BIOLOGY AND ITS MAKERS

With Portraits and Other Illustrations

BY

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Cover Image: The Scheleton from VESALIUS
"Plate from Vesalius's De Fabrica"

To
MY GRADUATE STUDENTS
Who have worked by my side in the Laboratory
Inspired by the belief that those who seek shall find
This account of the findings of some of
The great men of biological science
Is dedicated by
THE AUTHOR

PREFACE

The writer is annually in receipt of letters from students, teachers, ministers, medical men, and others, asking for information on topics in general biology, and for references to the best reading on that subject. The increasing frequency of such inquiries, and the wide range of topics covered, have created the impression that an untechnical account of the rise and progress of biology would be of interest to a considerable audience. As might be surmised, the references most commonly asked for are those relating to different phases of the Evolution Theory; but the fact is usually overlooked by the inquirers that some knowledge of other features of biological research is essential even to an intelligent comprehension of that theory.

In this sketch I have attempted to bring under one view the broad features of biological progress, and to increase the human interest by writing the story around the lives of the great Leaders. The practical execution of the task resolved itself largely into the question of what to omit. The number of detailed researches upon which progress in biology rests made rigid selection necessary, and the difficulties of separating the essential from the less important, and of distinguishing between men of temporary notoriety and those of enduring fame, have given rise to no small perplexities.

The aim has been kept in mind to give a picture sufficiently diagrammatic not to confuse the general reader, and it is hoped that the omissions which have seemed necessary will, in a measure, be compensated for by the clearness of the picture. References to selected books and articles have

been given at the close of the volume, that will enable readers who wish fuller information to go to the best sources.

The book is divided into two sections. In the first are considered the sources of the ideas—except those of organic evolution—that dominate biology, and the steps by which they have been molded into a unified science. The Doctrine of Organic Evolution, on account of its importance, is reserved for special consideration in the second section. This is, of course, merely a division of convenience, since after its acceptance the doctrine of evolution has entered into all phases of biological progress.

The portraits with which the text is illustrated embrace those of nearly all the founders of biology. Some of the rarer ones are unfamiliar even to biologists, and have been discovered only after long search in the libraries of Europe and America.

An orderly account of the rise of biology can hardly fail to be of service to the class of inquirers mentioned in the opening paragraph. It is hoped that this sketch will also meet some of the needs of the increasing body of students who are doing practical work in biological laboratories. It is important that such students, in addition to the usual classroom instruction, should get a perspective view of the way in which biological science has come into its present form.

The chief purpose of the book will have been met if I have succeeded in indicating the sources of biological ideas and the main currents along which they have advanced, and if I have succeeded, furthermore, in making readers acquainted with those men of noble purpose whose work has created the epochs of biological history, and in showing that there has been continuity of development in biological thought.

Of biologists who may examine this work with a critical purpose, I beg that they will think of it merely as an outline

sketch which does not pretend to give a complete history of biological thought. The story has been developed almost entirely from the side of animal life; not that the botanical side has been underestimated, but that the story can be told from either side, and my first-hand acquaintance with botanical investigation is not sufficient to justify an attempt to estimate its particular achievements.

The writer is keenly aware of the many imperfections in the book. It is inevitable that biologists with interests in special fields will miss familiar names and the mention of special pieces of notable work, but I am drawn to think that such omissions will be viewed leniently, by the consideration that those best able to judge the shortcomings of this sketch will also best understand the difficulties involved.

The author wishes to acknowledge his indebtedness to several publishing houses and to individuals for permission to copy cuts and for assistance in obtaining portraits. He takes this opportunity to express his best thanks for these courtesies. The parties referred to are the director of the American Museum of Natural History; D. Appleton & Co.; P. Blakiston's Sons & Co.; The Macmillan Company; The Open Court Publishing Company; the editor of the *Popular Science Monthly*; Charles Scribner's Sons; Professors Bateson, of Cambridge, England; Conklin, of Philadelphia; Joubin, of Rennes, France; Nierstrasz, of Utrecht, Holland; Newcombe, of Ann Arbor, Michigan; Wheeler and E. B. Wilson, of New York City. The editor of the *Popular Science Monthly* has also given permission to reprint the substance of Chapters IV and X, which originally appeared in that publication.

