands would make 17 580 grams Now, they went on, if we wish to apply these numbers to man, we must take a man weighing 64 kilograms or about four times as much as the dog m question, a calculation based on this ratio consequently gives us, for the man's submaxillary glands, 46 grams of saliva per hour, or 1 082 kilo- grams per day Eor the parotid glands, we have 70 grams per hour, or 1 687 kilograms per day which reduced one half gives about 1 40 kilograms of saliva secreted m twenty-four hours by the salivary glands of an adult man 20

As the authors themselves feel, only one thing is true m the above the crude result found m the dog , all the calculations deduced from this rest on false or doubtful foundations , first of all, doubling the product of one gland to get the product of both is incorrect, because phj siology teaches us that m most cases double glands secrete alter-

* Bidder and Schmidt, Die Verdauungssafte und der Stoffwechsel Mitt&u and Leipzig, 1852 p 12

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nately, and that, when one secretes a great deal, the other secretes less , then, besides

the two subxn axillary and parotid salivary glands, there are others which are not mentioned Next, it is a mistake to believe that multiplying one hour's output of saliva by 24 gives the saliva poured into an animal's mouth m 24 hours In fact, salivary secretion is highly intermittent and takes place only at meal time or when stimulated , during the rest of the time, the secretion 13 nil or insignificant Finally, the quantity of saliva got from the salivary glands of the dog m this experiment was not absolute, it would have been nil if the mucous membrane of the mouth had not been stimulated , it might have been greater or less if another stimulant, stronger or weaker than vinegar, had been used

Now the application of the above calculations to man is still more questionable If the quantity of saliva had been multiplied by the weight of the salivary glands, a closer relation would have been found , but I cannot concede the validity of calculating the quantity of saliva from the weight of the body taken as a whole Estimating a phenomenon m kilograms of the animal's body seems to me wholly incorrect, when all sorts of tissues foreign to the phenomenon m question are included

In the part of their investigation devoted to nutrition, Bidder and Schmidt described a very notable experiment, perhaps one of the most laborious ever performed From the point of view of elemen- tary analysis, they kept a balance sheet of everything taken m and given out by a cat during eight days' nourishment and nineteen days' fasting But this cat was m a physiological condition of which, they were unaware, she was pregnant, and she had her kittens on the seventeenth day of the experiment In these circumstances, our au- thors considered the kittens as excretions, and calculated them with other eliminated materials as a simple loss of weight 21 I believe that these interpretations should be rectified when trying to define such complex phenomena

In a word, I think that, if figures correspond with reality m these works of chemical statics applied to vital phenomena, it is only by chance or because the

experimenters' feeling guides and rearranges the calculation I repeat, nevertheless, that the criticism which I have just made is not directed against the principle of using calcu- lations m physiology, but against its application under present "Bidder and Schmidt, Ioc cit, p 397

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conditions I am fortunate, moreover, m being able here to rely on the opinion of the physicists and chemists most competent m such matters Regnault and Reiset, m their fine work on respiration, express themselves as follows about the calculations used to estab- lish the theoiy of animal heat "We have no doubt that animal heat is produced wholly by chemical reactions occurring m the bodily economy, but we think the phenomenon much too complex for pos- sible calculation of the heat from the quantity of oxygen consumed The substances burned m respiration are generally composed of car- bon, hydrogen, nitrogen or oxygen, often m considerable proportions , when they are completely destroyed in respiration, the oxygen which they contain contributes to the formation of water and carbonic acid , and the heat liberated is therefore necessarily quite different from what would be produced m burning the supposedly free carbon and hydrogen These substances, moreover, are not wholly destroyed, a portion is tiansformed into other substances which play special parts m the animal economy or escape, m excretions, m the foim of highly oxidized materials (urea, uric acid) Now, m all these trans- formations and m the assimilation of substances taking place m the organs, heat is liberated or absorbed, but the phenomena are obvi- ously so complex that there is little chance that we shall ever succeed m reducing them to calculation It was therefore by a fortuitous cir- cumstance m the experiments of Lavoisier, Dulong and Despretz, that the quantity of heat liberated by an animal was found to he about equal to what the carbon (contained m the carbonic acid produced) and the hydrogen would give off m

burning, — the quantity of hydro- gen being determined by a quite gratuitous assumption that the quantity of oxygen consumed, but not found m the carbonic acid, had been used m turning the hydrogen mto water ” 22

Ghemico-physical phenomena of living organisms are therefore still too complex to day to be embraced as a whole, except hy means of hypotheses To find correct solutions of such vast problems, we must begin by analj zing the results of complicated reactions, and by separating them experimentally mto distinct and simple questions In several attempts which I have made on this analytic path, I have shown that we should not handle the problem of nutrition en bloc,

Cf Regnault and Reiset, Rechcrches chimiques sur la respiration des animaux dcs diverse s classes (Annates de c/nmie et dc physique 3d Series, Vol XXVI, p 217)

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but rather should first define the nature of the physico-chemical phe- nomena taking place m an organ made of some definite tissue, such a3 a muscle, gland or nerve, that we must at the same time take account of the organ’s state of activity or rest. I have also shown that we can regulate an organ’s state of rest or activity at will, by means of its nerves, and that we can even act on it locally without reverbera- tion through the organism, if we first separate the peripheral nerves from the nervous centres 23 When we have analyzed the physico- chemical phenomena peculiar to each tissue and each organ, then only can we try to understand nutrition as a whole and to found biochemistry on a solid base, that is to say, on the study of definite, complete and comparable physiological facts

Another very frequent application of mathematics to biology is the use of averages which, m medicine and physiology, leads, so to speak, necessarily to error. There axe doubtless several reasons for this , but the greatest obstacle to applying calculation to physiological phenomena is still, at bottom, the excessive complexity

which pre- vents their being definite and comparable one with another By de- stroying the biological character of phenomena, the use of averages m physiology and medicine usually gives only apparent accuracy to the results From our point of view, we may distinguish between several kinds of averages physical averages, chemical averages and physiological and pathological averages If, for instance, we ob- serve the number of pulsations and the degree of blood pressure by means of the oscillations of a manometer throughout one day, and if we take the average of all our figures to get the true or average blood pressure and to learn the true or average number of pulsations, we shall simply have wrong numbers In fact, the pulse decreases m number and intensity when we are fasting and increases during di- gestion or under different influences of movement and rest, all the biological characteristics of the phenomenon disappear m the aver- age Chemical averages are also often used If we collect a man's urine during twenty-four hours and mix all this urine to analyze the average, we get an analysis of a urine which simply does not exist, for unne, when fasting, is different from urme during diges- tion A startling instance of this kind was invented by a physiologist

** Claude Bernard, Bur le changement de couleur du sang dans Vitat dc foncfton e(dc repos des gla tides — Analyse du sang des muscles au repos et en contraction Legons sur les liquides de I'organtsme Pane, 1859

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•who took urine from a railroad station unnal where people of all na- tions passed, and who believed he could thus present an analysis of average European urine 1 Aside from physical and chemical, there are physiological averages, or what we might call average descrip- tions of phenomena, which are even more false Let me assume that a physician collects a great many individual observations of a disease and that he makes an average description of symptoms observed m the individual

cases , he will thus have a description that will never be matched m nature So m physiology, we must never make aver- age descriptions of experiments, because the true relations of phe- nomena disappear m the average, when dealing with complex and variable experiments, we must study their various circumstances, and then present our most perfect experiment as a type, which, however, still stands for true facts In the cases just considered, averages must therefore be rejected, because they confuse, while aiming to unify, and distort while aiming to simplify Averages are applicable only to reducing very slightly varying numerical data about clearly de- fined and absolutely simple cases

Let me further point out that the reduction of physiological phe- nomena to an expression m kilograms of body weight is vitiated by many sources of errors For a certain number of years this method has been used by physiologists studying the phenomena of digestion (see p 131) We observe, for instance, how much oxygen or how much food an animal consumes m a day, we then divide by the animal's weight and get the intake of food or of oxygen per kilogram This method may also be applied to measure the action of toxic or medicinal materials We poison an animal with a maximum dose of strychnine or curare, and divide the amount by the weight of the body, to get the amount of poison per kilogram. For greater ac- curacy m the experiments just cited, we should have to calculate, not per kilogram of the animal's body taken as a whole, but per kilo- gram of blood and of the unit on which the poison acts, otherwise we could not deduce any direct law from the reductions But other con- ditions would still remain to be established similarly by experiment, conditions varying with age, height, state of digestion, etc , m these measures, physiological conditions should always hold first rank To sum up, every possible application of calculation would be excellent if the physiological conditions were quite accurately defined Physiologists and physicians should therefore concentrate their ef-

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fort, for the moment, on defining these conditions We must first accurately define the conditions of each phenomenon, this is true biological accuracy, and, without this preliminary study, all numer- ical data are inaccurate, and the more inaccurate because they include figures which mislead and impose on us by a false appearance of accuracy.

As for statistics, they are given a great role m medicine, and they therefore raise a medical question which we should examine here The first requirement m using statistics is that the facts treated shall be reduced to comparable units Now this is very often not the case m medicine Everyone familiar with hospitals knows what enors may mark the definitions on which statistics are based The names of diseases are very often given haphazard, either because the diag- nosis is obscure, or because the cause of death is carelessly recorded by a student who has not seen the patient, or by an employee unfa- miliar with medicine For this reason pathological statistics can be valid only when compiled from data collected by the statistician him- self But even then, no two patients are ever exactly alike, their age, sex, temperament and any number of other circumstances involve differences, with the result that the average, or the relation deduced from our comparison of facts, may always be contested. But I cannot accept even the hypothesis that facts can ever be absolutely alike and comparable m statistics, they must necessarily differ at some point, for statistics would otherwise lead to absolute scientific results, while they can actually show only probability, never certainty I acknowledge my inability to understand why results taken fiom statistics are called laws , for m my opinion scientific law can be based only on certainty, on absolute determinism, not on probability I should stray from my subject, if I went into all possible explanation of the value of statistical methods based on the calculus of proba- bilities , yet I cannot but say here what I think about the application of statistics to physiological science m general

and to medicine in particular

In every science, we must recognize two classes of phenomena, first, those whose cause is already defined, next, those whose cause is still undefined With phenomena whose cause is defined, statis- tics have nothing to do , they would even be absurd As soon as the circumstances of an experiment are well known, we stop gathering statistics we should not gather cases to learn how often water is made

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of oxygen and hydrogen , or when cutting the sciatic nerve, to learn how often the muscles to which it leads will be paralyzed The effect will occur always without exception, because the cause of the phenomena is accurately defined Only when a phenomenon in- cludes conditions as yet undefined, can we compile statistics , we must learn, therefore, that we compile statistics only when we cannot possibly help it, for m my opinion statistics can never yield scientific truth, and therefore cannot establish any final scientific method A single example will illustrate my meaning Certain experi- menters, as we shall later see, published experiments by which they found that the anterior spinal roots are insensitive, other experi- menters published experiments by which they found that the same roots were sensitive These cases seemed as comparable as possible , here was the same operation done by the same method on the same spinal roots Should we therefore have counted the positive and negative cases and said the law is that anterior rootB are sensitive, for instance, 25 times out of a 100 ? Or should we have admitted, according to the theory called the law of large numbers, that m an immense number of experiments we should find the roots equally often sensitive and insensitive ? Such statistics would be ridiculous, for there is a reason for the roots being insensitive and another rea- son for their being sensitive , this reason had to be defined , I looked for it, and I found it , so that we can now say the spinal roots are always sensitive m given conditions, and always

insensitive in other equally definite conditions

I will cite still another example borrowed from surgery A great surgeon performs operations for stone by a single method , later he makes a statistical summary of deaths and recoveries, and he con- cludes from these statistics that the mortality law for this operation is two out of five Well, I say that this ratio means literally nothing scientifically and gives us no certainty m performing the next opera- tion , for we do not know whether the next case will be among the recoveries or the deaths What really should be done, instead of gathering facts empirically, is to study them more accurately, each m its special determinism We must study cases of death with great care and try to discover m them the cause of mortal accidents, so as to master the cause and avoid the accidents Thus, if we ac- curately know the cause of recovery and the cause of death, we shall always ha\e a recovery m a definite case We cannot, indeed, admit

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that cases 'with different endings were identical at every point In the patient who succumbed, the cause of death was evidently some- thing which was not found m the patient who recovered , this some- thing we must determine, and then we can act on the phenomena or recognize and foresee them accurately But not by statistics shall we succeed m this , never have statistics taught anything, and never can they teach anything about the nature of phenomena I shall further apply what I have just said to all the statistics compiled with the object of learning the efficacy of certain remedies m curing diseases Aside from our inability to enumerate the sick who recover of them- selves m spite of a remedy, statistics teach absolutely nothing about the mode of action of medicine nor the mechanics of cure m those m whom the remedy may have taken effect

It is said that coincidence may play so large a part m causes of statistical errors, that

we should base conclusions only bn large num- bers But physicians have nothing to do with what is called the law of large numbers , a law which, according to a great mathematician's expression, is always true m general and false m particular This amounts to saying that the law of large numbers never teaches us anything about any particular case What a physician needs to know is whether his patient will recover, and only the search for scientific determinism can lead to this knowledge I do not understand how we can teach practical and exact science on the basis of statistics The results of statistics, even statistics of large numbers, seem indeed to show that some compensation m the variations of phenomena leads to a law , but as this compensation is indefinite, even the mathemati- cians confess that it can never teach us anything about any particular case , for they admit that if the red ball comes out fifty times m suc- cession, that is no reason why a white ball would be more' likely to come out the fifty-first time

Statistics can therefore bring to birth only conjectural sciences, they can never produce active experimental sciences, 1 e , sciences which regulate phenomena according to definite laws By statistics, we get a conjecture of greater or less probability about a given case, but never any certainty, never any absolute determinism Of course, statistics may guide a physician's prognosis , to that extent they are useful I do not therefore reject the use of statistics m medicine, but I condemn not trying to get beyond them and believing m statistics as the foundation of medical science This false idea leads cer-

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tain physicians to believe that medicine cannot but be conjectural , and from this, they infer that physicians are artists who must make up for the indeterminism of particular cases by medical tact Against these anti-scientific ideas we must protest with all our power, because they help to hold medicine back m the lowly state in

which it has been so long All sciences necessarily began by being conjectural , even to-day science has its conjectural parts Medicine is still almost wholly conjectural I do not deny it, I only mean to say that modem medical science must exert itself to get out of the temporary condition which is no more a final scientific state for medicine than for any other science The scientific state will be harder to reach and will take longer to establish m medicine, because of the com- plexity of the phenomena, but the goal of scientific physicians m their own science, as m the rest, is to reduce the indeterminate to the determinate Statistics therefore apply only to cases m which the cause of the facts observed is still indeterminate In these cir- cumstances, statistics in my opinion can serve only to guide the observer toward investigation of the indeterminate cause, but they can never lead to any real law I emphasize this point, because many physicians have great confidence m statistics when based on well- observed facts which they consider mutually comparable, and they believe that such statistics may lead to knowledge of phenomenal law I have already said that facts are never identical , therefore sta- tistics are simply an empirical enumeration of observations

In a word, if based on statistics, medicine can never be anything but a conjectural science, only by basing itself on experimental determinism can it become a true science, 1 e , a sure science I think of this idea as the pivot of experimental medicine, and m this respect experimental physicians take a wholly different point of view from so called observing physicians Indeed, if a phenomenon ap- pears just once in a certain aspect, we are justified m holding that, in the same conditions, it must always appear m the same way If, then, it differs m behavior, the conditions must be different But indeterminism knows no laws, laws exist only m experimental determinism, and without laws there can be no science Most phy- sicians seem to beheie that, m medicine, laws are elastic and indefi- nite These are false ideas which must disappear if we mean to found a scientific medicine As a science, medicine necessarily has definite and precise laws which, like those of all the sciences, are

derived from

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the criterion of experiment To the explanation of these ideas I shall especially" devote the work -which I have named Principles of Experimental Medicine, m order to show that the principles of experimental determinism must he applied to medicine, if it is to become an exact science founded on experimental determinism, instead of remaining a conjectural science based on statistics A conjectural science may indeed rest on the indeterminate, but an experimental science accepts only determinate or determinable phenomena

Only determinism m an experiment yields absolute law ; and he who knows the true law is no longer free to see a phenomenon other- wise The indeterminism of statistics leaves to thought a certain liberty limited by the numbers themselves, and m this sense phi- losophers were able to say that liberty begins where determinism ends But when determinism increases, statistics can no longer grasp and confine it within a limit of variations There we leave science, for we are forced to invoke chance or an occult cause to regulate phenomena. We shall certainly never reach absolute deter- minism m everything, man could no longer exist There will always be some indeterminism then, m all the sciences, and more m medicine than m any other But man’s intellectual conquest con- sists m lessening and driving back indeterminism m proportion as he gams ground for determinism by the help of the experimental method This alone should satisfy his ambition, for by this alone is he extending, and can he further extend, his power over nature.

X The Physiologist’s Laboratory and Various Methods Necessary to the Study of Experimental Medicine

Every experimental science requires a laboratory There the man of science withdraws, and by means of experimental analysis tries to understand phenomena

that he has observed m nature

A physician’s subject of study is necessarily the patient, and his first field for observation is the hospital But if clinical observa- tion teaches him to know the form and course of diseases, it cannot suffice to make him understand their nature, to this end he must penetrate into the body to find which of the internal parts are in- jured m their functions That is why dissection of cadavers and microscopic study of diseases were soon added to clinical observa-

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turn But to-day these various methods no longer suffice, we must push investigation further and, m analyzing the elementary phe- nomena of organic bodies, must compare normal with abnormal states "We showed elsewhere how incapable is anatomy alone to take account of vital phenomena, and we saw that we must add study of all physico-chemical conditions which contribute necessary elements to normal or pathological manifestations of life This simple suggestion already makes us feel that the laboratory of a physiologist-physician must be the most complicated of all labora- tories, because he has to experiment with phenomena of life which are the most complex of all natural phenomena.

Libraries may also be considered as part of the laboratory of a man of science or experimenting physician But this is on condi- tion that he shall read the observations, experiments and theories of his predecessors m order to know them and verify them in nature, and not to find opinions ready-made m books, thus saving himself the trouble of working and of trying to further the investigation of natural phenomena Misconceived erudition has been, and still is, one of the greatest obstacles to the advancement of experimental science Thus erudition, setting man’s authority m the place of facts, halted science through several centuries at Galen’s ideas, with- out any one’s daring to touch them, and this scientific superstition was

such that Mundmi and Yesalius, who first contradicted Galen by confronting his opinions with animal dissections, were considered in- novators and revolutionaries Yet such should always be the prac- tice of scientific erudition It should always be accompanied by critical investigations of nature, planned to verify the facts about which we speak, and to decide the opinions which we discuss. In this way science m advancing would be simplified and cleansed by sound experimental criticism, instead of being encumbered by exhuming an accumulation of numberless facts and opinions among uhich it is soon impossible to distinguish falsehood from truth It Mould be out of place for me here to say more of the mistakes and misdirection of most of the studies of medical literature, character- ized as historical or philosophical I may perhaps have occasion to explain mjself elsewhere on this subject, for the moment, I shall limit mjself to saving that, m my opinion, all these mistakes have their origin m a perpetual confusion between literary or artistic pro- duction and scientific production, between criticism of art and

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scientific criticism, between the history of science and the history of men

Literary and artistic productions never grow old, m this sense, that they are expressions of feeling, changeless as human nature We may add that philosophical ideas stand for aspirations of the human spirit which are also of all time But science, which stands for what man has learned, is essentially mobile m expression, it varies and perfects itself m proportion to the increase of acquired knowledge Present day science is therefore necessarily higher than the science of the past, and there is no sort of reason for going m search of any addition to modern science through knowledge of the ancients Their theories, necessarily false because they do not include facts discovered since then, can be of no real advantage to contemporary science No experimental science, then, can make progress except by advancing and

pursuing its work m the future It would be absurd to believe that we should go m search of it m the study of books bequeathed to us by the past We can find there only the history of the human mind, which is quite another matter

We must of course be familiar with what we call scientific litera- ture, and know what our predecessors have done But scientific criticism m the literary manner can be of no possible use to sci- ence Indeed, we need not ourselves be poets or artists to judge literary or artistic work, but this is not true of experimental sci- ence We cannot judge of a memoir on chemistry without being chemists nor of a memoir on physiology if we are not physiologists In deciding between two different scientific opinions, it is not enough to be a good philologist or a good translator, we must above all be deeply versed m technical science, we must even be masters of the special science and ourselves be able to experiment and do better than the men whose opinions we discuss Some time ago I discussed an anatomical question concerning the anastomoses of the pneumo- gastnc and spinal nerves 24 Willis, Scarpa and Bischoff had ex- pressed different and even opposite opinions on this subject A mere scholar could only have quoted these various opinions and more or less correctly compared the texts , that would not have answered the scientific question It was therefore necessary to dissect and

** Claude Bernard, Rechcrches exp&rimcntalcs sur les fonctions du nerf spinal (M6mcires prSsentSs par divers savants Grangers d l’Acad6mxe des eoionccs Vol X 1851)

to perfect our methods of dissection, so as to follow the nervous anastomoses more precisely and to compare each anatomist’s descrip- tion with nature This is what I did, and I found that the differ- ence between the authors m question came from their not having assigned the same limits to the nerves So anatomy, earned fur- ther,

explained their anatomical dissension I therefore refuse to acknowledge that science has a place for men who make cnticism their specialty, as m letters and m the arts. To he really useful, criticism m every science must he done by men of science themselves, and by the most eminent masters

Another somewhat frequent error consists m confusing the his- tory of man with the history of some science Theological and didac- tic evolution of experimental science is by no means expressed in the chronological history of the men concerned with it We must never- theless except the mathematical and astronomical sciences, but this cannot apply to the physico-chemical experimental sciences or to medicine m particular Medicine was bom of need, said Baglm, that is to saj, from the first time that anyone was ill, men went to his aid and sought to cure him. From its cradle, medicine has there- fore been an applied science mixed with religion and with the feel- ings of sympathy that men experienced one for another But did medicine as a science exist? Evidently not Continuing through centuries as blind empiricism, it enriched itself, little by little and almost by chance, with observations and investigations m unrelated directions Physiology, pathology and therapeutics developed as distinct sciences That was the wrong road Only to-day can we begin to see the conception of an experimental, scientific medicine m the fusion of these three m a single point of view

The experimental point of view is a coronation of perfected sci- ence, for we must not deceive ourselves, true science exists onlv when man succeeds m accurately foreseeing the phenomena of nature and mastering them Noting and classifying natural bodies and phe- nomena is not at all the equivalent of complete science True science acts and explains its action or its power that is its character, that is its aim Let me amplify mj idea I have often heard physi- cians saj that physiology or the explanation of vital phenomena m either the physiological or the pathological state is only a part of medicine, because medicine is knowledge of diseases m general I have similarly heard zoologists say that physiology, or the explana-

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** Claude Bernard, Recherchea earp&nmentales eur lea fonctiona du nerf spinal (M&nwires prSsentia par divers aavante Strangers d I'AoadSmie des sciences Vol X 1851)

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Another somewhat frequent error consists m confusing the his- tory of man with the history of some science Theological and didac- tic evolution of experimental science is by no means expressed in the chronological history of the men concerned with it We must never- theless except the mathematical and astronomical sciences , but this cannot apply to the physico-chemical experimental sciences or to medicine m particular Medicine was horn of need, said Baglivi, that is to say, from the first time that anyone was ill, men went to his aid and sought to cure him From its cradle, medicine has there- fore been an applied science mixed with religion and with the feel- ings of sympathy that men experienced one for another But did medicine as a science exist? Evidently not Continuing through centuries as blind empiricism, it enriched itself, little by little and almost by chance, with observations and

investigations m unrelated directions Physiology, pathology and therapeutics developed as distinct sciences That was the wrong road Only to-day can we begin to see the conception of an experimental, scientific medicine m the fusion of these three m a single point of view

The experimental point of view is a coronation of perfected sci- ence, for we must not deceive ourselves, true science exists onlv when man succeeds m accurately foreseeing the phenomena of nature and mastering them Noting and classifying natural bodies and phe- nomena is not at all the equivalent of complete science True science acts and explains its action or its power that is its character, that is its aim Let me amplify my idea I have often heard physi- cians say that physiology or the explanation of vital phenomena m either the physiological or the pathological state is only a part of medicine, because medicine is knowledge of diseases m general I have similarly heard zoologists say that physiology, or the explana-

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tion of vital phenomena m all their variety, is only a dismember- ment or specialty of zoology, because zoology is knowledge of ani- mals m general. Talking m the same way, a geologist or a mineral- ogist might say that physics and chemistry are only dismemberments of geology or mineralogy, which include knowledge of the earth and of animals in general Here are mistakes or at least misunder- standings which need to be explained First of all, we must recog- nize that our divisions into sciences are not a part of nature, they exist only in the mind which, by reason of its infirmity, is forced to create categories of bodies and of phenomena, so as to understand them better by studying their characteristics or properties from spe- cial points of view It follows that the same body may be studied mmeralogically, physically, chemically, etc , but m nature there is really neither chemistry nor physics, nor zoology, nor physiology, nor pathology , there are only bodies to be

classified or phenomena to be known and mastered. Now the science that gives man means of analyzing and experimentally mastering phenomena is the fur- thest advanced It must necessarily be the last established, that is no reason to consider it a dismemberment of earlier sciences In this respect, physiology, which is the highest and most difficult sci- ence of living beings, cannot be regarded as a dismemberment of medicine or zoology, any more than physics or chemistry are dismem- berments of geology or mineralogy Physics and chemistry are the two active mineral sciences by means of which man can master the phenomena of inorganic bodies Physiology is the vital, active sci- ence by whose aid man will be able to act on animals and on man, whether m health or m sickness It would be a grave illusion for physicians to believe they know diseases by giving them names, be- cause they classify and describe them, just as it would be an illusion for zoologists or botanists to believe they know animals and vegetables because they have named them, catalogued, dissected and shut them up in museums, after stuffing, preparing or drying them. Physicians will not know diseases until they can act on them rationally and ex- perimentally, just as zoologists will not know animals until they explain and regulate the phenomena of life To sum up, we must not be duped by our own works, we cannot assign any absolute value to scientific classifications, either in books or m academies. Men who leave the beaten track are innovators, and those who blindly persist m it hamper scientific progress The very evolution of

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human knowledge means that experimental science must be the goal, and this evolution requires that earlier sciences of classification shall lose importance as the experimental sciences develop

The spirit of man follows a necessary and logical course in the search for scientific truth It observes facts, compares them, de- duces appropriate results which it controls by experiment, to rise to more and more general propositions and truths In

this advanc- ing labor, a man of science must, of course, know and deal with his predecessors' work But he must be thoroughly convinced that this work is merely a support from which to go farther, and that new scientific truths are not to be found m study of the past, but rather m studies made anew on natuie, 1 e , m the laboratory Useful sci- entific literature, then, is preeminently the scientific literature of modem work which enables us to keep up with scientific progress, and even this must not he carried too far, lest it dry up the mind and stifle invention and scientific originality But what use can we find m exhuming worm-eaten theories or observations made without proper means of investigation* That may, of course, be helpful in learning the mistakes through which the human mind has passed m its evolution, but it is time wasted for science, properly speaking I deem it highly important to guide the minds of students early toward active experimental science, by making them understand that it develops m laboratories, instead of leaving them to believe that it awaits them m books or in the interpretation of ancient writings We know from history the sterility of the scholastic path and that science did not begin to soar until men substituted for the authority of books the authority of facts ascertained in nature with the help of more and more perfect experimental methods , Bacon's greatest merit was that he proclaimed this truth aloud As for me, I think that turning medicine back to-day toward the belated and aged com- mentaries of antiquity is a retrogression, a return to scholasticism, while guiding medicine toward laboratories and toward experimental, analytical study of disease is an advance along the path of true progress, that is, toward the foundation of experimental medical science With me, this is a deep conviction, I shall always seek to make it prevail both m my teaching and m my work.

A physiological laboratory, therefore, should now he the culmi- nating goal of any scientific physician's studies, but here again I must explain myself to avoid misunderstanding Hospitals, or

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rather hospital wards, are not physicians' laboratories, as is often believed , as we said before, these are only his fields for observation , there must be held what we call clinics, 1 e , studies of disease as complete as possible Medicine necessanly begins with clinics, since they determine and define the object of medicine, 1 e , the medical problem, but while they are the physician's first study, clinics are not the foundation of scientific medicine , physiology is the founda- tion of scientific medicine because it must yield the explanation of morbid phenomena by showing their lelations to the normal state We shall never have a science of medicine as long as we separate the explanation of pathological from the explanation of normal, vital phenomena

Here then lies the real medical problem, this is the foundation on which modem scientific medicine will be built As we see, ex- perimental medicine does not exclude clinical medicine, on the con- trary, it comes only after it But it is a higher science, and one necessarily more vast and general We easily imagine how an observational or empirical physician, never leaving his hospital, may think medicine completely shut m there, as a science distinct from physiology, of which it feels no need But for a man of science there is no sepai ate science of medicine or physiology, there is only a science of life There are only phenomena of life to be explained m the pathological as well as m the physiological state By putting this fundamental idea and this general conception of medicine into the minds of young people at the outset of their medical studies, we shall show them that the physico-chemical sciences which they have learned aie tools to help them analyze the phenomena of life m its normal and pathological states In frequenting hospitals, amphi- ' theatres and laboratories, they will easily grasp the general connec- tion uniting all the medical sciences, instead of learning them like fragments of detached knowledge with no relation between them

In a word, I consider hospitals only as the entrance to scien- tific medicine , they are the first field of observation which a phys- ician enters , but the true sanctuary of medical science is a labora- tory, only there can he seek explanations of life m the normal and pathological states by means of experimental analysis I shall not concern myself here with the clinical side of medicine , I assume it as known or as still being perfected m hospitals by the new methods of diagnosis which physics and chemistry are constantly giving to

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symptomatology In my opinion, medicine does not end m hos- pitals, as is often believed, but meiely begins there In leaving the hospital, a physician, jealous of the title m its scientific sense, must go into his laboratory , and there, by experiments on animals, he will seek to account for what he has observed m his patients, whether about the action of drugs or about the origin of morbid lesions m organs or tissues There, m a word, he will achieve true medical science Every scientific physician should, therefore, have a physiological laboratory, and this work is especially intended to give physicians rules and principles of experimentation to guide their study of experimental medicine, that is, their analytic and ex- perimental study of disease The principles of experimental medi- cine, then, will be simply the principles of experimental analysis applied to the phenomena of life m its healthy and its morbid states The biological sciences to-day are no longer seeking their path Because of their complex nature they vacillated longer than other simpler sciences m the regions of philosophy and system, but they launched at last into the experimental path where to-day they are well advanced So they now need only one thing more, and that is means of development Such means are laboratories and all the conditions and instruments necessary to cultivate the scientific field of biology

To the honor of French science, it must be stated that it had the glory of decisively

inaugurating the experimental method m the science of vital phenomena. Toward the end of the last century, the renewal of chemistry strongly influenced the advance of physio- logical science, and the work of Lavoisier and Laplace on breathing cleared a fertile path for analytic physico-chemical experimentation on the phenomena of life My teacher, Magendie, who was led into a medical career by this same influence, devoted his life to advocat- ing experimentation m the study of physiological phenomena Nevertheless, application of the experimental method to animals was hindered from the first by the lack of suitable laboratories and by all sorts of difficulties which are disappearing to-daj , but from which I m3 self often suffered m my youth The scientific impulse, started m France, spread through Europe, and little by little the analytic experimental method entered the realm of biological science as a general method of imestigation But this method was perfected more, and it brought forth more fruit m countries where conditions

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for its development were more favorable Throughout Germany to-day there are laboratories, called physiological institutes, which are admirably endowed and organized for the experimental study of vital phenomena They exist m Russia also, where new ones of gigantic size are being built Scientific production is naturally m proportion to the means of cultivation which a science possesses, theie is nothing astonishing, then, m the fact that Germany, where the means of cultivating the physiological sciences are most liberally installed, is distancing other countries m the quantity of its scien- tific production The genius of man, of course, cannot abdicate its supremacy m science In experimental science, however, a scientific man is the prisoner of his ideas, if he does not learn to question nature for himself, and if he does not possess suitable and necessary tools We cannot imagine a physicist or a chemist without his laboiatory But as for the physician, we are not yet m the habit of

believing that he needs a laboratory, we think that hospitals and books should suffice That is a mistake, clinical informa- tion no more suffices for physicians than knowledge of minerals suffices for chemists or physicists Physiological physicians must experimentally analyze the phenomena of living matter, as physi- cists and chemists experimentally analyze the phenomena of inorganic matter A laboratory is therefore a condition sine qua non of the development of experimental medicine, as it was for all the other physico-chemical sciences Without it, neither experimenters nor experimental science can exist

I shall no longer dwell on so important a subject which cannot here be sufficiently worked out, let me end by saying that one truth is well established m modem science, namely, that scientific courses can only serve to introduce and to create a taste for the sci- ences By pointing out, from a professional chair, the results as well as the methods of a science, a teacher may form the minds of his hearers and make them apt m learning and choosing their own direction, but he can never make them men of science The laboratory is the real nursery of true experimental scientists, 1 e , those who create the science that others afterward popularize Now if we want much fruit, we must first care for our nurseries of fruit trees The evidence of this truth will necessarily bring about gen- eral and deep reform m scientific teaching Por, I repeat, it is to-day everywhere recognized that pure science germinates and develops in

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laboratories, to spread out later and cover tbe world with useful applications We must, therefore, first of all attend to tbe scientific source, since applied science necessarily proceeds from pure science Science and men of science are cosmopolitans, and it seems hardly important whether a scientific truth develops at any particular spot on the globe, as long as the general diffusion of science allows all

men to share in it. However I cannot help praying that my coun- try, the evident promoter and protector of scientific progress and the starting point- of the brilliant era through which experimental physical science25 is now passing, may have great, public, physio- logical laboratories as soon as possible, so as to make pleiads of physi- ologists and young experimenting physicians Only laboratories can teach the difficulties of science to those who frequent them , they show that pure science has always been the source of all the riches ac- quired by man and of all his real conquests over the phenomena of nature This is also excellent education for the young, because it makes them understand that the present, very brilliant applications of science are merely the blossoming of earlier labors, and that those who reap the benefits to-day owe a tribute of gratitude to their pre- decessors who painfully cultivated the tree of science, but never saw its fruits

I cannot here treat all the conditions necessary to a good labora- tory of physiology or experimental medicine That would obviously amount to summarizing everything still to be explained in this work I shall therefore limit myself to adding one word I said above, that the laboratory of a physiological physician must be the most complex of all laboratories, because the experimental analyses to be made there are the most complex of all, requiring the help of all other sciences The laboratory of a medical physiologist must be connected with a hospital so as to receive the various pathological specimens on which scientific investigation is brought to bear It must next include healthy and diseased animals for the study of questions of normal and pathological physiology But as vital phe- nomena, whether m the normal or m the pathological state, are

*In 1771 a course m experimental physiology was given by Professor A. Portal at tbe College de France, the experiments were reported by Monsieur Collomb who published them in letter form in 1771, they were republished m 1808 with a few additions in the work by Portal entitled Mtmoires sur la nature et le traxtement de plumeurs maladies, aveo U prims d’ experiences sur les ammaux imams Pans, 1800

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analyzed mainly by means of tools borrowed from physico-chemical science, instruments must necessarily be somewhat liberally provided The solution of certain scientific questions often imperatively de- mands costly and complicated instruments, so that we may then say that scientific questions are secondary to the question of money However, I do not approve the luxury as to instruments to which certain physiologists have yielded In my opinion, we should seek to simplify instruments as much as possible, not only for pecuniary, but also for scientific leasons, for we need to learn that the more complicated the instrument, the more sources of error does it create Experimenters do not grow great by the number and complexity of instruments, it is really the other way The great experimenters, Berzelius and Spallanzani, made great discoveries by means of simple instruments In the course of this work, our principle, then, will be to seek, as far as possible, to simplify means of study, for instruments must be allies, not sources of error because of their complications

PART THREE

APPLICATIONS OF THE EXPERIMENTAL METHOD TO THE STUDY OF VITAL PHENOMENA

CHAPTER I

EXAMPLES OF EXPERIMENTAL PHYSIOLOGICAL

INVESTIGATION

The ideas explained m the first two parts of this introduction will he all the better understood if we can connect them with actual investigations m experimental physiology and medicine For this reason, I have put together in the following part a certain num- ber of examples that seem to me appropriate As far as possible, I have quoted from myself m all these examples, for the sole reason that, m the matter of reasoning and intellectual processes, I shall he much more certain of what I describe in telling what has happened to me than m interpreting what may have taken place m the minds of others I am not, however, so fatuous as to give these examples as models to follow , I use them only to express my ideas better and to make my thought easier to grasp

In scientific investigations, various circumstances may serve as starting points for research , I will reduce all these varieties, however, to two chief types

1 Where the starting point for experimental research is an observation ,

2 Where the starting pomt for experimental research is an hypothesis or a theory

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AH ObSEEVATION

Experimental ideas are often bom by chance, with the help of some casual observation Nothing is more common , and this is really the simplest way of beginning a piece of scientific work We take a walk, so to speak, in the realm of science, and we pursue

what happens to present itself to our eyes Bacon compares scien- tific investigation with hunting, the observations that present them- selves are the game Keeping the same simile, we may add that, if the game presents itself when we are looking for it,

it may also present itself when we are not looking for it, or when we are look- ing for game of another kind I shall cite an example m which these two cases presented themselves m succession At the same time I shall be careful to analyze every circumstance involved, so as to show how the principles apply which we explained m the first part of the introduction and especially in Chapters I and II

First example — One day, rabbits from the market were brought into my laboratory. They were put on the table where they uri- nated, and I happened to observe that their urine was clear and acid This fact struck me, because rabbits, which are herbivora, generally have turbid and alkaline unne, while on the other hand carnivora, as we know, have clear and acid urine This observation of acidity m the rabbits' unne gave me an idea that these animals must be m the nutritional condition of carnivora I assumed that they had prob- ably not eaten for a long time, and that they had been transformed by fasting, into veritable carnivorous animals, living on their own blood Nothing was easier than to venfy this preconceived idea or hypothesis by experiment I gave the rabbits grass to eat, and a few hours later, their unne became turbid and alkaline I then sub- jected them to fasting and after twenty-four hours or thirty-six hours at most, their urine again became clear and strongly acid, then after eating grass, their urine became alkaline again, etc. I repeated this very simple experiment a great many times, and always with the same result I then repeated it on a horse, an herbivorous animal which also has turbid and alkaline urine I found that fasting, as m rabbits, produced prompt acidity of the urine, with such an increase m urea, that it spontaneously crystallizes at times m the cooled unne As a result of my experiments, I thus reached the general proposition which then was still unknown, to wit, that all fasting animals feed on meat, so that herbivora then have unne like that of carnivora

We are here dealing with a very simple, particular fact which allows us easily to follow the evolution of expenmental reasoning When we see a phenomenon which we are not in the habit of seeing, we must always ask ourselves what it is connected

with, or putting it

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differently, what is its proximate cause , the answer or the idea, which presents itself to the mind, must then he submitted to experiment When I saw the rabbits' acid urme, I instinctively asked myself uliat could be its cause The experimental idea consisted m the con- nection, which my mind spontaneously made, between acidity of the rabbits' urine, and the state of fasting which I considered equivalent to a true flesh-eater's diet The inductive reasoning which I im- plicitly went through was the following syllogism the urine of carnivora is acid, now the rabbits before me have acid urine, therefore they are carnivora, 1 e , fasting This remained to be established by experiment

But to prove that my fasting rabbits were really carnivorous, a counterproof was required A carnivorous rabbit had to be ex- pel imentally produced by feeding it with meat, so as to see if its urme would then be clear, as it was during fasting So I had rab- bits fed on cold boiled beef (which they eat very nicely when they are given nothing else) My expectation was again verified, and, as long as the animal diet was continued, the rabbits kept their clear and acid urme

To complete my experiment, I made an autopsy on my animals, to see if meat was digested m the same way m rabbits as m carnivora I found, m fact, all the phenomena of an excellent digestion m their intestinal reactions, and I noted that all the chyliferous vessels were gorged with very abundant white, milky chyle, just as in. carnivora But d propos of these autopsies which confirmed my ideas on meat digestion m rabbits, lo and behold a fact presented itself which I had not remotely thought of, but which became, as we shall see, my start- ing point m a new piece of work.