W. A. L.

NORTHWESTERN UNIVERSITY,
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CONTENTS

PART I

The Sources of Biological Ideas Except Those of Organic Evolution

CHAPTER I

PAGE

CHAPTER IV

CHAPTER V

CHAPTER VI

CHAPTER XI

CHAPTER XIV

CHAPTER XV

PART II

The Doctrine of Organic Evolution

CHAPTER XVI

CHAPTER XVII

CHAPTER XVIII

CHAPTER XIX

PAGE

CHAPTER XX

ILLUSTRATIONS

PART I

THE SOURCES OF BIOLOGICAL IDEAS EXCEPT THOSE OF ORGANIC EVOLUTION

CHAPTER I

AN OUTLINE OF THE RISE OF BIOLOGY AND OF THE EPOCHS IN ITS HISTORY

"Truth is the Daughter of Time."

THE nineteenth century will be for all time memorable for the great extension of the knowledge of organic nature. It was then that the results of the earlier efforts of mankind to interpret the mysteries of nature began to be fruitful; observers of organic nature began to see more deeply into the province of life, and, above all, began to see how to direct their future studies. It was in that century that the use of the microscope made known the similarity in cellular construction of all organized beings; that the substance, protoplasm, began to be recognized as the physical basis of life and the seat of all vital activities; then, most contagious diseases were traced to microscopic organisms, and as a consequence, medicine and surgery were reformed; then the belief in the spontaneous origin of life under present conditions was given up; and it was in that century that the doctrine of organic evolution gained general acceptance. These and other advances less generally known created an atmosphere in which biology—the great life-science—grew rapidly.

In the same period also the remains of ancient life, long since extinct, and for countless ages embedded in the rocks, were brought to light, and their investigation assisted materially in understanding the living forms and in tracing their genealogy.

As a result of these advances, animal organization began to have a different meaning to the more discerning naturalists, those whose discoveries began to influence the trend of thought, and finally, the idea which had been so often previously expressed became a settled conviction, that all the higher forms of life are derived from simpler ones by a gradual process of modification.

Besides great progress in biology, the nineteenth century was remarkable for similar advances in physics and chemistry. Although these subjects purport to deal with inorganic or lifeless nature, they touch biology in an intimate way. The vital processes which take place in all animals and plants have been shown to be physico-chemical, and, as a consequence, one must go to both physics and chemistry in order to understand them. The study of organic chemistry in late years has greatly influenced biology; not only have living products been analyzed, but some of them have already been constructed in the chemical laboratory. The formation of living matter through chemical means is still far from the thought of most chemists, but very complex organic compounds, which were formerly known only as the result of the action of life, have been produced, and the possibilities of further advances in that direction are very alluring. It thus appears that the discoveries in various fields have worked together for a better comprehension of nature.

The Domain of Biology.—The history of the transformation of opinion in reference to living organisms is an interesting part of the story of intellectual development. The central subject that embraces it all is biology. This is one of the fundamental sciences, since it embraces all questions relating to life in its different phases and manifestations. Everything pertaining to the structure, the development, and the evolution of living organisms, as well as to their physiology, belongs to biology. It is now of commanding impor-

tance in the world of science, and it is coming more and more to be recognized that it occupies a field of compelling interest not only for medical men and scholars, but for all intelligent people. The discoveries and conquests of biology have wrought such a revolution in thought that they should be known to all persons of liberal culture. In addition to making acquaintance with the discoveries, one ought to learn something about the history of biology; for it is essential to know how it took its rise, in order to understand its present position and the nature of its influence upon expanding ideas regarding the world in which we live.

In its modern sense, biology did not arise until about 1860, when the nature of protoplasm was first clearly pointed out by Max Schultze, but the currents that united to form it had long been flowing, and we can never understand the subject without going back to its iatric condition, when what is now biology was in the germ and united with medicine. Its separation from medicine, and its rise as an independent subject, was owing to the steady growth of that zest for exploration into unknown fields which began with the new birth of science in the sixteenth century, and has continued in fuller measure to the present. It was the outcome of applying observation and experiment to the winning of new truths.

Difficulties.—But biology is so comprehensive a field, and involves so many details, that it is fair to inquire: can its progress be made clear to the reader who is unacquainted with it as a laboratory study? The matter will be simplified by two general observations—first, that the growth of biology is owing to concurrent progress in three fields of research, concerned, respectively, with the structure or architecture of living beings, their development, and their physiology. We recognize also a parallel advance in the systematic classification of animals and plants, and we note, furthermore, that

the idea of evolution permeates the whole. It will be necessary to consider the advances in these fields separately, and to indicate the union of the results into the main channel of progress. Secondly, in attempting to trace the growth of ideas in this department of learning one sees that there has been a continuity of development. The growth of these notions has not been that of a chaotic assemblage of ideas, but a well-connected story in which the new is built upon the old in orderly succession. The old ideas have not been completely superseded by the new, but they have been molded into new forms to keep pace with the advance of investigation. In its early phases, the growth of biology was slow and discursive, but from the time of Linnæus to Darwin, although the details were greatly multiplied, there has been a relatively simple and orderly progress.

Facts and Ideas.—There are many books about biology, with directions for laboratory observation and experiment, and also many of the leading facts of the science have been given to the public, but an account of the growth of the ideas, which are interpretations of the facts, has been rarely attempted. From the books referred to, it is almost impossible to get an idea of biology as a unit; this even the students in our universities acquire only through a coherent presentation of the subject in the classroom, on the basis of their work in the laboratory. The critical training in the laboratory is most important, but, after all, it is only a part, although an essential part, of a knowledge of biology. In general, too little attention is paid to interpretations and the drill is confined to a few facts. Now, the facts are related to the ideas of the science as statistics to history—meaningless without interpretation. In the rise of biology the facts have accumulated constantly, through observation and experiment, but the general truths have emerged slowly and periodically, whenever there has been granted to some mind an insight

into the meaning of the facts. The detached facts are sometimes tedious, the interpretations always interesting.

The growth of the knowledge of organic nature is a long story, full of human interest. Nature has been always the same, but the capacity of man as its interpreter has varied. He has had to pass through other forms of intellectual activity, and gradually to conquer other phases of natural phenomena, before entering upon that most difficult task of investigating the manifestations of life. It will be readily understood, therefore, that biology was delayed in its development until after considerable progress had been made in other sciences.

It is an old saying that "Truth is the daughter of Time," and no better illustration of it can be given than the long upward struggle to establish even the elemental truths of nature. It took centuries to arrive at the conception of the uniformity of nature, and to reach any of those generalizations which are vaguely spoken of as the laws of nature.

The Men of Science.—In the progress of science there is an army of observers and experimenters each contributing his share, but the rank and file supply mainly isolated facts, while the ideas take birth in the minds of a few gifted leaders, either endowed with unusual insight, or so favored by circumstances that they reach general conclusions of importance. These advance-guards of intellectual conquest we designate as founders. What were they like in appearance? Under what conditions did they work, and what was their chief aim? These are interesting questions which will receive attention as our narrative proceeds.

A study of the lives of the founders shows that the scientific mood is pre-eminently one of sincerity. The men who have added to the growth of science were animated by an unselfish devotion to truth, and their lasting influence has been in large measure a reflection of their individual char-

acters. Only those have produced permanent results who have interrogated nature in the spirit of devotion to truth and waited patiently for her replies. The work founded on selfish motives and vanity has sooner or later fallen by the wayside. We can recognize now that the work of scientific investigation, subjected to so much hostile criticism as it appeared from time to time, was undertaken in a reverent spirit, and was not iconoclastic, but remodelling in its influence. Some of the glories of our race are exhibited in the lives of the pioneers in scientific progress, in their struggles to establish some great truth and to maintain intellectual integrity.

The names of some of the men of biology, such as Harvey, Linnæus, Cuvier, Darwin, Huxley, and Pasteur, are widely known because their work came before the people, but others equally deserving of fame on account of their contributions to scientific progress will require an introduction to most of our readers.

In recounting the story of the rise of biology, we shall have occasion to make the acquaintance of this goodly company. Before beginning the narrative in detail, however, we shall look summarily at some general features of scientific progress and at the epochs of biology.

The Conditions under which Science Developed

In a brief sketch of biology there is relatively little in the ancient world that requires notice except the work of Aristotle and Galen; but with the advent of Vesalius, in 1543, our interest begins to freshen, and, thereafter, through lean times and fat times there is always something to command our attention.

The early conditions must be dealt with in order to appreciate what followed. We are to recollect that in the ancient

world there was no science of biology as such; nevertheless, the germ of it was contained in the medicine and the natural history of those times.

There is one matter upon which we should be clear: in the time of Aristotle nature was studied by observation and experiment. This is the foundation of all scientific advancement. Had conditions remained unchanged, there is reason to believe that science would have developed steadily on the basis of the Greek foundation, but circumstances, to be spoken of later, arose which led not only to the complete arrest of inquiry, but also, the mind of man being turned away from nature, to the decay of science.