Second example — (Sequel to the last) — In sacrificing the rab- bits which I had fed

on the meat, I happened to notice that the white and milky lymphatics were first visible in the small intestine at the lower part of the duodenum, about thirty centimeters below the pylorus This fact caught my attention because in dogs they are first visible much higher m the duodenum just below the pylorus On examining more closely, I noted that this peculiarity in rab- bits coincided with the position of the pancreatic duct which was inserted very low and near the exact place where the lymphatics began to contain a chyle made white and milky by emulsion of fatty nutritive materials

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Chance observation of this fact evoked the idea which brought to birth the thought m my mind, that pancreatic juice might well cause the emulsion of fatty materials and consequently their absorp- tion by the lymphatic vessels Instinctively again, I made the fol- lowing syllogism, the white chyle is due to emulsion of the fat, now m rabbits white chyle is formed at the level where pancreatic juice is poured into the intestine , therefore it is pancreatic juice that makes the emulsion of fat and forms the white chyle This had to be decided by experiment

In view of this preconceived idea I imagined and at once per- formed a suitable experiment to verify the truth or falsity of my suppositions The experiment consisted m trying the properties of pancreatic juice directly on neutral fats But pancreatic juice does not spontaneously flow outside of the body, like saliva, for instance, or urine, its secretory organ is, on the contrary, lodged deep m the abdominal cavity I was therefore forced to use the method of ex- perimentation to secure the pancreatic fluid from living animals m suitable physiological conditions and m sufficient quantity Only then could I carry out my experiment, that is to say, control my preconceived idea , and the experiment proved that my idea was cor- rect. In fact pancreatic juice obtained m suitable conditions from dogs, rabbits and various other

animals, and mixed with oil or melted fat, always instantly emulsified, and later split these fatty bodies into fatty acids, glycerine, etc , etc , by means of a specific ferment

I shall not follow these expenments further, having explained them at length m a special work 1 I wish here to show merely how an accidental first observation of the acidity of rabbits' unne sug- gested to me the idea of making experiments on them with carnivorous feeding, and how later, m continuing these expenments, I brought to light, without seeing it, another observation concerning the peculiar arrangement of the junction of the pancreatic duct in rabbits This second observation gave me, m turn, the idea of experimenting on the behavior of pancreatic juice

From the above examples we see how chance observation of a fact or phenomenon brings to birth, by anticipation, a preconceived idea or hypothesis about the probable cause of the phenomenon ob-

1 Claude Bernard, Mdmoirc sur Ic panoreaa et sur le r6lc du buo pancriaUque dans les phinomines digestifs Paris, 1856

served , how the preconceived idea begets reasoning which results m the experiment which verifies it , how, m one case, we had to have recourse to experimentation, 1 e , to the use of more or less compli- cated operative processes, etc , to work out the verification In the last example, experiment played a double role, it first judged and confirmed the provisions of the reasoning which it had begotten , hut what is more, it produced a fresh observation. We may there- fore call this observation an observation produced or begotten by experiment This proves that, as we said, all the results of an experiment must be observed, both those connected with the preconceived idea and those without any relation to it. If we saw only facts connected with our preconceived idea, we should often cut our- selves off from making discoveries

For it often happens that an unsuccessful experiment may produce an excellent observation, as the following example will prove

Third example — In 1857, I undertook a senes of experiments on the elimination of substances m the unne, and thiB time the results of the expenment, unlike the previous examples, did not confirm my previsions or preconceived ideas I had therefore made what we habitually call an unsuccessful expenment But we have already posited the pnnciple that there are no unsuccessful expen- ments, for, when they do not serve the investigation for which they were devised, we must still profit by observation to find occasion for other experiments

In investigating how the blood, leaving the kidney, eliminated substances that I had injected, I chanced to observe that the blood m the renal vein was crimson, while the blood in the neighboring veins was dark like ordinary venous blood This unexpected pecu- liarity struck me, and I thus made observation of a fresh fact begot- ten by the experiment, but foreign to the experimental aim pursued at the moment. I therefore gave up my unverified original idea, and directed my attention to the singular coloring of the venous renal blood , and when I had noted it well and assured myself that there was no source of error m my observation, I naturally asked myself what could be its cause As I examined the unne flowing through the urethra and reflected about it, it occurred to me that the red coloring of the venous blood might well be connected with the secreting or active state of the kidney On this hypothesis, if the renal secre- tion was stopped, the venous blood should become dark that is what

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happened, when the renal secretion was reestablished, the venous blood should become crimson again , this I also succeeded m verifying whenever I excited the secretion of unne I thus secured experi- mental proof that there is a connection between the secretion of urine and the coloring of blood in the renal vein

But that is still by no means all In the normal state, venous blood m the kidney is almost constantly crimson, because the unnary organ secretes almost continuously, though alternately for each kidney Now I wished to know whether the crimson color is a general fact characteristic of the other glands, and in this way to get a clear-cut counterproof demonstrating that the phenomenon of secretion itself was what led to the alteration m the color of the venous blood I reasoned thus if, said I, secretion, as it seems to be, causes the crimson color of glandular venous blood, then, m such glandular organs as the salivary glands which secrete intermit- tently, the venous blood will change color intermittently and become dark, while the gland is at rest, and red during secretion So I un- covered a dog's submaxillary gland, its duets, its nerves and its ves- sels In its normal state, this gland supplies an intermittent secretion which we can excite or stop at pleasure Now while the gland was at rest, and nothing flowed through the salivary duct, I clearly noted that the venous blood was, indeed, dark, while, as soon as secretion appeared, the blood became crimson, to resume its dark color when the secretion stopped, and it remained dark as long as the intermission lasted, etc 2

These last observations later became the starting point for new ideas which guided me m making investigations as to the chemical cause of the change m color of glandular blood during secretion I shall not further describe these experiments which, moreover, I have published m detail 3 It is enough for me to prove that scientific investigations and experimental ideas may have their birth in almost involuntary chance observations which present themselves either spontaneously or m an experiment made with a different purpose

3 Claude Bernard, Logons sur les propri6t6s physiologiqucs et les alterations pathologiqiics dcs Uquidcs dc Vorgantsme Paris, 1859 Vol II

* Claude Bernard, Sur la quantitd d'oxygtne que conUcnt le sang vein cun dcs organcs glandulaircs (Compt rend dc l 'Acad dcs sciences Vol XLVII, Sept 6, 1858

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Let me cite another case, — one m -which an experimenter pro- duces an observation and voluntarily brings it to birth This case is, so to speak, included m the preceding case , but it differs from it m this, that, instead of -waiting for an observation to present itself by chance in fortuitous circumstances, we produce it by experiment Returning to Bacon's comparison, we might say that an experimenter, m this instance, is like a hunter who, instead of waiting quietly for game, tries to make it rise, by beating up the locality where he assumes it is We use this method whenever we have no precon- ceived idea m respect to a subject as to which previous observations are lacking So we experiment to bring to birth observations which m turn may bring to birth ideas This continually occurs m medi- cine when we wish to investigate the action of a poison or of some medicinal substance, on an animal's economy , we make experiments to see, and. we then take our direction from what we have seen

Fourth example — In 1845, Monsieur Pelouze gave me a toxic substance, called curare, which had been brought to him from Amer- ica We then knew nothing about the physiological action of this substance Prom old observations and from the interesting accounts of Alex, von Humboldt and of Roukn and Boussmgault, we knew only that the preparation of this substance was complex and difficult, and that it very speedily kills an animal if introduced under the skin But from the earlier observations, I could get no idea of the mechan- ism of death by curare , to get such an idea I had to make fresh obser- vations as to the organic disturbances to which this poison might lead I therefore made experiments to see things about which I had abso- lutely no preconceived idea Pirst, I put curare under the skm of a frog it died after a few minutes , I opened it at once, and m this physiological autopsy I studied

m succession what had become of the known physiological properties of its various tissues I say physiological autopsy purposely, because no others are really instructive The disappearance of physiological properties is what ex- plains death, and not anatomical changes Indeed, m the present state of science, we see physiological properties disappear in any number of cases without being able to show, by our present means of observation, any corresponding anatomical change, such, for example, is the case with curare Meantime, we shall find examples, on the contrary, m which physiological properties persist, m spite of very marked anatomical changes with which the functions are by

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no means incompatible Now in my frog poisoned with curare, the heait maintained its movements, the blood was apparently no more changed m physiological properties than the muscles, which kept their normal contractility But while the nervous system had kept its normal anatomical appearance, the properties of the nerves had nevertheless completely disappeared There were no movements, either voluntary or reflex, and when the motor nerves were stimulated directly, they no longer caused any contraction in the muscles To learn whether there was anything accidental or mistaken m this first observation, I lepeated it several times and verified it m various ways, for when we wish to reason experimentally, the first thing necessary is to he a good observer and to make quite certain that the starting point of our reasoning is not a mistake m observation In mammals and m birds, I found the same phenomena as m frogs, and disappeaiance of the physiological properties of the motor neivous system became my constant fact Starting from this well established fact, I could then carry analysis of the phenomena fur- ther and deteimme the mechanism of death from curare I still proceeded by reasonings analogous to those quoted m the above exam- ple, and, from idea to idea and

experiment to experiment, I pro- gressed to more and more definite facts I finally reached this gen- eral proposition, that curare causes death by destroying all the motor nerves , without affecting the sensory nerves*

In cases where we make an experiment m which both precon- ceived idea and reasoning seem completely lacking, we yet neces- sarily reason by syllogism without knowing it In the case of curare,

I instinctively reasoned m the following way no phenomenon is with- out a cause, and consequently no poisoning without a physiological lesion peculiar or proper to the poison used , now, thought I, curare must cause death by an activity special to itself and by acting on certain definite organic parts So by poisoning an animal with curare and by examining the properties of its various tissues immedi- ately after death, I can perhaps find and study the lesions peculiar to it.

The mind, then, is still active here, and an experiment m order to see is included, nevertheless, in our general definition of an experi- ment (p 10) In every enterprise, m fact, the mmd is always rea- ct Claude Bernard, Lecons sur les effets des substances tongues , Paris, 1837, Du curare { Revue des Deux Mondes, Sept 1, 1804)

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soiling, and, even when we seem to act without a motive, an instinctive logic still directs the mind Only we are not aware of it, because wTe begin by reasoning before we know or say that we are reasoning, just as we begin by speaking before we observe that we are speaking, and just as we begin by seeing and hearing before we know what we see or what we hear

Fifth example — About 1846, I wished to make experiments on the cause of poisoning with carbon monoxide I knew that this gas had been described as toxic, but I knew literally nothing about the mechanism of its poisoning, I therefore could

not have a precon ceived opinion What, then, was to be done? I must bring to birth an idea by making a fact appear, 1 e , make another experiment to see In fact I poisoned a dog by making him breathe carbon monoxide and after death I at once opened his body I looked at the state of the organs and fluids What caught my attention at once was that its blood was scarlet m all the vessels, m the veins as well as the arteries, m the right heart as well as m the left I repeated the experiment on rabbits, birds and frogs, and everywhere I found the same scarlet coloring of the blood But I was diverted from continuing this investigation, and I kept this observation a long time unused except for quoting it in my course d propos of the coloring of blood

In 1856, no one had carried the experimental question further, and in my course at the College de France on toxic and medicinal substances, I again took up the study of poisoning by carbon mon- oxide which I had begun in 1846 I found myself then in a con- fused situation, for at this time I already knew that poisoning with carbon monoxide makes the blood scarlet m the whole circulatory system. I had to make hypotheses, and establish a preconceived idea about my first observation, so as to go ahead Now, reflecting on the fact of scarlet blood, I tried to interpret it by my earlier knowl- edge as to the cause of the color of blood Whereupon all the fol- lowing reflections presented themselves to my mind The scarlet color, said I, is peculiar to arterial blood and connected with the presence of a large proportion of oxygen, while dark coloring belongs with absence of oxygen and presence of a larger proportion of carbonic acid , so the idea occurred to me that carbon monoxide, by keeping venous blood scarlet, might perhaps have prevented the oxygen from changing into carbonic acid m the capillaries. Yet

it seemed hard to understand how that could be the cause of death But still keeping

on with my inner preconceived reasoning, I added If that is true, blood taken from the veins of animals poisoned with carbon monoxide should he like arterial blood m containing oxygen , we must see if that is the fact

Hollowing this reasoning, based on interpretation of my obser- vation, I tried an experiment to verify my hypothesis as to the per- sistence of oxygen m the venous blood I passed a current of hydro- gen through scarlet venous blood taken from an animal poisoned with carbon monoxide, but I could not liberate the oxygen as usual I tried to do the same with arterial blood , I had no greater success My preconceived idea was therefore false But the impossibility of getting oxygen from the blood of a dog poisoned with carbon monoxide was -a second observation which suggested a fresh hypoth- esis What could have become of the oxygen m the blood? It had not changed into carbonic acid, because I had not set free large quantities of that gas m passing a current of hydrogen through the blood of the poisoned animals Moreover, that hypothesis was contrary to the color of the blood I exhausted myself m conjec- tures about how carbon monoxide could cause the oxygen to disappear from the blood , and as gases displace one another I naturally thought that the carbon monoxide might have displaced the oxygen and driven it out of the blood To learn this, I decided to vary my experimen- tation by putting the blood m artificial conditions that would allow me to recover the displaced oxygen So I studied the action of carbon monoxide on blood experimentally For this purpose I took a certain amount of arterial blood from a healthy animal , I put this blood on the mercury m an inverted test tube containing carbon monoxide, I then shook the whole thing so as to poison the blood sheltered from contact with the outer air Then, after an interval.

I examined whether the air m the test-tube m contact with the poi- soned blood had been changed, and I noted that the air thus m contact with the blood had been remarkably enriched with oxygen, while the proportion of carbon monoxide was lessened Repeated m the same conditions, these experiments taught me that what had oc- curred was an exchange, volume by volume, between the carbon monoxide

and the oxygen of the blood But the carbon monoxide, in displacing the oxygen that it had expelled from the blood, remained chemically combined m the blood and could no longer be displaced

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either by oxygen, or by other gases So that death came through death of the molecules of blood, or m other -words by stopping their exercise of a physiological property essential to life.

This last example, which I have very briefly described, is com- plete , it shows from one end to the other, how we proceed with the experimental method and succeeded m learning the immediate cause of phenomena. To begin with I knew literally nothing about the mechanism of the phenomenon of poisoning with carbon monoxide I undertook an experiment to see, 1 e , to observe I made a pre- liminary observation of a special change in the coloring of blood I interpreted this observation, and I made an hypothesis which proved false But the experiment provided me with a second observation about which I reasoned anew, using it as a starting point for making a new hypothesis as to the mechanism, by which the oxygen in the blood was removed By building up hypotheses, one by one, about the facts as I observed them, I finally succeeded in showing that carbon monoxide replaces oxygen in a molecule of blood, by combin- ing with the substance of the molecule Experimental analysis, here, has reached its goal This is one of the cases, rare in physiology, which I am happy to be able to quote Here the immediate cause of the phenomenon of poisoning is found and is translated into a theory which accounts for all the facts and at the Bame time includes all the observations and experiments. Eormulated as follows, the the- ory posits the mam facts from which all the rest are deduced Carbon monoxide combines more intimately than oxygen with the hemoglobin in a molecule of blood It has quite recently been proved that

carbon monoxide fonns a definite combination with hemoglobin 5 So that the molecule of blood, as if petrified by the stability of the combination, loses its vital properties Hence everything is logically deduced because of its property of more intimate combination, carbon monoxide drives out of the blood the oxygen essential to life, the molecules of blood become inert, and the animal dies, with symp- toms of hemorrhage, from true paralysis of the molecules

But when a theory is sound and indeed shows the real and defi- nite physico-chemical cause of phenomena, it not only includes the observed facts but predicts others and leads to rational appli- cations that are logical consequences of the theory Here again we

• Hoppe-Seyler, Handbuch der physiologisch - und pathologisch chcmischen Analyse Berlin, 1805

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meet this criterion In fact, if carbon monoxide has the property of driving out oxygen by taking its place m combining with a mole- cule of blood, we should be able to use the gas to analyze the gases m blood, and especially for determining oxygen From my experi- ments I deduced this application which has been generally adopted to-day 6 Applications of this property of carbon monoxide have been made m legal medicine for finding the coloring matter of blood , and from the physiological facts described above we may also already deduce results connected with hygiene, experimental pathology, and notably with the mechanism of certain forms of anemia.

As m every other case, all the deductions from the theory doubt- less still require experimental verification, and logic does not suf- fice But this is because the conditions m which carbon monoxide acts on the blood may present other complex circumstances and any number of details which the theory cannot yet predict

Otherwise, as we have often said (p 29), we could reach conclusions by logic alone, without any need of experimental verifications Because of possible unforeseen and variable new elements in the conditions of a phenomenon, logic alone can m experimental science never suffice Even when we have a theory that seems sound, it is never more than relatively sound, and it always includes a certain proportion of the unknown

II When the Starting Point of Experimental Beseaeoh Is an Hypothesis or a Theory

We have already said (p 25) and we shall see further on, that m noting an observation we must nevei go beyond facts But in making an experiment, it is different. I wish to show that hypotheses are indispensable, and that they are useful, therefore, precisely because they lead us outside of facts and carry science forward The object of hypotheses is not only to make us try new experiments , they also often make us discover new facts which we should not have perceived without them In the preceding examples, we saw that we can stait from a particular fact and rise one by one to more general ideas, i.e , to a theory But as we have just seen, we can also sometimes

* Claude Bernard, De Vemploi de I’oxyde de carbons pour la determination do Voxygdne du sang (Compt rend de I’Acad dea sciences, Meeting of Sept C, 1858, Vol XL VII)

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start with an hypothesis deduced from a theory Though we are dealing m this case with reasoning logically deduced from a theory, we have an hypothesis that must still be verified by experiment Indeed, theories are only an assembling of the earlier facts, on which our hypothesis rests, and cannot be used to demonstrate it experimentally We said that, m this instance, we must not submit to the yoke of theories, and that keeping our mental independence is the best way to discover the truth This

is proved by the following examples

First example — In 1843, in one of my first pieces of work, 1 undertook to study what becomes of different alimentary substances m nutrition As I said before, I began with sugar, a definite substance that is easier than any other to recognize and follow m the bodily economy With this m view, I injected solutions of cane sugar into the blood of animals, and I noted that even when injected m weak doses the sugar passed into the urine I recog- nized later that, by changing or transforming sugar, the gastric juice made it capable of assimilation, 1 e , of destruction m the blood 7

Thereupon I wished to learn m what organ the nutritive sugar disappeared, and I conceived the hypothesis that sugar introduced into the blood through nutrition might be destroyed m the lungs or m the general capillaries The theory, indeed, which then pre- vailed and which was naturally my proper starting point, assumed that the sugar present m animals came exclusively from foods, and that it was destroyed m animal organisms by the phenomena of com- bustion, i e , of respiration Thus sugar had gained the name of respiratory nutriment But I was immediately led to see that the theory about the origin of sugar m animals, which served me as a starting point, was false As a result of the experiments which I shall describe further on, I was not indeed led to find an organ for destroying sugar, but, on the contrary, I discovered an organ for making it, and I found that all animal blood contains sugar even when they do not eat it So I noted a new fact, unforeseen in the- ory, which men had not noticed, doubtless because they were under the influence of contrary theories which they had too confidently ac- cepted I therefore abandoned my hypothesis on the spot, so as to pursue the unexpected result which has since become the fertile

’ Claude Bernard, Thesis for doctorate in medicine. Pans, 1S43

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origin of a new path for investigation and a mine of discoveries that is not yet exhausted.

In these researches I followed the principles of the experimental method that we have established, i e , that, m presence of a well-noted, new fact which contradicts a theory, instead of keeping the theory and abandoning the fact, I should keep and study the fact, and I hastened to give up the theory, thus conforming to the precept which we proposed m the second chapter “When we meet a fact which contradicts a prevailing theory, we must accept the fact and abandon the theory, even when the theory is supported by great names and generally accepted ”

We must therefore distinguish, as we said, between principles and theories, and never believe absolutely m the latter We had a theory here which assumed that the vegetable kingdom alone had the power of creating the individual compounds which the animal kingdom is supposed to destroy According to this theory, established and supported by the most illustrious chemists of our day, animals were incapable of producing sugar m their organisms If I had be- lieved m this theory absolutely, I should have had to conclude that my experiment was vitiated by some inaccuracy , and less wary ex- perimenters than I might have condemned it at once, and might not have tarried longer at an observation which could be theo- retically suspected of including sources of error, since it showed sugar m the blood of animals on a diet that lacked starchy or sugary materials But instead of being concerned about the theory, I con- cerned myself only with the fact whose reality I was trying to estab- lish By new experiments and by means of suitable counterproofs, I was thus led to confirm my first observation and to find that the liver is the organ m which animal sugar is formed m certain given cir- cumstances, to spread later into the whole blood supply and into the tissues and fluids

Animal glycogenesis which I thus discovered, i,e , the power of producing sugar,

possessed by animals as well as vegetables, is now an acquired fact for science , but we have not yet fixed on a plausiblo theory accounting for the phenomenon The fresh facts which I made known are the source of numerous studies and many varied theories in apparent contradiction with each other and -with my own When entering on new ground we must not be afraid to express even risky ideas so as to stimulate research m all directions As Priestley

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put it, we must not remain inactive through false modesty based on fear of being mistaken So I made more or less hypothetical theories of glycogenesis , after mine came others, my theories, like other men's, will live the allotted life of necessarily very partial and tem- porary theories at the opening of a new series of investigations , they will be replaced later by others, embodying a more advanced stage of the question, and so on Theories are like a stairway , by climbing, science widens its horizon more and more, because theories embody and necessarily include proportionately more facts as they advance Progress is achieved by exchanging our theories for new ones which go further than the old, until we find one based on a larger number of facts In the case which now concerns us, the question is not one of condemning the old to the advantage of a more recent theory What is important is having opened a new road , for well-observed facts, though brought to light by passing theories, will never die, they are the material on which alone the house of science will at last be built, when it has facts enough and has gone sufficiently deep into the analysis of phenomena to know their law or their causation

To sum up, theories are only hypotheses, verified by more or less numerous facts Those verified by the most facts are the best, but even then they are never final, never to be absolutely believed We have seen m the preceding examples that if we had had complete con- fidence m the prevailing theory of the destruction of sugar m

ani- mals, and if we had only had its confirmation m view, we should probably not have found the road to the new facts which we met It is true that an hypothesis based on a theory produced the experiment, but as Boon as the results of the experiment appeared, theory and hy- pothesis had to disappear, for the experimental facts were now just an observation, to be made without any preconceived idea (p 21)

In sciences as complex and as little developed as physiology, the great principle is therefore to give little heed to hypotheses or the- ories and always to keep an eye alert to observe everything that ap- pears m every aspect of an experiment An apparently accidental and inexplicable circumstance may occasion the discovery of an im- portant new fact, as we shall see m the continuation of the example just noted

Second example (Sequel to the Last) —After finding, as I said above, that there is sugar m the livers of animals m their normal state, and with every sort of nutriment, I wished to learn the pro-

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portion of tins substance and its variation in certain physiological and pathological states So I began to estimate the sugar m the livers of animals placed m various physiologically defined circumstances I always made two determinations of carbohydrate for the same liver tissue But pressed for time one day, it happened that I could not make my two analyses at the same moment, I quickly made one determination just after the animal’s death and postponed the other analysis till next day But then I found much larger amounts of sugar than those which I got the night before with the same mate- rial I noticed, on the other hand, that the proportion of sugar, which I had found just after the animal’s death the night before, was much smaller than I had found m the experiments which I had announced as giving the normal proportion of liver sugar I did not know how to account for this singular variation, got with the same liver and the same method of analysis What was to be

done 2 Should I consider two such discordant determinations as an unsuc- cessful experiment and take no account of them * Should I take the mean between these experiments? More than one experimenter might have chosen this expedient to get out of an awkward situation But I disapprove of this kind of action for reasons which I have given elsewhere I said, indeed, that we must never neglect anything m our observation of fact, and I consider it indispensable, never to admit the existence of an unproved source of error in an experiment and always to try to find a reason for the abnormal cir- cumstances that we observe Nothing is accidental, and what seems to us accident is only an unknown fact whose explanation may fur- nish the occasion for a more or less important discovery So it proved m this case

I wished, in fact, to learn the reason for my having found two such different values m the analysis of my rabbit's liver After assuring myself that there was no mistake connected with the method of analysis, after noting that all parts of the liver were practically equally rich m sugar, there remained to be studied only the elapsed time between the animal's death and the time of my second determi- nation Without ascribing much importance to it, up to that time I had made my experiments a few hours after the animal's death, now for the first time I was m the situation of making one deter- mination only a few minutes after death and postponing the other till next day, 1 e , twenty-four hours later In physiology, questions

of time are always very important because organic matter passes tbrougb numerous and incessant changes Some chemical change might therefore have taken place m the liver tissue To make Bure, I made a series of new experiments which dispelled every obscurity by showing me that liver tissue becomes more and more rich m sugar for some time after death Thus we may have a very variable amount of sugar according to the moment when we make our examination I was therefore led to

correct my old determination and to discover the new fact that considerable amounts of sugar are produced m animals' livers after death For instance, by forcibly injecting a current of cold water through the hepatic vessels and passing it through a liver that was still warm, just after an animal's death, I showed that the tissue was completely freed from the sugar which it contained , but next day or a few hours later, if we keep the washed liver at a mild temperature, we again find its tissue charged with a large amount of sugar produced after it was washed 8

Once m possession of the first discovery that sugar is formed m animals after death as during life, I wished to carry my study of this singular phenomenon further, I was then led to find that sugar is produced m the liver with the help of an enzyme reacting on an amylaceous substance which I isolated and which I called glyco- genous matter , bo that I succeeded in proving m the most clear-cut way that sugar is formed m animals by a mechanism m every respect like the mechanism found m vegetables

This second senes of facts embodied results, which are also firmly acquired for science, and which have greatly advanced our knowl- edge of glycogenesis m animals I have just very briefly told how these facts were discovered, and how they started with an expenmen- tal circumstance that was apparently inconsequential I quote this case so as to prove that we must never neglect anything m experi- mental research, for every accident has a necessary cause We must, therefore, never be too much absorbed by the thought we are pursuing, nor deceive ourselves about the value of our ideas or scientific theo- ries , we must always keep our eyes open for every event, the mind doubting and independent (p 80), ready to study whatever presents itself and to let nothing go without seeking its reason In a word,

• Claude Bernard, Bur le micamsme de la formation du sucre dans le foie (Comptcs rendus par VAcad des sciences, Sept 24, 1855, and Comptes ren due dc l' Acad dcs sciences, March 23, 1857)

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•we must be in an intellectual attitude -which seems paradoxical but -which, m my opinion, expresses the true spirit of an investigator. We must have robust faith and not believe Let me explain myself by saying that m science we must firmly believe m principles, but must question formulas, on the one hand, indeed, we are sure that deter- minism exists, but we are never certain we have attained it. We must be immovable as to the principles of experimental science (de- terminism), but must not absolutely believe m theories The aphor- ism which I just uttered is sustained by what we expounded else- where (p 67), to wit, that for experimental science principles are m our mind, while formula are external things In practical matters, we are indeed forced to tolerate the belief that truth (at least temporary truth) is embodied m a theory or a formula But m scientific experimental philosophy those who put their faith in formula and theories are wrong All human science consists in seeking the true formula and true theory We are always approach- ing it, but shall we ever find it completely? This is not the place to go into an explanation of philosophic ideas let us return to our subject and pass on to a fresh experimental example

Third example — About the year 1852, my studies led me to make experiments on the influence of the nervous system on the phenomena of nutrition and temperature regulation. It had been observed m many cases that complex paralyses with their seat m the mixed nerves are followed, now by a nse and again by a fall of tem- perature m the paralyzed parts Now this is how I reasoned, m order to explain this fact, basing myself first on known observa- tions and then on prevailing theories of the phenomena of nutrition and temperature regulation Paralysis of the nerves, said I, should lead to cooling of the parts by slowing down the phenomena of com- bustion m the blood, since these phenomena are considered as the cause of animal heat On the other hand, anatomists long ago noticed that the sympathetic nerves

especially follow the arteries So, thought I inductively, m a lesion of a mixed trunk of nerves, it must be the sympathetic nerves that produce the slowing down of chemical phenomena m capillary vessels, and their paralysis that then leads to cooling the parts If my hypothesis is true, I went on, it can be verified by severing only the sympathetic, vascular nerves leading to a special part, and sparing the others I should then find the part cooled bj paralysis of the vascular nerves, without loss of

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either motion or sensation, since the ordinary motor and sensory nerves would still be intact To carry out my experiment, I therefore sought a suitable experimental method that would allow me to sever only the vascular nerves and to spare the others Here the choice of animals was important m solving the problem (p 122) , for in cer- tain animals, such as rabbits and horses, I found that the anatomical arrangement isolating the cervical sympathetic nerve made this solu- tion possible.

Accordingly, I severed the cervical sympathetic nerve m the neck of a rabbit, to control my hypothesis and see what would happen in the way of change of temperature on the side of the head where this nerve branches out On the basis of a prevailing theory and of earlier observation, I had been led, as we have just seen, to make the hypothe- sis that the temperature should be reduced How what happened was exactly the reverse After severing the cervical sympathetic nerve about the middle of the neck, I immediately saw m the whole of the corresponding side of the rabbit’s head a striking hyperac- tivity m the circulation, accompanied by increase of warmth The result was therefore precisely the reverse of what my hypothesis, de- duced from theory, had led me to expect, thereupon I did as I always do, that is to say, I at once abandoned theories and hypothesis, to observe and study the fact itself, so as to define the experimental conditions as precisely as possible To-day my

experiments on the vascular and thermo-regulatory nerves have opened a new path for investigation and are the subject of numerous studies which, I hope, may some day yield really important results m physiology and path- ology a This example, like the preceding ones, proves that m experi- ments we may meet with results different from what theories and hypothesis lead us to expect But I wish to call more special atten- tion to this third example, because it gives us an important lesson, to wit without the original guiding hypothesis, the experimental fact which contradicted it would never have been perceived Indeed, I was not the first experimenter to cut this part of the cervical sym- pathetic nerve m living animals Pourfonr du Petit performed the experiment at the beginning of the last century and discovered the

/J/^laUde^eTJnairf' *eoJlcrc7les cxpinmentales sur le grand sympathique, etc (iremoxre, del a Bocxiti de Ixologie, Vol Y, 1853) Sur les nerfe valculaxres

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nerve's action on the pupil, by starting from an anatomical hypothesis according to -which this nerve was supposed to carry animal spirits to the eye 10 Many physiologists have since repeated the same opera- tion, with the purpose of verifying or explaining the changes m the eye which Pourfour du Petit first described But none of them no- ticed the local temperature phenomenon, of which I speak, or con- nected it with the severing of the cervical sympathetic nerve, though this phenomenon must necessarily have occurred under the very eyes of all who, before me, had cut this part of the sympathetic nerve. The hypothesis, as we see, had prepared my mind for seeing things in a certain direction, given by the hypothesis itself, and this is proved by the fact that, like the other experimenters, I myself had often divided the cervical sympathetic nerve to repeat Pourfour du Petit's experiment, without perceiving the fact of heat production which I later discovered when an hypothesis led me to make investigations m this direction Here, therefore,

the influence of the hypothesis could hardly be more evident, we had the fact under our eyes and did not see it because it conveyed nothing to our mind However, it could hardly be simpler to perceive, and since I described it, every physi- ologist without exception has noted and verified it with the greatest ease

To sum up, even mistaken hypotheses and theories are of use in leading to discoveries This remark is true m all the sciences The alchemists founded chemistry by pursuing chimerical problems and theories which are false In physical science, which is more ad- vanced than biology, we might still cite men of science who make great discoveries by relying on false theories It seems, indeed, a necessary weakness of our mind to be able to reach truth only across a multitude of errors and obstacles

What general conclusions shall physiologists draw from the above examples 2 They should conclude that m the present state of biological science accepted ideas and theories embody only limited and risky truths which are destined to perish They should conse- quently have very little confidence m the ultimate value of theo- ries, but should still make use of them as intellectual tools necessary to the evolution of science and suitable for the discovery of new facts

10 Pourfour du Petit, Mimoire dans lequel it cst dimontri que Ies ncrfs m tcrcostnux foumtsscnt des rameaux guv portent des espnts dans lee yaw (Etstoire de VAcadim\e pour Vannie 1727)

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The art of discovering new phenomena and of noting them accurately should to-day he the special concern of all biologists We must estab- lish experimental criticism by creating rigorous methods of investiga- tion and experimentation, which will enable us to define our observa- tions unquestionably, and thus get rid of the errors of fact which are the source of errors in theory A man who to-day attempted a gen- eralization for biology as a whole would prove that he had no accurate feeling for

the present state of the science To-day, the biological problem has hardly begun to be put , and, as stones must first be got together and cut, before we dream of erecting a monument, just so must the facts first be got together and prepared which are destined to create the science of living bodies This role falls to experimen- tation , its method is fixed, but the phenomena to be analyzed are so complex that, for the moment, the true promoters of science are those who succeed in giving its methods of analysis a few principles of simplification or in introducing improvements m instruments of research When there are enough quite clearly established facts, generalizations never keep us waiting I am convinced that, in. experi- mental sciences that are evolving, and especially in those as complex as biology, discovexy of a new tool for observation or experiment is much more useful than any number of systematic or philosophic dis- sertations Indeed, a new method or a new means of investigation increases our power and makes discoveries and researches possible which would not have been possible without its help Thus researches as to the formation of sugar in animals could be made only after chemistry gave us reagents for recognizing sugar, which were much more sensitive than those we had before

CHAPTER II

EXAMPLES OF EXPERIMENTAL PHYSIOLOGICAL CRITICISM

Experimental criticism rests on absolute principles which must guide experimenters m noting and interpreting the phenomena of nature It will be particularly useful m the biological sciences where prevailing theories are so often propped up with false ideas or based on poorly observed facts We shall here deal with examples recalling the principles, by virtue of which we may well judge physio- logical theories, and

discuss the facts on which they are based As we already know, our criterion par excellence is the principle of experimental determinism united with philosophic doubt In this connection, let me again recall the fact that, m science, we must never confuse principles with theories Principles are scientific axioms ; as absolute truths, they are an immutable criterion. Theories are sci- entific generalizations or scientific ideas which sum up our present state of knowledge, they are always relative truths, destined to change with the progress of science So if we posit as a basic conclusion, that we must not believe absolutely m the formula} of science, we must, on the contrary, believe absolutely in its principles Men who too completely believe m theories and neglect principles, take the shadow for reality, they lack any solid criterion and are liable to all the consequent sources of error In every science, progress con- sists m so changing our theories as to get more and more perfect ones Indeed, of what use would study be, if we could not change our opinions or theories 2 But principles and the scientific method are higher than theory , they are immutable and can never change

Experimental criticism must therefore forearm itself, not only against belief m theories, but against being led astray by too highly valuing the words which we have created to picture to ourselves tho supposed forces of nature In every science, but m the physiological sciences more than all others, we are m danger of deceiving ourselves about words We must never forget that our characterizations of the

phenomena of nature, as mineral or vital forces, are merely figurative language by which we must not allow ourselves to he duped The only realities are manifestations of phenomena and the conditions of these manifestations which remain to be determined , experimental criticism should never lose sight of that. In a word, experimental criticism casts doubt on everything except the principle of scientific,

rational determinism m the realm of facts (pp 52-67) It is always founded on this same base, whether we direct it against ourselves or others, that is why we shall usually present two examples m what follows, one chosen from our own researches, the other from other men’s work In science, indeed, we must not only try to criticise others, but every man of science must always be a severe critic of himself Whenever he proffers an opinion or proposes a theory, he must be the first to try to control it by criticism and to base it on well observed and accurately determined facts

I The Principle op Experimental Determinism Does Not Admit of Contradictory Facts

First example — It is now a long time since I announced an experiment which greatly surprised physiologists the experiment consists m making an animal artificially diabetic by means of a punc- ture m the floor of the fourth ventricle I was led to try this punc- ture as a result of theoretical considerations which I need not recall , all that we here need to know is that I succeeded at the first attempt, 1 e , that I saw the first rabbit on which I operated become strikingly diabetic. But I afterward had the experience of repeating the ex- periment many times (eight or ten times) without getting the same lesult I then found myself in presence of a positive fact and of eight or ten negative facts , yet I never thought of denying my first positive experiment in favor of the negative experiments which fol- lowed it Thoroughly convinced that my failures were due only to not knowing the true conditions of my first experiment, I persisted in experimenting, to tiy to discover them As a result, I succeeded m defining the exact place for the puncture, and showing the con- ditions m which the animal to be operated on should be placed, so that we can to-day reproduce artificial diabetes whenever we place ourselves m the conditions known to be necessary to its appearance

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Let me add to the above a reflection showing how many sources of error may surround physiologists m the investigation of vital phe- nomena Let me assume that, instead of succeeding at once m making a rabbit diabetic, all the negative facts had first appeared, it is clear that, after failing two or three times, I should have concluded, not only that the theory guiding me waB false, but that punc- ture of the fourth ventricle did not produce diabetes Yet I should have been wrong How often men must have been and still must be wrong m this way ! It even seems impossible absolutely to avoid this kind of mistake We wish to draw from this experiment another general conclusion which will be corroborated by subsequent exam- ples, to wit, that negative facts when considered alone, never teach us anything

Second example — Every day we see discussions which remain profitless for science, because we are not thoroughly enough imbued with the principle that, since every fact has its own appropriate cause, a negative fact proves nothing and can never destroy a posi- tive fact To prove what I am setting forth, I will quote the criticisms which M Longet formerly made on Magendie'B experiments I choose this example, on the one hand, because it is highly instruc- tive, and, on the other, because I was involved m it, and know all the circumstances accurately Let me begin with M Longet's criti- cisms about Magendie's experiments on the properties of recurrent sensitivity in the anterior spinal roots 1 The first objection which M Longet makes to Magendie is that he changed his opinion as to the sensitivity of the anterior roots, holding m 1822 that the anterior roots were scarcely sensitive, and m 1839 that they were very sen- sitive, etc Thereupon M Longet exclaims "Truth is single, from the midst of these contrasted, contradictory assertions of the same author, let the reader choose if he dare " (loc cit , p 22) Finally M Longet goes on, "M Magendie ought at least to have told us, — to get us out of our difficulties, — which of his experiments were prop- erly made, the 1822 experiments or those m 1839 " (loc cit , p 23) These criticisms are all ill founded and completely violate the

'FA Longet, Jlechcrchca chn\qucs et expinmcntales eur l cs fanchonn da faisccaux

dc la mocllc 6pini6rc el dcs racincs dee nerfs rachidicns, pr6c6d6cs d'un J ramcn histonque ct critique dcs cxpiricnces faites sur ces organcs depuis Sir Ch Hell, ct suiucs (Tautrcs rechcrchce sur dtterscs parties du syslimc vrrvcux (UrcJnve* g(n6rales dc midcanc, 1841, 3d Sene'!, Vol X, p 290 and \ ol X' p 129)

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lules of experimental scientific criticism In fact, if Magendie in 1822 said that tlie anterior roots ivere insensitive, and if he said later m 1839 that the anterior roots are very sensitive, it was because lie then found them very sensitive We do not have to choose be- tween the two results, as M Longet believes , we must accept them both and merely explain and define them m their respective condi- tions When M Longet exclaims "Truth is single," does he mean that if one of these results is true, the other must be false ? By no means, they are both true, unless we say that m one case Magendie lied, and that is certainly not the critic's idea But by virtue of the scientific principle of the determinism of phenomena, we must absolutely affirm a pnon that m 1822 and m 1839 Magendie did not see the phenomena m identical conditions, the differences m condi- tions are precisely what we must seek out and define, so as to har- monize the two results and thus find the cause of variation m the phenomenon The only objection which M Longet might have made to Magendie was that he did not himself seek out the reason for the difference m the two results , but the criticism by exclusion that M Longet directed against Magendie's experiments is false and, as we said, out of harmony with the principles of experimental criticism We cannot doubt that the above criticism is sincere and purely scientific, for m other circumstances connected with the same discussion M Longet directed against himself the Bame criticism by exclusion and in his own criticism was led into the same kind of miBtake as m the criticism directed against Magendie

In 1839 M Longet, like myself, was working m the laboratory of the College de France when Magendie discovered the sensitivity of the anterior spinal roots and showed that it is derived from the posterior roots and returns by the periphery, whence the name re- vel se sensitivity or recurrent sensitivity which he gave it Like Magendie and me, M Longet then saw that the anterior root was sensitive and that it was so under the influence of the posterior root, and he saw it so clearly that he claimed discovery of the latter fact for himself 2 But later, m 1841, when Longet wished to repeat Magendie's experiment, he found no sensitiveness m the anterior root In rather amusing circumstances, M Longet thus found him-

1 Longet, Comptes rendus de VAcadimie des sciences, Yol VIII, p 787, June 3 and 10, Comptes rendus de VAcaddmie des sciences, June 4, Oaeette des hdpttaux June 13 and 18, 1839 '

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self m exactly the same position in relation to the same fact of sen- sitiveness m the anterior spinal roots with which he had reproached Magendie, 1 e , M Longet m 1839 saw that the anterior spinal root was sensitive and, m 1841, saw that it was insensitive Magendie's sceptical mind was not disturbed by these seeming obscurities and contradictions , he went on experimenting and always said what he saw M Longet's mind, on the contrary, wished to have the truth on one side or the other, that is why he decided m favor of the 1841 experiments, i e , the negative experiments , and here is what he said "Though at that time (1839) I brought forward my claim to the discovery of one of these facts (recurrent sensitiveness), now that I have made many and varied experiments on this point m physiology, I combat these very facts as erroneous, whether they are regarded as Magendie's property or my own When we have made a mistake, the service which we owe to tiuth requires that we should never fear retraction I shall here only recall the

insensitivity of the anterior roots and sheaves which we have so often proved, so that the reader may readily understand how meaningless are these results which, like so many others, merely encumber science and embarrass its advance ”3 After this confession, we may be sure that M Longet is animated only by a desire to find the truth, which he proves when he says that we must never be afraid of retraction if we have made an error I wholly share this feeling Let me add that it is always instructive to acknowledge an error The precept, therefore, is excellent, for we are all likely to make mistakes, except those of us who do nothing. But the first requirement m acknowledging a mistake is to prove that there is an error It is not enough to say I was mistaken ; we must say how we were mistaken, the important point is precisely that Now M Longet explains nothing, he seems purely and simply to say In 1839 I saw sensitive roots, m 1841, I saw insensi- tive ones more often, therefore I was mistaken in 1839 Such rea- soning is inadmissible Here, m fact, are a number of experiments m 1839, a propos to the sensitivity of anterior roots, — experiments m which the spinal roots were cut one by one, and to note their properties, their ends were pinched Magendie wrote half a volume on the subject Later when people fail to obtain the same results, the question cannot be decided simply by saying that wo made a mis- take the first time and are right the second time. After all, why

• Longet, loc cit p 21

should -we be mistaken ? Shall we say that our senses played us false at one period and not the other ? In that event we must give up experimentation , for the first requirement of experimenters is con- fidence m their senses and never any doubt except as to interpreta- tions If we cannot find the concrete reason for an error, despite all our efforts and all our investigations, we must suspend judgment and

meantime keep both results, but never believe that denying positive facts can suffice even m the name of more numerous negative facts, or vice versa Negative facts, no matter how numerous they may be, can never destroy a single positive fact That is why pure and simple negation is not criticism, and this method should be absolutely rejected m science, because science is never built up by negation

To sum up, we must maintain the conviction that negative facts are determined like positive facts We posited the principle that all experiments are successful, m that their conditions are determined , m research into the conditions of each of these determinations lie the lessons that teach us the law of a phenomenon , because m this way we learn the conditions necessary to its existence and its non-exist- ence After witnessing Magendie's experiments m 1839 and M. Longet's discussions in 1841, I have made this principle my guide, when I wished to take account of the phenomena myself and to judge the differences I repeated the experiments, and, like Magendie and like M Longet, I found cases of sensitivity and cases of insensitivity of the anterior spinal roots , but as I was convinced that the two cases depended on different experimental conditions, I tried to define the conditions , by dint of observation and perseverance, I finally found * the conditions in which we must place ourselves to get both results. Now that the conditions of the phenomenon are known, it is no longer questioned M Longet himself 5 and all physiologists accept the fact of recurrent sensitivity as constant m the conditions which I an- nounced

From what has gone before, we must therefore establish the abso- lute and necessary determination of phenomena as a principle of ex- perimental criticism This principle, when thoroughly understood, should make us cautious about our natural tendency to contradic-

‘ Claude Bernard, Le cons sur la physiologic et la pathologic do eystime ncrveus, p 32

• 8ee Longet, Trait £ dc physiologic, 1860, VoL II, p 177

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tion Certainly every experimenter, especially every beginner, feels a secret pleasure whenever he finds something different from what others have seen before him His first impulse is to contradict, espe- cially when contradicting someone high m the scientific world We must protect ourselves against this tendency, for it is not scientific. Pure contradiction would amount to an accusation of lying, and we should avoid it because happily scientific falsifiers are ram As such cases, moreover, have no connection with science, I need not offer any precept on the subject I wish merely to point out here that science does not consist in. proving that others are mistaken, and even if we proved that an eminent man was mistaken, that would not be a great discovery , it can be a profitable work for science only in so far as we show how he was mistaken Indeed, great men often teach us by their errors as much as by their discoveries I some- times hear it said that pointing out an error is equivalent to a dis- covery Yes, on condition that we bring to light a new truth by show- ing the source of error, m which event it is unnecessary to combat the error, it falls of itself Thus only is criticism equivalent to a discovery, when it explains everything without denying anything and finds the correct causation of apparently contradictory facts By such determinism everything is unified, everything becomes transparent ; and as Leibnitz says, science, as it broadens, grows clear and simple.

II The Principle of Determinism Ejects Causeless and Irrational Pacts from Science

We said elsewhere (p 54) that our reason scientifically includes the determinate and the indeterminate but that it cannot accept the indeterminable, because that would be nothing but accepting the mar- vellous, occult or supernatural which should be absolutely banished from all experimental science The result is that a fact gams scientific value only through knowledge of its causation A crude fact is not scientific, and a fact whose causation is irrational should also be ejected from science Indeed, if an experimenter must submit bis ideas to tbe criterion of facts, I

do not acknowledge that be must submit his reason , for then he would extinguish the torch of his inner criterion and would necessarily fall into the realm of the indeter- minable, 1 e , the occult and the marvellous In science, many crude

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facts are doubtless still incomprehensible , I do not mean to conclude that -we should willfully reject all these facts, I wish simply to say that thej should be held m reserve, for a time, as crude facts, and not introduced into science, 1 e , into experimental reasoning, until their necessary conditions are defined m terms of rational determinism Otheiwise, our experimental reasoning would be continually halted or else inevitably led into the absurd

The following examples, among many others, will prove what I assert

First example — A few years ago,6 I experimented on the influ- ence of ether on intestinal secretions Now a propos of this, I hap- pened to observe that injecting ether into the intestinal canal of a dog kept without food even for several days gave nse to splendid white lymphatics, absolutely like those in an animal actively digesting mixed food m which there is fat. After frequent repetitions, the fact was unquestionable But what meaning could be ascribed to it * What reasoning was possible about its cause * Should we say ether causes secretion of chyme* This is a fact But that would be absurd, since there was no food m the intestine As we see, rea- son rejected this causation as irrational and absurd m our present state of knowledge I therefore tried to find the reason for this in- comprehensible fact, and I finally saw that there was a source of error, because the ether dissolved the oil lubricating the piston of the syringe with which it was injected into the stomach, when the ether was injected with a glass pipette, instead of a syringe, it no longer produced the phenomenon The irrationality of the fact, therefore, led me to see a. prvon that it must be false, and that it could not be used as a basis for scientific

reasoning Otherwise I should not have found the curious source of error located in the piston of a syringe But when the source of error was once recognized, every- thing was explained, and the fact became rational m this sense, that the chyle was produced there, as everywhere else, by the absorption of fat , only the ether stimulated absorption and made the phenome- non more evident

Second example — Able and accurate expenmenteis 7 had seen

* Claude Bernard, Lemons sur lea effete des substances tomques et midtea- menteuses, p 428

7 Vulpian, Comptes rendus et M (moires de la Boctiti de htologte, 1854, p 133, 1856, p 125, 1858, 2d Series, Vol V, Pans, 1859, p 113, 1864

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that the venom of a toad speedily poisons frogs and other animals, while it has no effect on the toad himself Here, m fact, is a quite simple experiment that seems to prove it if we take venom on a lan- cet from the parotid glands of a domestic toad and insert it under the skin of a frog or a bird, the animals soon pensh, while if we insert the same amount of venom under the skin of a toad of about the same size, he does not die of it, indeed he feels no effect Here again is a crude fact which could become scientific only on condition that we learn how venom acts on a frog, and why it does not act on a toad. To do this, I necessarily studied the mechanism of death, for special circumstances might be encountered which would explain the differ- ence m results on the frog and on the toad Thus a special arrange- ment of the nostrils and the epiglottis explains very well why, for ex- ample, section of the two facial nerves is mortal m horses and not m other animals But this exceptional fact is rational , it confirms the rule, as we say, m that it makes no change fundamentally m the ner- vous paralysis which is the same m all animals There was nothing of the kind m the case with which we are concerned • study of the mechanism of death by

toad’s venom led to the conclusion that toad’s venom kills by stopping the heart m frogs, while it does not act on a toad’s heart Now, m logic, we should necessarily have to admit that the muscular fibres of a toad’s heart have a different nature from those of a frog’s heart, since the poison which acts on the former does not act on the latter That was impossible for admitting that or- ganic units identical m structure and in physiological characteristics are no longer identical m the presence of a toxic action identically the same would prove that phenomena have no necessary causation , and thus science would be denied Pursuant to these ideas, I rejected the above-mentioned fact as irrational, and decided to repeat the ex- periments, even though I did not doubt their accuracy as crude fact.

I then saw 8 that toad’s venom easily kills frogs with a dose that is wholly insufficient for a toad, but that the latter is nevertheless poi- soned if we increase the dose enough. So that the difference de- scribed was reduced to a question of quantity and did not have the contradictory meaning that might be ascribed to it The irrational- ity of the fact was, therefore, again what led me to ascribe to it an- other meaning

’Claude Bernard, Court de pathologte erptnmentale (Medical Ttmer, 1880)

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III The Principle of Determinism Requires Comparative Determination of Pacts

We have just seen that our reason forces us to reject apparently causeless facts and leads us to criticise them so as to find for them a rational meaning before using them in experimental reasoning But since criticism, as we said, rests at once on reason and on philosophic doubt, it follows that a simple and logical appearance is not enough to make us accept an experimental fact, we should still doubt and by a counter experiment should see whether the rational appearance is not misleading This is an absolutely strict precept, especially m medical science which by its complexity

conceals additional sources of error I have elsewhere (p 55) described the experimental char- acter of counterproofs, I will not return to that subject, I wish merely to point out here that, even when a fact seems logical, 1 e , rational, we are never justified m omitting a counterproof or counter experiment, so that I consider this precept a kind of order which we must blindly follow even m cases which Beem the clearest and most rational I am going to quote two examples which will show the necessity of thus making a comparative experiment always and m spite of everything

First example — I explained before (p 164:) how I was once led to study the part played by sugar in nutrition and to investigate the mechanism by which this nutritive principle was destroyed m the organism To solve this problem, I had to hunt for sugar m the blood and follow it into the intestinal vessels which absorbed it, until I could note the place where it disappeared To carry out my experi- ment, I gave a dog sweetened milk soup , then I sacrificed the animal during digestion and found that the blood m the superhepatic ves- sels, which hold all the blood of the intestinal organs and the liver, contained sugar It was quite natural and, as we say, logical to think that the sugar found m the superhepatic vessels was the same that I had given the animal m his soup I am certain indeed that more than one experimenter would have stopped at that and would have considered it superfluous, if not ridiculous, to make a comparative experiment. However, I made a comparative experiment, because I was convinced of its absolute necessity on principle which means that I am convinced that we must always doubt m physiology, even in cases where doubt seems least allowable However, I must add

that a comparative experiment was also required here by another circumstance, viz , that I used the reduction of copper as a test for sugar This, however, is an empirical

characteristic of sugar which might be shown by substances still unknown m the bodily economy But, even apart from that, I repeat, a comparative experiment would have had to be made as an experimental necessity, for this very case proves that we can never foresee its importance

So for comparison with the dog fed on sugary soup, I took another dog to which I gave meat to eat, being careful moreover to exclude all sugary or starchy material from its diet, then I sacrificed the ani- mal during digestion and examined comparatively the blood m its superhepatic veins Great was my astonishment at finding that the blood of the animal which had not eaten any also contained sugar We therefore see that comparative experiment led me to the dis- covery that sugar is constantly present m the blood of the superhe- patic veins, no matter what the animal's diet may be You may imagine that I then abandoned all hypotheses about destruction of sugar, to follow this new and unexpected fact I first excluded all doubt of its existence by repeated experiments, and I noted that sugar also existed m the blood of fasting animals But if benefits are linked with comparative experiment, not performing them has its necessary annoyances This is proved by the following example Second example — Magendie once made investigations on the uses of the cerebrospinal fluid and was led to the conclusion that removing this fluid produces a kind of titubation m animals and a characteristic disturbance m their motions Indeed, after uncover- ing the occipito-atloidian membrane, if we pierce it to let the cere- brospinal fluid run out, we notice that the animal is seized with peculiar motor disturbances Apparently nothing could be simpler or more natural than the influence on their motions of removal of the cerebrospinal fluid , yet this was an error, and Magendie told me how another experimenter chanced to find it After cutting the neck muscles, this experimenter was interrupted m his experiment at the moment when he had just laid bare the occipito-atloidian membrnne Now when he came back, to go on with his experiment, he saw that the simpto preliminary operation had produced the same titubation, though the cephalorachidian fluid had not been

removed What nas mere!) the result of severing the neck muscles had therefore been attributed to removal of tho cerebrospinal fluid Comparative ex-

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penment would obviously have solved the difficulty In this case, two animals, as we have said, ought to be placed in the same condi- tions save one, that is, the oecipito-atloidian membrane should be laid bare m both animals, and it should be pierced, to let the fluid flow out, m only one of them , then it would be possible to judge by com- parison and thus ascertain the precise part which the removal of the fluid plajs m the disturbances I might quote a great many errors into which able experimenters have fallen by neglecting the precept about comparative experiment Only, as the examples that I have quoted prove, it is often hard to know m advance whether comparative experiment is necessary or not, and so I repeat that, to avoid all annoyance, we should accept comparative experiment as a veritable command, to be executed even when useless, so as not to be miBsmg when it is necessary Comparative experiments are sometimes made, now on two animals, or for greater accuracy, on two similar organs m the same animal Thus, at the time when I wished to judge the in- fluence of certain substances on the glycogen of the liver, I could never find two animals comparable m this respect, even by putting them m exactly similar dietary circumstances, 1 e , without food for the same number of days According to their age, sex, plumpness, etc , animals bear starvation better or worse and destroy more glyco- gen or less, so that I could never be sure that the differences I found were the result of difference m diet To remove this source of error, I was forced to make the whole experiment on the same animal, by taking away a preliminary piece of its liver before the dietary injec- tion, and another afterward So when we want to see the influence of contraction on the metabolism of the muscle in a frog, we have to compare both members of a single animal, because in this respect

two frogs are not always comparable

IV Experimental Criticism Should Bear on Pacts Alone and Never on Words

At the beginning of this chapter, I said that we are often deceived by false values ascribed to words I wish to explain my idea by examples

First example — In 1859 I made a report to the Philomathic Society, m which I discussed Brodie's and Magendie's experiments on ligature of the bile duct, and I showed that the divergent results

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■which the two experimenters reached, depended on the fact that one operated on dogs and tied only the bile duct, while the other operated on cats and, without suspecting it, included m his ligature, both the bile duct and a pancreatic duct Thus I showed the reason for the difference m the results they reached, and I concluded that, m physiology as everywhere else, experiments are rigorous and give identical results whenever we operate m exactly similar conditions A propos of this, a member of the society took the floor to attack my conclusions, it was Gerdy, surgeon at the Chante, professor m the faculty of medicine, and known through various works on surgery and physiology "Your anatomical explanation of Brodie's and Magendie's experiments," said he, "is correct, but I cannot accept your general conclusion You say, m fact, that the results of experi- ments m physiology are identical, I deny it Your conclusion would be correct for inert nature, but it cannot be true for living nature Whenever life enters into phenomena," he went on, "conditions may be as similar as we please, the results may still be different." To support his opinion, Gerdy cited cases of individuals with the same disease, to whom he had given the same drugs, with different results He also recalled cases of like operations for the same disease, but followed by cure m one case and death m another These differences, according to him, all depended on life itself altering the

results, though the experimental conditions were the same , but this could not happen, he thought, m phenomena of inert bodies, into which life does not enter Opposition to these ideas was prompt and general m the Philomathie Society Everyone pointed out to Gerdy that his opin- ions were nothing less than a denial of biological science, and that, in the cases of which he spoke, he completely deceived himself ns to the identity of conditions, m this sense, that the diseases which he regarded as similar or identical were not m the least alike, and that he attributed to the influence of life what should be accounted for by our ignorance about phenomena as complex as those of pathology Gerdy continued to maintain that life had the effect of altering phenomena so as to make them differ m different individuals, even when the conditions m which they took place were identical Gerdy believed that one man’s vitality was not the same as another’s, and that there must therefore be between individuals differences impos- sible to define He would not give up his ideas, he entrenched him- self behind the word vitality and could not be made to understand

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that it was only a word, devoid of meaning and corresponding to nothing , and that saying that something was due to vitality amounted to calling it unknown

In fact, we are often duped by such words as life, death, health, disease, idiosyncrasy We think we have explained when we say that a phenomenon is due to a vital influence, a morbid influence, or an individual idiosyncrasy We must really learn, however, that vital phenomenon means only a phenomenon peculiar to living beings, whose cause we do not yet know , for I think that every phenomenon, called vital to-day, must sooner or later be reduced to definite proper- ties of organized or organic matter We may, of course, use the expression vitality as chemists use the word affinity, but knowing that fundamentally there are only phenomena and

conditions of phe- nomena which we must learn , when the conditions necessary to phe- nomena are known, then occult, vital and mineral forces will dis- appear

I am very happy to be m perfect harmony on this point with my colleague and friend, M Henn Sainte-Claire Deville This will be seen in the following words spoken by M Sainte-Claire Deville m explaining his splendid discoveries on the effects of high tempera- tures to the Chemical Society of Pans 8 “We must not conceal from ourselves the fact that studying primary causes of the phenomena which we observe and measure has its grave dangers Escaping exact definition, independent of particular facts, it leads us, much oftener than we think, really to beg the question, and to content ourselves with specious explanations that cannot withstand severe cnticism Chiefly affinity, defined as the force which presides over chemical combinations, has long been and still is an occult cause, a sort of archeus to which we refer all the facts which we do not understand and which we thenceforth consider explained, though they are often only classified and often wrongly classified m the same way we attribute to catalytic 10 force any number of extremely obscure phe- nomena which, m my opinion, become more so when we refer them en bloc to an entirely unknown cause In giving them the same name,

* H Samte Claire Deville, Levons ear la dissociation prononcies dev ant la Eoci&ti chimique Pans, 1866

“ All this applies to those recently invented forces, to the forces of dissolu- tion and diffusion, to crystalogemc force, to all the special attractive and re pelling forces brought m to explain phenomena of heating and superfusion, electric phenomena, etc

we certainly believe we are placing them in. the same category. But this classification is not even proved legitimate What, indeed, could be more arbitrary

than setting side by side catalytic phenomena that depend on the action or the presence of platinum sponge and con- centrated sulphuric acid, when the platinum and the acid are not, so to speak, parties to the operation ? These phenomena will per- haps later be explained m an essentially different way, according to whether they are produced under the influence of a porous material like platinum sponge or under the influence of a highly energetic chemical agent like concentrated sulphuric acid

“In our studies, we must therefore lay aside unknown forces, to which we have recourse only because we have not measured their effects On the contrary, we should direct our attention to the ob- servation and numerical determination of effects, which alone aie within our range By such work, we establish differences and anal- ogies, and new light results from comparisons and measurements “Thus heat and affinity are constantly face to face m our chemical theories Affinity completely escapes us, and yet we attribute combi- nation to it, as the effect of an unknown cause Bet us simply study the physical circumstances which accompany a combination, and we shall see how many measurable phenomena, how many curious lelations present themselves at every moment Heat, they say, de- stroys affinity Let us patiently study the decomposition of bodies under tho influence of heat measured m quantity of work, heat or energy we shall immediately see how fruitful this study is, and how independent of every unknown force, unknown even from the point of view of the kind of units to which we must refer it for precise or approximate measurement Especially m this sense affinity, consid- ered as a force, is an occult cause, unless it simply expresses a quality of matter In that case, it would be used simply to designate tho fact that such and such substances can or cannot be combined in such and such definite circumstances ”

When a phenomenon takes place outside the living body and does not occur m the organism, that is not because an entity called hfc prevents the phenomenon from taking place, but because the neces- sary condition for the phenomenon is not met

with inside, as it is outside, the bod\ Thus it has actually been said that life prevents fibrin from coagulating m living animals' blood vessels, though it docs coagulato outside the vessels because life no longer affects it. It

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is nothing of the sort , certain physico-chemical conditions are nee'ded to make fibrin coagulate , they are harder to produce, but may never- theless be found m the living, and, as soon as they appear, fibrin coagulates as well inside as outside the organism The life invoked here is therefore only a physical condition which does or does not exist I have shown that sugar is produced m the liver more abun- dantly after death than during life, certain physiologists drew the conclusion that life influences the formation of sugar m the liver, they said that life hinders its formation and death favors it One is surprised to hear such vitalistic opmions m our day and to see them supported by men who pique themselves on applying to physiology and medicine the accuracy of physical science I shall later show that here again physical conditions are either present or absent, but nothing else is real , because again, at the base of all these explana- tions, only the conditions of phenomena are to be found

To sum up, we must learn that the words we use to express phe- nomena whose cause we do not know are nothing m themselves , and that the moment we grant them any value in criticism or discussion, we abandon experience and fall into scholasticism In discussing or explaining phenomena, we must be very careful never to abandon observation or put a word m place of a fact. Very often we even ex- pose ourselves to attack, solely because we abandon facts and con- clude with a word that goes beyond what we have observed The following example will prove it clearly

Second example — When I made my investigations of pancreatic juice, I noted that this fluid includes a peculiar material, pancrea- tm, which has characteristics of both albumen and casein It resem- bles albumen m being coagulated by heat, but, like

casein, differs from it m being precipitated by sulphate of magnesia. Magendie had made experiments, before me, on pancreatic juice, and had said that, according to his tests, pancreatic juice is a fluid containing albu- men, while, from my investigations, I concluded that pancreatic juice does not comprise albumen, but does contain pancreatm, which is a material distinct from albumen I showed my experiments to Ma- gendie, pointing out that we disagreed on the conclusion, but that we nevertheless agreed on the fact that pancreatic juice is coagulated by heat, only that other new characteristics that I had seen pre- vented my deciding on the presence of albumen Magendie an- swered “This difference between us comes from my having inferred

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more than I saw, if I had simply said, pancreatic juice is a liquid coagulated by heat, I should have remained within the facts, and should have been unassailable ” This example, which I have always remembered, shows how little value we should ascribe to words apart from the facts they represent. Thus the word albumen means noth' ing in itself , it merely recalls characteristics and phenomena. By extending this example to medicine, we should see that the words, fever, inflammation, and the names of diseases in general have no meaning at all in themselves.

When we create a word to characterise a phenomenon, we then agree in general on the idea that we wish it to express and the precise meaning we are giving to it, but with the later progress of science the meaning of the word changes for some people, while for others the word remains in the language with its original meaning The re- sult is often such discord that men using the same word express very different ideas Our language, in fact, is only approximate, and even in science it is so indefinite that if we lose sight of phenomena and cling to words, we are speedily outside of reality We therefore only injure science by arguing in favor of a word which is now merely

a source of error, because it no longer expresses the same idea for everyone Let us therefore conclude that we must always cling to phenomena and see in words only expressions empty of meaning, if the phenomena they should represent are not definite, or if they are absent

The mind by its very nature has systematic tendencies, that is why we try to seek agreement about words rather than things For experimental criticism, this is a false direction which confuses ques- tions and makes us believe m differences of opinion which generally exist only m our way of interpreting phenomena, instead of having some bearing on the existence of facts and on their real importance Like everyone who has had the good fortune of bringing into science unexpected facts or new ideas, I have been and still am the object of much criticism Up to this time, I have not answered my oppo- nents, because I have always had investigations on hand so that tune and opportunity have been lacking , but in the remainder of this work, occasion to study them will quite naturally present itself, and by applying the principles of experimental criticism suggested m earlier paragraphs, we shall easily weigh the criticisms m question Mean- time I shall merely say that it is essential to distinguish between two

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things m experimental criticism experimental fact and its interpre- tation Science requires us first of all to agree on fact, because that is the basis on which we muBt reason As to interpretations and ideas, they may vary, and discussing them is an actual advantage, because such discussion leads us to make other investigations and to undertake new experiments In physiology, we should therefore never lose sight of the principles of true scientific criticism nor mix them with personalities or artifice Among the artifices of criticism, many do not concern us because they are extra-scientific, one of them, however, we must point out It consists in. considering

m a piece of work only what is defective and open to attack, while neglecting or concealing what is valid and important This is the method of false criticism In science the word criticism is not a synonym for dis- paragement, criticising means looking for truth by separating the true from the false and distinguishing the good from the had While just to men of science, such criticism alone is profitable for science And this we shall easily show m the particular examples which we shall mention

CHAPTER III

INVESTIGATION AND CRITICISM AS APPLIED TO EXPERIMENTAL MEDICINE

Methods of investigation and of scientific criticism cannot vary from one science to another nor, for that matter, m different parts of the same science It will therefore he easy to show that the rules for physiological investigation, suggested in the last chapter, are absolutely the same as those which should be followed in pathology and therapeutics Thus methods of investigation of the phenomena of life should be the same m normal as m pathological conditions This seems to us fundamental m biological science

I Pathological and Therapeutic Investigation

As m physiology, so m pathology and m therapeutics, the starting point of scientific investigation is now a casual fact or one occurring by chance, now an hypothesis, i e , an idea.

I have sometimes heard physicians express the opinion that medi- cine is not a science, because all our knowledge of practical medicine is empirical and bom of chance, while scientific knowledge is de- duced with certainty from theories or

principles There is an error here, to which I wish to call attention.

All human knowledge had to begin with casual observations Man indeed could know things only after seeing them, and the first time, necessarily, he saw them "by chance, then he came to conceive ideas about things, to compare old facts and to deduce from them new ones, in a word, after empirical observation, he was no longer led to find other facts by chance, but by induction

Fundamentally, then, all the sciences began with empiricism, that is to say, observation or chance experience had to form the first period But empiricism is not a permanent state m any science In the com- plex sciences of humanity, empiricism will necessarily govern prac- tice much longer than m simpler sciences Medical practice to-day is

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empirical in most cases, but that does not mean that medicine will never escape from empiricism The complexity of its phenomena will make it harder to escape , but that should make us redouble our efforts to enter the scientific path as soon as we can In a word, empiricism is not the negation of science, as certain physicians seem to think , it is only its first stage We must even add that empiricism never wholly disappears from any science Sciences, in fact, are not lighted up m every portion at once, they develop only a little at a time In parts of physics and chemistry, empiricism still persists This is proved every day by chance discoveries, unforeseen by pre- vailing theories I therefore conclude that we make discoveries m the sciences only because all are still partially obscure In medicine more numerous discoveries are still to be made, because almost every- where empiricism and obscurity prevail So this very complicated science is proved further behind the times than others , but that is all New medical observations are generally made by chance, if a patient with a hitherto unknown affection is admitted to a hospital where a

physician comes for consultation, surely the physician meets the patient by chance But a botanist in the field happens on an unfamiliar plant m exactly the same way, and by chance also an astronomer catches sight of a planet, whose existence he did not know of, m the sky In such circumstances, the physician's origi- nality consists m seeing the fact that chance presents to him and m not letting it escape, and his only merit is accurate observation I cannot here analyze the characteristics of good medical observation. Reporting instances of chance medical observations would be just as dull Medical works teem with them, everybody knows them I shall therefore limit myself to saying m general that, to make a good medical observation, it is not only necessary to have an observing mind, but also to be a physiologist. We shall the better interpret the various meanings of a morbid phenomenon, we shall assign it the proper value, and we shall certainly not fall into the difficulty, with which Sydenham 1 reproached certain physicians, of puttmg important phenomena of a disease on the same plane as insignificant and accidental facts, like the botanist who described caterpillar bites among the characteristics of a plant Besides, we must bring to observation of a pathological phenomenon, i e , a disease, exactly the same state of mind and the same rigor, as to observation of a physio- 1 Sj denhatn, Mtdccinc pratique Preface, p 12

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logical phenomenon. We must never go beyond facta and must be, as it were, photographers of nature.

But once made, every medical observation becomes the starting point, as m physiology, for ideas and hypotheses which experimental physicians go on to investigate through fresh observations of pa- tients or by experiments on animals.

We said that, m making physiological investigations, it often happens that a fresh fact arises unsought, that also occurs m pa- thology To prove it, I need only cite the

recent case of Zenker, who,2 in pursumg his investigations of certain muscular changes in typhoid fever, found trichinae which he was not looking for.

Pathological investigation may also take for its starting point a theory, an hypothesis or a preconceived idea. We might easily give examples to prove that absurd ideas, m pathology as m physiology, may sometimes lead to useful discoveries, just as it would not be hard to find arguments to prove that even the best accredited theories should be regarded only as temporary, and not as absolute truths to which facts should be bent.

Therapeutic investigation conforms to exactly the same rules as physiological and pathological investigation. Everyone knows that the first promoter of therapeutic science was chance, and that only by chance were the effects of most medicines first observed Physi- cians have also often been guided m their therapeutic attempts by ideas, and it muBt also be said that they were often the strangest and most absurd theories or ideas I need only cite the theories of Paracelsus, who deduced the action of drugs from astrological influ- ences, and recall the ideas of Porta, who assigned medicinal uses to plants, deduced from their resemblances to certain diseased organs, thus carrots cured jaundice, lung-wort, phthisis, etc3

Summing up, we cannot establish any valid distinction between methods of investigation that should be applied m physiology, m pathology and m hygiene The method of observation and experi- ment is still the same, unchangeable m its principles and offering only a few peculiarities m its application, according to the relative complexity of phenomena We cannot, indeed, find any radical dif-

JSee Rapport dee pnx de mddecine et de chvrurgie pour 1864 (Compt rendus do VAcad des sciences)

’See Chevreul, Considerations sur Vhislmre de la partie de la mddecine qui conceme la prescription des remides (Journal des savants, 1805)

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ference m the nature of physiological, pathological and therapeutic phenomena. Since all these phenomena depend on laws peculiar to living matter, they are identical in essence and vary only with the various conditions in which phenomena appear "We shall see later that physiological laws are repeated in pathological phenomena, whence it follows that the foundations of therapeutics must reside in knowledge of the physiological action of morbid causes, of medi- cines and of poisons, and that is just the same thing

II Experimental Criticism in Pathology and Therapeutics

Criticism of facts gives sciences their true individuality All scientific criticism should explain facts rationally If criticism is attributed, on the other hand, to personal feeling, science disappears, because such criticism rests on a criterion that can neither be proved nor conveyed as scientific truths should be I have often heard phy- sicians answer, when asked the reason for a diagnosis, “I do not know how I recognize such and such a case, but it is evident”, or when one asks them why they give certain remedies, they answer that they cannot exactly tell, and besides that they need not explain, since they are guided by their medical tact and intuition It is easy to understand that physicians who reason m that way deny science But we cannot too strongly protest against such ideas, which are bad, not only because they stifle every germ of science, but also be- cause they especially encourage laziness, ignorance and charlatanism I entirely understand a physician’s saying that he cannot always rationally account for what he is doing, and I accept his conclusion that medical science is still plunged m the shades of empiricism , but if he goes on to proclaim his medical tact or his intuition as a criterion which he then means to impose on others without further proof, that is wholly antiscientific

As m physiology, the only scientific criticism possible in pa- thology and m therapeutics is experimental criticism, and whether applied to ourselves or to the

work of others, this criticism should always be based on absolute determination of facts Experimental criticism, as we have seen, should reject statistics as a foundation for experimental therapeutic and pathological science Xu p 8.tliol and therapeutics, we should repudiate undetermined facts, that is to

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say, those badly made, and sometimes imaginary, observations which are constantly brought forward as perpetual objections As m physi- ology, there are crude facts which can enter into scientific reasoning only on condition that they be determined and exactly defined as to their necessary conditions

But it is characteristic of criticism m pathology and therapeutics, first and foremost to require comparative observation and experiment. How, indeed, can a physician judge the etiology, if he does not make a comparative experiment to eliminate all the secondary circum- stances, that might become sources of error, and make him take mere coincidences for relations of cause and effect? Especially m thera- peutics, the need of comparative experiment has always struck physi- cians endowed with the scientific spirit We cannot judge the influ- ence of a remedy on the course and outcome of a disease if we do not previously know the natural course and outcome of the disease That is why Pmel said m his clinic “This year we will observe diseases without treating them, and next year we will treat them ” Scien- tifically, we ought to adopt PmePs idea without, however, accepting the long-range, comparative experiment which he proposed Dis- eases, m fact, may vary m seriousness from one year to another, Sydenham’s observations on the undetermined or unknown influence of what he calls the epidemic genius prove it To be valid, comparative experiments have therefore to be made at the same time and on as comparable patients as possible In spite of that, such comparisons still bristle with immense difficulties which phy- sicians must strive to lessen , for comparative

experiment is the sine qua non of scientific experimental medicine, without it a physician walks at random and becomes the plaything of endless illusions A physician, who tries a remedy and cures his patients, is inclined to believe that the cure is due to his treatment Physicians often pride themselves on curing all their patients with a remedy that they use But the first thing to ask them is whether they have tried doing nothing, le, not treating other patients, for how can they otherwise know whether the remedy or nature cured them? Gall wrote a little known book 4 on the question as to what is nature's share and what is the share of medicine in healing disease, and he very naturally concludes that their respective shares are quite hard to

4 Gall, Phtlosophtsche medicimschc Dntersuehungen fiber Eunst und Eatur im gesunden und kranken Zustand des ilenschen Leipzig, 1800

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assign We may be subject daily to tbe greatest illusions about the value of treatment, if -we do not have recourse to comparative experi- ment I shall recall only one recent example concerning the treat- ment of pneumonia Comparative experiment showed, m fact, that treatment of pneumonia by bleeding, which was believed most effi- cacious, is a mere therapeutic illusion 5

From all this, I conclude that comparative observation and experi- ment are the only solid foundation for experimental medicine, and that physiology, pathology and therapeutics must be subject to this criticism in common

'Bdclard, Rapport gGn&ral sur les prix dicernts en 1862 {Mimoires de 1'A.caddmte de nuldecinc, Pans, 1863, Vol XXVI, p xxm)

CHAPTER IV

PHILOSOPHIC OBSTACLES ENCOUNTERED BY EXPERIMENTAL MEDICINE

According to everything so far said in this Introduction, the principal obstacles encountered by experimental medicine lie m the enormous complexity of the phenomena studied. I need not return to this point already explained from every angle But besides these wholly material and, so to speak, objective difficulties, there are obstacles to experimental medicine arising from vicious methods, bad mental habits and certain false ideas about which we shall now say a few words

I The False Application of Physiology to Medicine

I certainly do not claim to have been the first to propose apply* mg physiology to medicine That was long ago recommended, and numerous attempts have been made in this direction. In my works and my teaching at the College de France, I am therefore merely fol- lowing out an idea which is already bearing fruit through its appli- cation to medicine More than ever to-day, young physicians are advancing along this path, rightly considered the path of progress However, I have frequently seen the application of physiology to medicine misunderstood, so that it not only fails to produce the good results which we have a right to expect, but becomes actually harm- ful, and thus furnishes arguments to the detractors of experimental medicine It is therefore most important to make the subject plain , for m dealing with the important question of method, we shall find a fresh opportunity to define more exactly the true point of view of what we call experimental medicine.

Experimental medicine differs m object from the medicine of observation, just as the sciences of observation m general differ from the experimental sciences The object of any science of observation is to discover the laws of natural phenomena so as to foresee them ,

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but it cannot master them or alter them at pleasure Astronomy is typical of these sciences, we can. foresee astronomical phenomena, hut we cannot change them in any way The object of an experi- mental science is to discover the laws of natural phenomena, for the purpose not only of foreseeing them, but of regulating them at pleasure and mastering them such are physics and chemistry

Among physicians, there are some who actually believe that medi- cine should remain a science of observation, 1 e , that it should be able to foresee the course and outcome of diseases, but should not directly act on disease There are others, and I am one of them, who think that medicine can be an experimental science, 1 e , that it should delve into the interior of organisms and find ways of altenng and, to a certain extent, regulating the hidden springs of living machines Observing physicians look on a living organism as a little world contained m the great world, like a kind of ephemeral living planet whose motions are ruled by laws which we discover by simple observation, so as to foresee the progress and evolution of vital phenomena in health or disease, but without ever being able to alter their natural course in any way This doctrine is found m Hippocrates m its purest form Medicine of simple observation obviously excludes all manner of active medical intervention, for this reason it is also known as expectant medicine, that is to say, medicine that observes and foresees the course of diseases without aimmg to act directly on their progress 1 It is rarely that we find a physician purely Hippocratic m this respect, and it would be easy to prove that many physicians, who loudly applaud Hippocratism, do not trust to its precepts m the least when they give themselves up to the most active and disordered flights of empirical medication Not that I condemn these therapeutic attempts which, most of the time, are only experimentations to see, only I say that this is not Hippocratic medicine, but empiricism Empirical physicians, acting more or less blindly, are, after all, experimenting on vital phenomena, and thus class

themselves m the empirical period of experimental medicine

Experimental medicine is therefore medicine that claims knowl- edge of the laws of healthy and diseased organisms, not only so as to foresee phenomena, but also so as to be able to regulate and alter them

1 iefon d’ouverture du court de mSdectne au College de France (Revue des court ectenttfigues, Dec 31, 1864)

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within certain limits Accordingly, -we easily perceive that medicine necessarily tends to become experimental, and that every physician v?ho gives his patients active medicines cooperates m building up experimental medicine But if such action, on the part of experi- menting physicians, is to transcend empiricism and deserve the name of science, it must be based on knowledge of the laws govern- ing action m the organism’s inner environment, whether m a healthy or a pathological state The scientific basis of experimental medi- cine is physiology, we have often said this, it must be proclaimed aloud, because without it no medical science is possible Diseases at bottom are only physiological phenomena m new conditions still to be determined , toxic and medicinal action, as we shall see, come back to simple physiological changes m properties of the histological units of our tissues In a word, physiology must be constantly ap- plied to medicine, if we are to understand and explain the mechanism of disease and the action of toxic and medicinal agents Now, pre- cisely this application of physiology must here be carefully defined

We saw above how expenmental medicine differs from Hip- pocratlsm and from empiricism, but we did not say that experi- mental medicine should therefore renounce observational medicine or the empirical use of medicines, far from it, experimental medi- cine makes use of medical observation as a necessary support In fact, experimental medicine never systematically rejects any fact or popular

observation , it must examine everything experimentally, and it seeks the scientific explanation of facts which observational medicine and empiricism have already noted Experimental medi- cine, then, is what I might call the second period of scientific medicine, the first period being observational medicine, and quite naturally, therefore, the second period is added to the first and rests on it The first requirement, then, m practising experimental medi- cine, is to be an observing physician and to start from pure and simple observations of patients made as completely as possible, ex- perimental science comes next, analyzing every symptom by trying to connect it with explanations and vital laws that shall include the relation of the pathological state to the normal or physiological condition

But m the present state of biological science, no one can presume to explain pathology by physiology alone, ve must move m that direction because it is the scientific path, but we must shun belief

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m tlie illusion that our problem is solved For the moment, there- fore, the prudent and reasonable thing to do is to explain all that ■we can explain m a disease by physiology and leave what is still inexplicable to the future progress of biological science This kind of analysis, advancing only step by step as the progress of physiologi- cal science permits, isolates the essential elements of a disease by elimination, a little at a time, grasps its characteristics more ac- curately and allows us to guide therapeutics more intelligently Besides, the analytic, progressive advance still keeps the individual character and aspect of the disease But if we take advantage, instead, of a few possible connections between pathology and physiol- ogy, to try to explain the whole disease at a single stroke, then we lose sight of the patient, we distort the disease, and by our false application of physiology, we retard experimental medicine, instead of promoting its progress

Unfortunately I must blame not only pure physiologists for the wrong application of physiology to pathologv, but also professional pathologists and physicians In various recent publications on medi- cine, whose physiological tendencies, by the way, I approve and praise, I see that before any exposition of medical observations, the authors begin with a summary of everything learned by experimental phys- iology about phenomena connected with the disease with which tlie\ are concerned Then they contribute observations of patients, some- times without definite scientific object, sometimes to show that phys- iology and pathology are m agreement But aside from the fact that agreement is not always easy to prove, because points in experi- mental physiology are often still under consideration, I find this sort of procedure essentially disastrous to medical science, m that it subordinates the more complex science, pathology, to physiology, a simpler science This is, m fact, the inverse of what we previously said should be done we should first of all state the medical problem as given by observation of the disease, then try to find the physi- ological explanation, by experimentally analyzing the pathological phenomena But in this analysis, medical observation must never disappear or be lost sight of, it must remain as the constant basis or common ground of all our studies and explanations

In this work, I cannot develop as a whole the things that I ave just said, because I have had to limit myself to giving the re- sults of my experience m physiological science with which I am

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most familiar In publishing a simple essay on the principles of scientific medicine, my idea is to be of some use to medicine Medicine, indeed, is so vast that we can never hope to find a man able to cultivate all parts of it fruitfully at one time. But m the part where each physician takes up his quarters, he must thoroughly understand the scientific connections between all the medical sciences, so as to avoid scientific

anarchy by guiding his investigations m a dnection useful to the whole I am not practising clinical medi- cine here , but I must take account of it, nevertheless, and assign it the first place m experimental medicine So if I were planning a treatise on experimental medicine, I should go to work by invariably making observation of disease the basis of every experimental analysis I should then proceed with my explanations, symp- tom by symptom, until I had exhausted all the information obtain- able from present experimental physiology, and the result of all this would be medical observation reduced to its simplest terms.

In saying above that we must explain by experimental physiology only what can be explained m disease, I do not want my idea misun- derstood or taken as an admission that there are things m disease which can never be physiologically explained My idea is just the reverse, because I believe that we shall explain everything m pathol- ogy, but little by little and m step with the development of experi- mental physiology. We can just now explain nothing about cer- tain diseases, for instance the eruptive diseases, because the related physiological phenomena are unknown So the objection, which some physicians find here, to physiology as a help to medicine, is not worthy of consideration That kind of argumentation is tinged with scholasticism and proves that those who use it have no correct idea of such a science as experimental medicine can be

To sum up, as the natural foundation of experimental medicine, experimental physiology cannot suppress observation of the sick or lessen its importance Moreover, physiological knowledge is not only indispensable m explaining disease, but is also necessary to good clinical observation For example, I have seen observers sur- prised into describing as accidents certain thermal phenomena which occasionally result from nerve lesions , if they had been physiologists, they would have known how to evaluate morbid symptoms which are really nothing but physiological phenomena

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II Scientific Ignorance and Certain Illusions of the Scien- tific Spirit Hinder the Deielopment of Experimental

Medicine

We have just said that knowledge of physiology is indispensable to physicians , we must therefore cultivate the physiological sciences, if we wish to further the development of experimental medicine This is all the more necessary, because it is the only way to provide a foundation for scientific medicine, and unfortunately we are still far from the time when we shall see the scientific spirit generally prevailing among physicians Now the absence of the scientific habit of mind is a serious hindrance, because it favors belief m occult forces, rejects determinism in vital phenomena, and leads to the notion that the phenomena of living beings are governed by mys- terious, vital forces which are continually invoked When an obscure or inexplicable phenomenon presents itself, instead of saying “I do not know,” as every scientific man should do, physicians are m the habit of saying, “This is life” , apparently without the least idea that they are explaining darkness by still greater darkness We must therefore get used to the idea that science implies merely determin- ing the conditions of phenomena , and we must always seek to exclude life entirely from our explanations of physiological phenomena as a whole Life is nothing but a word which means ignorance, and when we characterize a phenomenon as vital, it amounts to saying that we do not know its immediate cause or its conditions Science should always explain obscurity and complexity by clearer and sim- pler ideas Now since nothing is more obscure, life can never explain anything I emphasize this point, because I have seen even chemists at times appeal to life to explain certain physico-chemical phenomena peculiar to living beings Thus the ferment m yeast is an organic, living material which has the property of converting sugar into alcohol, carbonic acid and several other products I have

sometimes heard it said that the property of decomposing sugar was due to the life inherent m a globule of yeast This vitalistic explana- tion means nothing and explains nothing about the action of yeast We do not know the nature of this property, but it must necessarily belong to the physico-chemical order and be as precisely defined as, for instance, the property of platinum sponge which produces a more or less analogous action that cannot be attributed to vital force. In

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a word, all tlie properties of living matter are, at bottom, either known and defined properties, m which case we call them physico- chemical properties, or else unknown and undefined properties, m which case we name them vital properties Certainly a special force m living beings, not met with elsewhere, presides over their organi- zation, but the existence of this force cannot m any way change our idea of the properties of organic matter, — matter which, when once created, is endowed with fixed and determinate, physico-chemical properties Vital force is, therefore, an organizing and nutritive force , but it does not m any way determine tbe manifestation of the properties of living matter. In a word, physiologists and physicians must seek to reduce vital properties to physico-chemical properties, and not physico-chemical properties to vital properties

The habit of vitalistic explanation makes us credulous and pro- motes the introduction of erroneous or absurd data into science Thus, quite recently I was consulted by an honorable and much respected practising physician who asked my opinion of a most unusual case, of which, he said, he was very sure, because he had taken all precautions necessary to observing it well here was a woman m good health except for a few nervous anomalies, who had neither eaten nor drunk anything for several years Evidently the physician was persuaded that vital force is capable of anything, so that he sought no other explanation The slightest idea of sci-

ence, however, and the simplest notions of physiology, would have been enough to undeceive him, by showing that his statement ven nearly amounted to saying that a candle can go on shining and burning for several years without growing any shorter

Belief that the phenomena of living beings are dominated by an indeterminate vital force often also gives experimentation a false basis and puts a vague word m place of exact experimental analysis I have seen physicians submit questions to expenmental analy- sis m which they took as their starting point the vitality of certain organs, the idiosyncrasy of certain individuals or the antagonism of certain medicines Now, vitally, ldiosincrasy and antagonism are merely vague words which should first be qualified and reduced to a definite meaning In the experimental method, then, it is a matter of absolute principle always to take, as our starting point for experimentation or reasoning, an exact fact or a good observation, and not a vague word When the discussions of physicians and

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naturalists lead to nothing, it is usually because they fail to conform to this analytic precept. In a word, m experimentation on living beings, as with inorganic bodies, it is essential, before beginning our experimental analysis of a phenomenon, to make sure that the phenomenon exists and never to let ourselves be deceived by words that lose sight of facts as they are

As we have elsewhere explained, doubt is the foundation of ex- perimentation, yet we must not confuse philosophic doubt with that systematic negation which casts doubt on the very principles of science We must doubt only theories, and we must doubt even them only to the point of experimental determinism Some physicians believe that the scientific spirit sets no limit to doubt. Aside from these physicians, who deny medical science by admitting that nothing positive can be known, others deny it by the opposite method, admit- ting, as they do, that they have learned their

medicine they know not how, and are masters of it through a kind of intuitive science which they call clinical sense or instinct In medicine, as m other prac- tical sciences, I do not of course question the existence of what is called tact or clear-sightedness Everyone knows, m fact, that habit may give a kmd of empirical knowledge of things sufficient to guide practitioners, even though they cannot always precisely account for it at first But what I blame is willfully staying m this empirical state and not trying to get out of it By attentive observation and study, we can always manage to account for our actions and so succeed m trans- mitting our knowledge to others Besides, I do not deny that the practice of medicine has severe requirements , but here I am talking pure science and am attacking medical tact as an anti-scientific datum whose natural exaggerations are decidedly harmful to science Another false opinion, which is pretty well accredited and even professed by great practising physicians, is expressed in saying that medicine is not destined to become a science, but only an art, and that physicians accordingly should be artists, not men of science I find this idea erroneous and essentially harmful to the development of experimental medicine First, what is an artist? An artist is a man who carries out a personal idea or feeling m a work of art Here, then, are two things the artist and his work, the artist is necessarily judged by his work. But what can a medical artist be? If he is a physician who treats disease according to his personal idea or feeling, then where is the work of art by which the medical

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artist is to be judged 2 Is it cure of tbe disease 2 That would be a strange kind of work of art, and the physician’s authorship would be seriously disputed by nature When a great painter or a great sculptor makes a beautiful picture or a magnificent statue, no one imagines that the statue grew out of the earth or that the picture made itself, while we can perfectly well maintain that a disease has cured itself and can

often prove that the cure would have been better without the artist's interference Then what has become of the criterion, or medical work of art 2 The criterion evidently dis- appears; because no physician's ability can be judged by the num- ber of patients that he says he has cured , he must first of all prove scientifically that it was he who cured them, and not nature I shall not further emphasize this untenable medical claim to art In reason, physicians can be men of science only, or, m the mean- time, empiricists Empiricism, which means experience at bottom (kfnceipla , experience), is only unconscious or non-rational experi- ence, acquired by every-day observation of facts, m which the experi- mental method itself originates (see p 12) But as we shall see again m the next paragraph, empiricism m its true sense is merely the first step m experimental medicine Empirical physicians should strive toward science, for though they often decide m practice according to unconscious experience, they should at least still guide themselves by induction based on as solid medical learning as pos- sible In a word, since there is no such thing as a medical work of art, there is no such thing as a medical artist , physicians calling them- selves such injure medical science, because they exalt a physician's personality by lowering the importance of science, thus they prevent men from seeking, m the experimental study of phenomena, the support and criterion which they believe they, through inspiration or mere feeling, have within themselves But as I just said, this supposed therapeutic inspiration is often supported by no other proofs than some chance fact which might favor an untaught man or a charlatan, just as much as an educated man This bears no sort of relation to the artist's inspiration which is embodied at last m a work judged by all the world, and always requiring, for its execu- tion, exact study often accompanied by unwearied labor In my opinion, then, the inspiration of physicians, who do not rely on experimental science, is mere fantasy, and m the name of science and humanity they should be rebuked and proscribed

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To sum up, experimental medicine, which is a synonym for scien- tific medicine, can be established only by spreading the scientific spirit more and more among physicians In my opinion, the one thing to do, to reach this goal, is to give our young men solid instruc- tion m experimental physiology I do not mean to say that physiol- ogy is the whole of medicine, I have explained myself elsewhere on this point, but I do mean to say that experimental physiology is the most scientific part of medicine, and that in studying it, young physicians will acquire scientific habits which they will later carry into pathological and therapeutic investigation The wish that I am expressing here roughly corresponds to Laplace's idea when he was asked why, since medicine was not a science, he had proposed admit- ting physicians to the Academy of Sciences, he answered "This is why to get them among men of science "

III EmpiFwICal and Experimental Medicine Are by No Means Incompatible, on the Contrast, They Must Be Inseparable.

Bor a long time, men have said and repeated that the physicians most learned in physiology are the worst physicians, and that they axe the most awkward when action is necessary at the patient's bed- side Does this mean that physiological science is harmful to prac- tice2 In that case, I must have taken a completely false point of view We must therefore carefully study this opinion, which is a favorite theme of many practising physicians, but which I, for my part, consider completely erroneous

To begin with, we must remember that the practice of medicine is exceedmgly complex, involving any number of social and extra- scientific questions Even m practical veterinary medicine, thera- peutics is often dominated by considerations of profit or of agricul- ture I recall my membership in a commission studying what was to be done to prevent the ravages of certain murrains of homed cattle We were all

weighing physiological and pathological considerations, to decide on the proper treatment to cure the sick animals, when a practismg veterinarian took the floor to say that this was not the question, and he proved clearly that curative treatment would be the rum of agriculture, and that the best thing to do was to slaughter the sick animals and turn them to the best possible account Con- siderations of this kind never enter into human medicine, because

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preserving human life is the physician’s sole aim Yet physicians, m their treatment, often have to take account of the so-called influ- ence of the moral over the physical, and also of any number of family and social considerations ■which have nothing to do with science Therefore, an accomplished practising physician should be not only learned m his science, but also upright and endowed with keenness, tact and good sense Practising physicians exert an influence m every rank of society In numberless cases, physicians are the custo- dians of state interests in major affairs of public administration , at the same time they are the confidants of families and often hold reputation and most cherished interests m their hands Able prac- titioners can acquire great and legitimate influence among men, be- cause apart from science, they have a moral influence on society And so, like Hippocrates, everyone having the dignity of medicine at heart has always insisted strongly on moral qualities m physicians

I have no intention of discussing here the social and moral in- fluence of physicians nor of penetrating what might be called the mysteries of medical practice, I am simply treating the scientific side and am separating it so as to judge its influence better I certainly do not here intend to study the question whether an edu- cated physician would treat his patients better or worse than an uneducated one Put in that form, the question would be absurd, I naturally assume two physicians equally well

educated m methods of treatment, and I intend to consider here only whether the scientific physician, 1 e , the physician endowed with the experimental spirit, will treat his patient less successfully than the empirical physician who contents himself with noting facts solely on the basis of medical tradition, or the systematic physician who acts according to the prin- ciples of some doctrine or other

In medicine, there have always been two divergent tendencies resulting from the very nature of things The first tendency m medi- cine, arising from the kindly feelings of man, is to help a neighbor in trouble, and to relieve him with remedies or by moral or religious means Medicine must therefore have been mingled with religion, from its beginning, while possessing at the same time numberless more or less active agents Found by chance or of necessity, these remedies were later handed down by tradition, either alone or to- gether with religious practices But after this first flight, which started, so to speak, from the heart, men must have begun to reflect,

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and seeing the sick recover of themselves and without medicine, they were inclined to ask, not only whether the medicmes given were useful, but whether they were not harmful The first medical reflec- tion, or first medical reasoning, resulting from study of the sick, made men recognize a spontaneous, medicinal force in the living organism , and observation taught them to respect it and try merely to guide and help it m its fortunate tendencies The first steps in scientific medicine taken by Hippocrates mvolved a doubt about the curative results of empirical methods and the appeal to the laws of living or- ganisms to effect the cure of the sick But this kind of medicine, founded as science on observation, and as treatment on expectancy, still allows other doubts to subsist While recognizing how direful for the patient it may be to use empirical medicaments to disturb the tendencies of nature when they are

favorable, men must have asked themselves, on the other hand, whether it might not be possible, and useful to the patient, to disturb and change them when they were bad. It was therefore no longer merely a case of physicians guiding and helping nature in its fortunate tendencies, Quo vergit natura, eo ducendum J but also of combating and dominating nature m its evil tendencies, medtcus naturae superator The heroic reme- dies, the universal panaceas, the specifics of Paracelsus and others, are merely the empirical expression of a reaction against Hip- pocratic medicine, 1 e , against expectancy

By its very nature, experimental medicine has no system and rejects nothing in the way of treatment or cure of disease, it believes and accepts everything that is founded on observation and proved by experience Though we have repeated it often already, we must here recall the fact that experimental medicine, as it is called, is certainly not a new theory of medicine It is one with the medicme of all people and times, in all its solid gams and sound observations Scientific, experimental medicine goes as far as possible in the study of vital phenomena, it cannot limit itself to observing diseases or content itself with expectancy or stop at remedies empirically given, but in addition it must studj experimentally the mechanism of diseases and the action of remedies, so as to account for them scientifically Above all, the analytic spirit of the experimental method m modem science must be brought into medicine, but this will not absolve experimental physicians from beinS observers, they must be thoroughly educated in clinics,

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must know diseases accurately m all their normal, abnormal and insidious forms, be familiar with every method of pathological in- vestigation, and be good, as we say, m diagnosis and prognosis Be sides this, they must be consummate therapeutists and know every- thing that empirical or systematic attempts have taught us about the

action of remedies in different diseases. In a word, experimental physicians, like all educated physicians, must have every kind of knowledge that we have^ just enumerated , but they will differ from systematic physicians in not conducting themselves according to any system , but, instead of taking as their goal observation of dis- ease and notation of the action of remedies, they will be distinguished from Hippocratic and empirical physicians by their will to go fui- ther and, with the help of experimentation, enter into the explanation of vital mechanisms For their part, Hippocratic physicians are satisfied when they succeed m clearly describing a disease m its course, m learning and foreseeing its various favorable or direful endings by exact signs, so as to be able to intervene, if necessary, to help nature and to guide it toward a happy ending , scientific medi- cine, they believe, should set itself this goal Empirical physicians are satisfied when, with the help of empiricism, they succeed m knowing that a given remedy cures a given disease, m learning the exact doses m which to administer it, and the cases in which it must be used , they may also believe they have reached the limits of medi- cal science. But while experimenting physicians are the first to admit and understand the scientific and practical importance of the preceding ideas, without which medicine could not exist, they do not believe that medicine as a science should stop at observation and empirical knowledge of phenomena or be satisfied with somewhat vague systems So that Hippocratic, empirical and experimenting physicians do not differ m the least m the nature of their knowl- edge, they differ only m the mental point of view which leads them to carry the medical problem somewhat further. The mediating power of nature invoked by Hippocratists, and the therapeutic or other force assumed by empiricists are simple hypotheses m the eyes of experimenting physicians With the help of experimentation, they must penetrate into the inmost phenomena of living machines and define their mechanism m its normal as well as its pathological state We must investigate the immediate causes of normal phe- nomena, which should be found m definite organic conditions m

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relation to the properties of fluids and tissues It is not enough to know the phenomena of mineral nature empirically as well as their results , hut physicists and chemists mean to go hack to their neces- sary conditions, 1 e , to their immediate causes, so as to he able to regulate their manifestation In the same way, it is not enough for physiologists to know empirically the normal and abnormal phe- nomena of living nature, hut like physicists and chemists, they mean to go back to the immediate causes of phenomena, 1 e , to their neces- sary conditions In a word, it is not enough for experimenting phy- sicians to know that quinine cures fever , hut what is above all signifi- cant to them is knowing what fever is and accounting for the mechanism by which quinine cures All this is significant to ex- perimenting physicians because, as soon as they know it, the fact of curmg fever with quinine will no longer he an empirical, isolated fact, hut a scientific fact This fact will then connect itself with conditions which will relate it to other phenomena, and we shall thus he led to knowledge of the laws of organisms and the possibility of regulating their manifestations Experimental physicians are there- fore concerned most of all with seeking to establish medical science on the same principles as all the other experimental sciences Let us now see how a man animated with thiB scientific spirit should behave at a patient’s bedside

HippocratiBts, believing in a mediatmg nature, and but little m the curative effect of drugs, quietly follow the course of a disease, m almost passive expectancy, they limit themselves to encouraging the fortunate tendencies of nature with a few simple medicmes Empiricists, with their faith m the efficacy of drugs as a means of changing the direction of diseases and curing them, content them- selves with empirically noting medicinal effects, without trying to understand their mechanism scientifically They are never per- plexed when one remedy fails, they try another, they always have receipts or formulas at hand for any and every case, because they

draw on an immense therapeutic arsenal Empirical medicine is certainly the most popular People believe that through a kind of compensation nature provides a remedy for every ill, and that medicine consists m a collection of recipes for all ills, handed down to us, age by age, since the beginnings of the healing art Experimenting physicians are Hippocratists and empiricists at one and the same time, m that they believe in the power of nature and the effi-

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cacy of drugs, only they want to know what they are doing, it is not enough for them to observe and to act empirically, they want to experiment scientifically and to understand the physiological mech- anism producing disease and the medicinal mechanism effecting a cure If this were their exclusive mental tendency, it is true that experimenting physicians would be as much, as empirical physicians are little, perplexed Indeed m the present state of medicine, we know so little about the action of drugs that, if experimenting phy- sicians were logical, they would be reduced to doing nothing and to remaining most of the time m the state of expectancy enjoined by their doubts and uncertainties In this sense it is possible to say that scientific physicians are always the most perplexed at a patient’s bedside That is thoroughly true, they are really per- plexed, because, on the one hand, they are convinced that we can take action with the help of powerful medicinal means, while, on the other hand, their ignorance of the mechanism of such action holds them back, for the experimental scientific spirit is utterly averse to producing effects and studying phenomena without trying to under- stand them

There is evidently an excess of these two radical turns of mind among empiricists and among experimenters, m practice the two points of view should be fused, and the seeming contradiction be- tween them should disappear. What I am saying here is by no means a kind of compromise or arrangement for convenience m medi- cal

practice I am maintaining a purely scientific opinion, because I can easily prove that the true experimental method consists m a logical union of empiricism and experimentation In fact, we have seen that, belore foreseeing facts according to the laws which gov- ern them, we must first observe them empirically or by chance, just as before experimenting along the lines of a scientific theory, we must first experiment empirically, m order to see Now, m this respect, empiricism is nothing but the first step of the experimental method, for, as we said, empiricism cannot be a final stage, the vague, unconscious experience, which may be called medical tact, is later transformed into a scientific idea, by the experimental method which is conscious and logical Experimental physicians, there- fore, are empirical to begin with, but instead of stopping at that, they try to pass through empiricism so as to reach the second step m the experimental method, 1 e , exact and conscious experiment

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which gives experimental knowledge of the law of phenomena In a word, we must suffer empiricism, but trying to set it up as a system is an antiscientific tendency As for systematic and doc- trinal physicians, they are empiricists who, instead of having recourse to experimentation, take pure hypotheses, or else the facts taught them by empiricism, and 30m them together with the help of an ideal system, from which they later deduce their line of medical conduct.

Consequently, I think that experimenting physicians who wish to use, at the patient’s bedside, only medicmes whose physiological effect they understand would exaggerate m a direction that made them distort the true meamng of the experimental method Before understanding facts, experimenters must first note them and free them from every source of error with which their minds be tainted Experimenters must therefore first apply their minds to collecting medical or

therapeutic observations empirically made But they do still more, they are not limited to subjecting to the experimental criterion all the empirical facts that medicine presents to them , they go out to meet them Instead of waiting for chance or accidents to teach them the effects of medicmes, they try them empirically on animals, to get indications to guide them m the experiments that they afterward make on man

I consider then that true experimenting physicians should be no more perplexed at a patient’s bedside than empirical physicians They will make use of all the therapeutic means advised by empiri- cism, only instead of using them according to authority and with a confidence akm to superstition, they will administer them with that philosophic doubt which is appropriate to true experimenters, they will verify the results on animals, and by comparative observations on man, so as to determine rigorously the relative influence of nature and of medicine m curing disease In case it is proved that the remedy does not cure, and all the more so if it is shown to be harmful, experimenters should renounce it, and, like the Hippocrat- ists, should await events Certain practising physicians, fanatically convinced of the excellence of their medications, cannot understand the experimental therapeutic criticism of which I have just spoken They say we can give sick people only medicmes in which we ave faith, and they think administering to our neighbors a remedy, which we doubt, is a failure of medical morals. I do

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not accept this reasoning, for it would lead U3 both to deceive ourselves and to deceive others without scruple As for myself, I think it better to try to enlighten ourselves, so as to deceive no one

Experimenting physicians should, therefore, not be mere physiol- ogists waiting with folded arms for experimental medicine to be established scientifically, before

taking action m behalf of their patients Far from it, they should use the remedies that are empir- ically known, not only on equal terms with empiricists, but should go even further and try new medicines according to the rules sug- gested above Experimental physicians, then, like empiricists, should be able to aid the sick by every means m the possession of practical medicine What is more, with the help of the scientific spirit that guides them, they will do their part m founding experimental medi- cine, and that should be the most ardent wish of all physicians who want to see medicine rise out of its present state We must suffer empiricism, as we said, as a transient and imperfect stage of medi- cine, but must not set it up as a system In our faculties of medicine, we must therefore not limit ourselves, as men have actually said, to making empirical healers, that would degrade medicine and reduce it to the level of business First of all, we must inspire young men with the scientific spirit and initiate them into the ideas and tenden- cies of modem science Doing anything else would be inconsistent, besides, with the great variety of knowledge demanded of doctors, solely to enable them to cultivate medical science, for much narrower knowledge is demanded of health officers who are concerned only with empirical practice

But the objection may be raised that experimental medicine, about which I am talking at such length, is a theoretic conception whose reality has not yet been vindicated m practice , because facts have not demonstrated that we may expect the same scientific pre- cision m medicine as m the experimental sciences. As far as pos- sible, I wish to leave no doubt m the reader’s mind and no am- biguity m my own thought, I am therefore going to return to -this subject with a few words, m order to show that experimental medi- cine is only the natural blossom of practical medical investigation, guided by a scientific spirit

I said above that compassion and blind empiricism are the prime movers of medicine, later came reflection bringing doubt, then scien-

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tific verification This medical evolution can still be verified around

us every day, for every man goes on learning, as does all human- kind

Expectancy, whatever help it may give the tendencies of nature, can be only an incomplete method of treatment Moreover, we muBt often act against the tendencies of nature If, for example, an artery is open, we clearly must not favor nature which makes the blood come out and leads to death We must act m the opposite direction, stop the hemorrhage and save a life Just so, when a patient has an attack of septicemia, we must act against nature and stop the fever if we mean to cure our patient Empiricists, then, may save patients whom expectancy would leave to die, just as ex- pectancy might permit the recovery of a patient whom empiricism would kill So that empiricism is also an insufficient method of treatment, m that it is uncertain and often dangerous Now experi- mental medicine is only a union of expectancy with empiricism, enlightened by reasoning and experimentation But experimental medicine will be the last to establish itself, and only then can medi- cine become scientific. We shall see, in fact, that all parts of medi- cal knowledge are interrelated and are necessarily subordinate one to another in their evolution

When a physician is called to a patient, he should decide on the diagnosis, then the prognosis, and then the treatment of the disease The diagnosis can be established only through observation , m recog- nizing a disease, physicians connect it with some form of disease already observed, known and described Observation also gives the progress and prognosis of the disease , physicians must know the evo- lution of the disease, its duration and gravity in order to predict its course and outcome. Here statistics intervene to guide phy- sicians, by teaching them the proportion of mortal cases, and if observation has also shown that the successful and unsuccessful cases

can be recognized by certain signs, then the prognosis is more certain Finally comes the treatment when physicians are Hip- pocratists, they limit themselves to

expectancy , when they are

empiricists they give remedies, still basing their action on observa- tion which has taught by experiments or otherwise that such and such a remedy has succeeded in this disease a certain number of

times, when physicians are systematic, they may accompany their treatment with vitalistic or other explanations, that will make no

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difference m the result Here again, only statistics are invoked to establish the value of the treatment.

Such, m fact, is the state of empirical medicine, which is con- jectural medicine because it is based on statistics which collect and compare cases that are analogous or more or less similar m their outer characteristics, hut undefined as to their immediate causes

Conjectural medicine must necessarily precede exact medicine, which I call experimental medicine because it is based on the experi- mental determination of the cause of disease In the meantime, we must resign ourselves to practising conjectural or empirical medi- cine, but, I repeat, though I have often said it before, we must recognize that medicine should not stop there, and that it is des- tined to become experimental and scientific We are doubtless far from the time when all medicine will be scientific, but that need not prevent our conceiving it possible and making every effort to strive toward it, by trying even to-day to introduce into medicine the method that must lead us to that goal

Medicine will necessarily first become experimental m the dis- eases most easy of experimental approach Among these, let me choose an example to show my idea of how empirical medicine can become scientific The itch is a disease whose causation is now pretty well defined scientifically, but this has not always been the case

Formerly we knew the itch and its treatment only empirically Then we guessed about lesions m the itch and collected statistics on the value of one salve or another for curing the disease Now that the cause of the itch is known and experimentally determined, it has all become scientific, and empiricism has disappeared We know the tick, and by it we explain the transmission of the itch, the skin changes and the cure, which is only the tick's death through appro- priate application of toxic agents No further hypotheses need now be made about the metastasis of the itch, no further statistics collected about its treatment We cure it always without any exception, when we place ourselves m the known experimental conditions for reaching this goal 2

Here, then, is a disease that has reached the experimental stage, and physicians are masters of it just as much as physicists and cbem-

* Hardy, Bulletin de VAcadimxe de mideane Paris, 1803 04, Vol XXIX, p 546

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ists are masters of a phenomenon, of mineral nature Experimenting physicians -will exeit their influence successively on diseases one by one, as soon as they experimentally learn their correct determinism, 1 e , their immediate cause Even the best informed empirical phy- sicians lack the experimenter's sureness One of the clearest eases of empirical treatment is curing fever with quinine , yet this cure is far from being as certain as curing the itch Diseases that have their seat m the outer organic environment, such as epidemic diseases, are the easiest to study and to analyze experimentally These diseases will more quickly reach the stage where their causation is known and their treatment scientific But later, in proportion as physiol- ogy progresses, we shall be able to get at the inner environment, 1 e , the blood, discover there the parasitic and other changes that cause diseases and determine the medicinal, physico-chemical or specific agents capable of acting in this inner

environment, altering the pathological mechanisms located there and reechoing thence through- out the whole organism

My conception of experimental medicine is summed up above As I have often repeated, it is nothing but the consequence of the wholly natural evolution of scientific medicine In this respect, medicine does not differ from other sciences which have all passed through empiricism before reaching their final experimental stage In chemistry and m physics, practical methods of extracting metals, making magnifying glasses, etc , were known before the scientific theory evolved

Empiricism, then, also guided these sciences through their nebu- lous days, but only since the advent of experimental theories have physics and chemistry taken such brilliant flights as applied sci- ences, for we must be careful to avoid confusing empiricism with applied science Applied science always implies pure science as its support Medicine will doubtless pass through empiricism much more slowly and laboriously than the physico-chemical sciences, not only because the organic phenomena with which it is concerned are much more complex, but also because the requirements of medical practice, which I need not study here, help to keep medicine m the personal realm, and thus oppose the experimental development I need not here return to what I have elsewhere so amply explained, to wit, that the spontaneity of living beings does not prevent the application of the experimental method, and that knowledge of the

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simple or complex causation of vital phenomena is the one foundation of scientific medicine

The object of experimenting physicians is to discover and grasp the original causation of a series of obscure and complex morbid phe- nomena, as a result they will dominate all secondary phenomena, thus we have seen that, on mastering the

tick which causes the itch, we naturally master all the derived phenomena. By learning the ultimate cause of poisoning with curare, we easily explain all secondary phenomena, and to find a cure, we must always go back, m the end, to the original causation of phenomena

Medicine is destined, then, to get away from empiricism little by little, like all other sciences, it will get away by the scientific method This deep conviction sustains and guides my scientific life I am deaf to the physicians who ask us to explain measles and scarlet fever experimentally, and who believe they can find m them an argument against using the experimental method These discouraging, negative objections generally come from systematic or lazy mmds that prefer resting on their systems or sleeping in the dark, to working and making an effort to get away. The different branches of physico-chemical science were elucidated only gradually, step by step, by the experimental method, and they still have to- day obscure parts which we are studying with the help of the same method In spite of all the obstacles that it meets, medicine will follow the same course, it will follow it necessarily In extolling the introduction of the experimental method into medicine, I am therefore only trying to guide men’s minds toward a goal that science is instinctively and unconsciously pursuing, — a goal that it will more quickly and certainly reach if it can succeed m seeing it clearly Time will then do the rest Of course, we shall not see scientific medicine blossoming m our day, but that is man’s lot, those who sow and laboriously cultivate the field of science are not also destined to rpap the harvest

To sum up, experimental medicine, as we conceive it, includes the problem of medicine as a whole and compnses both the theory and the practice of medicine But when I said that every physician should be an experimenter, I did not mean to suggest that each one should cultivate the whole extent of experimental medicine Of necessity, there will always be physicians especially devoting them- selves to physiological experiments, others to investigation of normal

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and pathological anatomy, others to surgical or medical practice, etc. This splitting up is not had for the progress of science , on the con- trary, practical specialties are an excellent thing for science, prop- erly speaking, hut on the condition that men devoting themselves to the investigation of a special part of medicine be so educated as to be conversant with experimental medicine as a whole, and to know the place which the special science they cultivate should occupy in that whole. By specializing in this way, they will direct their studies so as to contribute to the progress of scientific or experimental medi- cine Practical studies and theoretic studies will thus work toward the same object, that is all that we can ask in a science, like medi- cine, which is forced to be ceaselessly in action before it is fully established.

Experimental or scientific medicine is tending on every side to establish itself on the basis of physiology The tendency of studies published every day, whether m France or abroad, furnishes unmistakable proof In my research and teaching at the College de France, I unfold every idea that can help or encourage this tendency m medicme I consider this my duty as a man of science and pro- fessor of medicine at the College de France In fact, the College de France is by no means a medical faculty m which every part of medi- cine should he treated systematically By the very nature of its establishment, the College de France should always be in the fore- front of science, embodying its movement and its tendencies Consequently the course in medicine with which I am entrusted must embody the part of medical science which is by way of the greatest present development, and which involves the rest in its evolution I have already explained myself at length on the proper character of the course m medicine at the College de France, I shall not return to that 3 Let me simply say that, while I acknowledge that the experi- mental trend of science must be slow to establish itself because of difficulties inherent m the complexity of medicme, we

must recog- nize that it is now a definite trend In fact, this has not been brought about by the ephemeral influence of some personal system or other, it results from the scientific evolution of medicme itself My convictions, m this respect, are what I am seeking to impress on the

• Claude Bernard, Lesona de phytnologie exp6nmentale appUquie d la mMenne au College de France) FirBt lesson, PariB, 1857 Court de ntdemne au Collige de France First lesson, Pans, 1855

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minds of the young physicians attending my courses at the College de France I try to show them that they are all called to contribute their share to the increase and development of experimental or scien- tific medicine For that reason I ask them to familiarize them- selves with the modem methods of investigation put in use in anatom- ical, physiological, pathological and therapeutic science, because these various branches of medicine must always remain inseparably united in theory and m practice. I tell those whose path leads them toward theory or toward pure science, never to lose sight of the medi- cal problem, which is to preserve health and cure disease. I tell those whose career, on the contrary, guides them toward practice, never to forget that if theory is meant to enlighten practice, prac- tice m turn should be of use to science Physicians thoroughly im- bued with these ideas will always keep their interest m the progress of science, at the same time that they do their duty as practitioners In noting accurately and acutely the interesting cases that present themselves, they will understand how fully science may profit by them Experimental scientific medicine will thus become the achievement of us all, and every one of us, even if he be only a simple country doctor, will make his own useful contribution.

Returning now to the title of this long section, I conclude that empirical medicine and experimental medicine are far from being incompatible, but on the contrary

must be intimately united, for both are indispensable m building up experimental medicine. I think that this conclusion is well established by all that has gone before

IV Experimental Medicine Does Not Correspond to Any Medical Doctrine or Any Philosophic System

We said that experimental medicine is not a new system of medi- cine, but on the contrary is the negation of all systems In fact, tbo advent of experimental medicine will cause all individual views to disappear from the science, to be replaced by impersonal and general theories which, as m other sciences, will be only a regular and logical coordination of facts furnished by experience

Scientific medicine is certainly not yet well established to-day; but thanks to the experimental method which is permeating it more and more, it is tending to become an exact science. Medicine is m

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transition, the day of personal doctrines and systems is past, and little by little they ’will be replaced by theories embodying the present state of the science and showing from that point of view the results of all our efforts But that must not make us believe that theories are ever absolute truths , they may always be improved, and so are always mobile That is why I have been careful to say that we must not, as men often do, confuse advancing and perfectible pro- gressive theories, which may be improved, with scientific methods and principles that are fixed and unshakable We must remember that the one unchangeable scientific principle, m medicine as well as in the other experimental sciences, is the absolute determinism of phenomena We gave the name of determinism to the immediate or determining cause of phenomena We never act on the essence of natural phenomena, but only on their determining causes, and be- cause we act thus, determinism differs from fatalism, on which we cannot act Fatalism assumes that the manifestation of any phe- nomenon is

necessary and independent of its conditions, while de- terminism is the condition necessary to a phenomenon, whose mani- festation is free When search for the causes determining phenom- ena is once posited as the fundamental principle of the experimental method, materialism, spiritualism, inert mattei and living matter cease to exist, only phenomena are left, whose conditions we must determine, 1 e , the conditions which play the part of immediate cause. Scientific determinism ceases here, there are only words beyond, which are of course necessary, but which may delude us if we are not constantly on guard against the traps which our minds perpetually set for themselves

As experimental medicine, like all the experimental sciences, should not go beyond phenomena, it does not need to be tied to any system, it is neither vitalistic, nor animistic, nor organistic, nor solidistic, nor humoral , it is simply the science which tries to reach the immediate causes of vital phenomena m the healthy and in the morbid state It has no reason, m fact, to encumber itself with systems, none of which can ever embody the truth

In this connection it may be useful to recall, m a few words, the essential characteristics of the scientific method and to show how the ideas derived from it differ from systematic and doctrinal ideas In the experimental method we never make experiments except to see or to prove, 1 e , to control or verify As a scientific method, the

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experimental method rests wholly on the experimental verification of a scientific hypothesis We obtain this verification with the help, sometimes of a fresh observation (observational science), sometimes of an experiment (experimental science) In) the experimental method, the hypothesis is a scientific idea that we submit to experi- ment Scientific invention consists in the creation of fortunate and

fertile hypotheses, these are suggested by the feeling or even the genius of the men of science who create them

When an hypothesis is submitted to the experimental method, it becomes a theory, while if it is submitted to logic alone, it becomes a system A system, then, is an hypothesis with which we have connected the facts logically with the help of reason, but without ex- perimental, critical verification A theory is a verified hypothesis, after it has been submitted to the control of reason and experimental criticism The soundest theory is one that has been verified by the greatest number of facts But to remain valid, a theory must be continually altered to keep pace with the progress of science and must be constantly resubmitted to verification and criticism as new facts appear

If we consider a theory perfect and stop verifying it by daily scientific experience, it becomes a doctrine A doctrine, then, is a theoiy which we regard as immutable, which we take as a starting point for later deduction, and which we believe we are no longer obliged to submit to experimental verification

In a word, systems and doctrines m medicine are hypothetical or theoretic ideas transformed into immutable principles This sort of method belongs essentially to scholasticism and differs radically from the experimental method These two methods of the mind, indeed, are contradictory Systems and doctrines proceed by affirma- tion and purely logical deduction , the experimental method always proceeds by doubt and experimental verification Systems and doc- trines are individual , they are meant to be immutable and to preserve their personal aspect The experimental method, on the other hand, is impersonal, it destroys individuality by uniting and sacrificing everyone’s particular ideas, and turning them to the advantage of uni- versal truth as established with the help of the experimental cri- terion It advances slowly and laboriously and m this respect will always be less pleasing to the mind Systems, on the contrary, are alluring because they give us a

science absolutely regulated by logic

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alone, and that frees us from studying and makes medicine easy Experimental medicine, then, is anti-systematic and anti-doctrinal by nature, or rather it is free and independent m its essence and does not try to attach itself to any kmd of medical system

What I have just been saymg about medical systems, I can apply to philosophic systems Experimental medicine (like all experi- mental sciences, for that matter) does not need to be attached to any philosophic system A physiologist's role, like every scientific man's, is to seek truth for its own sake, without wishing to use it to con- trol one system of philosophy or another When a man of science takes a philosophic system as his base m pursuing a scientific in- vestigation, be goes astray in regions that are too far from reality, or else the system gives his mind a sort of fake confidence and an inflexibility out of harmony with the freedom and suppleness that experimenters should always maintain m their researches We must therefore carefully avoid every species of system, because systems are not found in nature, but only m the mind of man Positivism, like the philosophic systems which it rejects m the name of science, has the fault of being a system Now, to find truth, men of science need only stand face to face with nature, and m following experimental medicine, question her with the help of more and more perfect means of investigation In this case, I think that the best philosophic system consists m not having any

As an experimenter, then, I avoid philosophic systems, but I cannot for that reason reject the philosophic spirit which, without being anywhere, is everywhere and, without belonging to any system, ought to reign, not only over all science but over all human knowl- edge So even while avoiding philosophic systems, I like

philosophers and greatly enjoy their converse Indeed, from the scientific point of view, philosophy embodies the eternal aspiration of human rea- son toward knowledge of the unknown Therefore philosophers always live in controversial questions and m lofty regions, the upper boundaries of science Hence they impart to scientific thought an enlivening and ennobling motion , they develop and fortify the mind by general intellectual exercise, while ceaselessly bearing it toward the inexhaustible solution of great problems, thus they nourish a kmd of thirst for the unknown, the sacred fire of research must therefore never be extinguished m men of science

Ardent desire for knowledge, m fact, is the one motive attracting

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and supporting investigators in their efforts, and just this knowl- edge, really grasped and yet always flying before them, becomes at once their sole torment and sole happiness Those who do not know the torment of the unknown cannot have the joy of discovery which is certainly the liveliest that the mind of man can ever feel But by a whim of our nature, the joy of discovery, so sought and hoped for, vanishes as soon as found It is but a flash whose gleam dis- covers for us fresh horizons, toward which our insatiate curiosity repairs with still more ardor Thus, even m science itself, the known loses its attraction, while the unknown is always full of charm Therefore the minds that rise and become really great are never self-satisfied, but still continue to strive The feeling, about which I am speaking now, is familiar to men of science and to philosophers This is the feeling that made Priestley 4 say that each discovery we make shows us many others that should be made , this is the feeling which Pascal expressed m somewhat paradoxical form, when he said “We are m search never of things, but of the search for things ” Yet truth itself is surely what concerns us and, if we are still m search of it, that is because the part which we

have so far found . cannot satisfy us In our investigations, we should else be per- forming the useless and endless labor pictured m the fable of Sisy- phus, ever rolling up the rock which continually falls back to its starting point This comparison is not scientifically correct a man of science rises ever, m seeking truth , and if he never finds it m its wholeness, he discovers nevertheless very significant fragments, and these fragments of universal truth are precisely what constitute science.

Men of science, then, do not seek for the pleasure of seeking, they seek the truth to possess it, and they possess it already within the limits expressed in the present state of the sciences But men of science must not halt on the road , they must climb ever higher and strive toward perfection , they must always seek, as long as they see anything to be found Without constant stimulation by the spur of the unknown, without constantly recurring thirst, it might be feared that men of science would become system-ridden m their acquirements and their knowledge Then science would hnlt through intellectual inertness, just as minerals, m saturated solution,

* Priestley, Experiments and Obsermtions on Different Kinds of Air Intro duction, p 15

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become chemically inert and crystallize We must therefore preven- our minds from becoming too much absorbed m the known parts of any particular science or dragging themselves along the ground and losing sight of questions still to be solved By ceaselessly stir- ring the inexhaustible mass of unsolved questions, philosophy stimu- lates and maintains this healthful movement m science For only the indeterminate belongs to philosophy, m the restricted sense m which I am here considering it, while the determinate necessarily falls into the realm of science I can no more accept a philosophy, then, which tries to assign boundaries to science, than a science which claims to suppress philosophic truths that are at present outside its

own domain True science suppresses nothing, but goes on searching, and is undisturbed in looking straight at things that it does not yet understand If we denied these facts, we should not suppress them , we should only be shutting our ejes and believing there was no light, we should be sharing the delusion of the ostrich which believes it banishes danger by hiding its head m the sand In my opinion the true scientific spirit is that whose high aspirations fertilize the sciences and draw them on m search of truths which are still be- yond them, but which must not be suppressed, because they have been attacked by stronger and more delicate philosophic minds Has this aspiration of the human spirit any end, — will it find its limit ? That, I cannot know , but meantime, as I said above, men of science can do no better than to push steadily forward, because they can always go forward

One of the greatest obstacles to the free and universal movement of human knowledge is the tendency that leads different kinds of Knowledge to separate into systems This is not a consequence of things in themselves, because everything m nature is connected with everything else and nothing should be viewed in the isolation of a system, but the feeble yet dominating tendency of our minds leads us to absorb other kinds of knowledge into our personal systems A science that halted m a system would remain stationary and would he isolated, because systematization is really a scientific encysting, and every encysted part of an organism ceases to take part m the organism’s general life Systems therefore strive to enslave the human mind, and, in my opinion, their only ascertainable use is to promote conflicts which destroy them, by stirring and stimulating the vitality of science We must try, indeed, to break the fetters of

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philosophic and scientific systems, as we would break the chains of intellectual slavery Truth, if we can find it, belongs to every system, and to discover it,

experimenters need free movement on every side, without feeling themselves stopped by the barriers of any system. Philosophy and science, then, must never be systematic without trying to dominate one another, they must unite Their separation could only be harmful to the progress of human knowledge Striving ever upward, philosophy makes science rise toward the cause or the source of things It shows science that there are questions beyond it, torturing humanity, which it has not yet solved Solid union between science and philosophy is useful to both it lifts the one and confines the other But if the bonds uniting philosophy to science should break, philosophy, lacking the support or the counter- poise of science would rise out of sight and be lost m the clouds, while science, without guidance and without high aspiration, would sail at random.

But if philosophy, instead of contenting itself with this fraternal union, tried to enter the household of science and dogmatically lord its productions and its methods of manifestation, then their under- standing would cease Claiming to absorb the special discoveries of a science into any philosophic system would, m fact, be a delusion. For making scientific observations, experiments and discoveries, phil- osophic method and procedure are vague and powerless; the only means available for that are scientific methods and procedures that can be known only by experimenters, men of science or philosophers, practising some definite science. The different kinds of human knowledge are so entangled and so interdependent m their evolution, that we cannot possibly believe that any individual influence can advance them unless the elements of progress are present m tho scientific soil itself While recognizing the superiority of great men, I therefore still think that, even m their special or general in- fluence on science, they are always necessarily more or less a function of their time It is the same with philosophers they can only follow the movement of the human mind, and they contribute to its advance, only by opening the path of progress wider But m that, they are an expression of their time No philosopher, coming at a moment when science takes a fertile turn, should create a system, then,

m harmony with the movement of science, and afterward cry out that all the scientific progress of his day is due to the influence of his

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system In a word, if men of science are useful to philosophers, and philosophers to men of science, men of science remain free, none the less, and masters m their own house, as for myself, I think that men of science achieve their discoveries, their theories and their science apart from philosophers If we meet with incredulity with regard to this, we can perhaps easily prove that, as J de Maistre says, those who make the most discoveries m science know Bacon E least, while those who read and ponder him, like Bacon himself, have poor success For scientific methods and processes are learned, in fact, only m laboratories, where experimenters grapple with the problems of nature , the young must be guided thither first of all , men of riper age have as their portion erudition and scientific criti- cism which can bear fruit only when we have begun our initiation into science in its true sanctuary, the laboratory Processes of reasonmg should endlessly vary for experimenters, according to the different sciences and to the more or less difficult questions to which they apply them Only scientific men, and indeed scientific men specializing in each science, can take up such questions, because a naturalist’s mind is not a physiologist’s mmd, any more than a chemist’s mmd is a physicist’s As for Bacon and the other more modem philosophers who try a general systematization of precepts for scientific research, they may Beem alluring to people who look at science only from a distance , but works like theirs are of no use to experienced scientists, and by false simplification of things, they mislead men who wish to devote themselves to cultivating sci- ence What is more, they embarrass them by burdening the mmd ■with vague and inapplicable precepts that we must hasten to forget if we wish to become true experimenters.

I have said that scientific men and experimenters can be edu- cated only m special laboratories of the sciences they wish to culti- vate and that precepts are useful only when derived from the details of experimental practice in some definite science In this Introduc- tion, I have tried to give as exact an idea as possible of physiological science and of experimental medicine However, I am far fom pre- suming to believe that I have given rules and precepts which experi- menters should follow rigorously and absolutely I have tried merely to study the nature of the problems to be solved m the experimental science of living bemgs, so that everyone might thoroughly under- J de Maistre Examen de la philosophie de Bacon, VoL I, p 81

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stand the scientific questions belonging to tbe domain of biology and know tbe means wbicb that science now bas to attack them. I have quoted examples of investigation, but have been very careful not to give needless explanations or to formulate a single or absolute rule, because I think a teacher’s role should be limited to clearly showing his pupil the goal that a science sets itself and to pointing out all possible means at his disposal for reaching it. But a teacher should then leave his pupil free to move about m his own way and, accord- ing to his own nature, to reach his goal, only coming to his aid if he sees that he is going astray. I believe, m a word, that the true scientific method confines the mind without suffocating it, leaves it as far as possible face to face with itself, and guides it, while re- specting the creative originality and the spontaneity which are its most precious qualities Science goes forward only through new ideas and through creative or original power of thought. In educa tion we must, therefore, take care that knowledge which should arm the mind does not overwhelm it by its weight, and that rules, in- tended to support weak parts of the mind, do not atrophy the strong and fertile parts I need not enter into further explanations here ,

I have had to limit myself by forewarning biological science and experimental medicine against exaggerating the importance of erudi- tion and against invasion and domination by systems, because sciences submitting to these would lose their fertility and would abandon the independence and freedom of mind essential to the prog- ress of humanity.

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