Aristotle the Founder of Natural History.—The Greeks represented the fullest measure of culture in the ancient world, and, naturally, we find among them the best-developed science. All the knowledge of natural phenomena centered in Aristotle (384–322 B.C.), and for twenty centuries he represented the highest level which that kind of knowledge had attained.

It is uncertain how long it took the ancient observers to lift science to the level which it had at the beginning of Aristotle's period, but it is obvious that he must have had a long line of predecessors, who had accumulated facts of observation and had molded them into a system before he perfected and developed that system. We are reminded that all things are relative when we find Aristotle referring to the ancients; and well he might, for we have indubitable evidence that much of the scientific work of antiquity has been lost. One of the most striking discoveries pointing in that direction is the now famous papyrus which was found by Georg Ebers in Egypt about 1860. The recent translation of this ancient document shows that it was a treatise on medicine, dating from the fifteenth century B.C. At this time the science of medicine had attained an astonishingly

high grade of development among that people. And since it is safe to assume that the formulation of a system of medicine in the early days of mankind required centuries of observation and practice, it becomes apparent that the manuscript in question was no vague, first attempt at reducing medicine to a system. It is built upon much scientific knowledge, and must have been preceded by writings both on medicine and on its allied sciences.

It is not necessary that we should attempt to picture the crude beginnings of the observation of animated nature and the dawning of ideas relative to animals and plants; it is suitable to our purpose to commence with Aristotle, and to designate him, in a relative sense, as the founder of natural history.

That he was altogether dissatisfied with the state of knowledge in his time and that he had high ideals of the dignity of science is evidenced in his writings. Although he refers to the views of the ancients, he regarded himself in a sense as a pioneer. "I found no basis prepared," he says, "no models to copy. . . . Mine is the first step, and therefore a small one, though worked out with much thought and hard labor. It must be looked at as a first step and judged with indulgence." (From Osborn's *From the Greeks to Darwin.*)

There is general agreement that Aristotle was a man of vast intellect and that he was one of the greatest philosophers of the ancient world. He has had his detractors as well as his partisan adherents. Perhaps the just estimate of his attainments and his position in the history of science is between the enthusiastic appreciation of Cuvier and the critical estimate of Lewes.

This great man was born in Stagira in the year 384 B.C., and lived until 322 B.C. He is to be remembered as the most distinguished pupil of Plato, and as the instructor of

Alexander the Great. Like other scholars of his time, he covered a wide range of subjects; we have mention, indeed, of about three hundred works of his composition, many of which are lost. He wrote on philosophy, metaphysics, psychology, politics, rhetoric, etc., but it was in the domain of natural history that he attained absolute pre-eminence.

His Position in the Development of Science.—It is manifestly unjust to measure Aristotle by present standards; we must keep always in mind that he was a pioneer, and that he lived in an early day of science, when errors and crudities were to be expected. His greatest claim to eminence in the history of science is that he conceived the things of importance and that he adopted the right method in trying to advance the knowledge of the natural universe. In his program of studies he says: "First we must understand the phenomena of animals; then assign their causes; and, finally, speak of their generation." His position in natural history is frequently misunderstood. One of the most recent writers on the history of science, Henry Smith Williams, pictures him entirely as a great classifier, and as the founder of systematic zoölogy. While it is true that he was the founder of systematic zoölogy, as such he did not do his greatest service to natural history, nor does the disposition to classify represent his dominant activity. In all his work classification is made incidental and subservient to more important considerations. His observations upon structure and development, and his anticipation of the idea of organic evolution, are the ones upon which his great fame rests. He is not to be remembered as a man of the type of Linnæus; rather is he the forerunner of those men who looked deeper than Linnæus into the structure and development of animal life—the morphologists.

Particular mention of his classification of animals will be found in the chapter on Linnæus, while in what follows

in this chapter attention will be confined to his observation of their structure and development and to the general influence of his work.

His great strength was in a philosophical treatment of the structure and development of animals. Professor Osborn in his interesting book, *From the Greeks to Darwin*, shows that Aristotle had thought out the essential features of evolution as a process in nature. He believed in a complete gradation from the lowest organisms to the highest, and that man is the highest point of one long and continuous ascent.

His Extensive Knowledge of Animals.—He made extensive studies of life histories. He knew that drone bees develop without previous fertilization of the eggs (by parthenogenesis); that in the squid the yolk sac of the embryo is carried in front of the mouth; that some sharks develop within the egg-tube of the mother, and in some species have a rudimentary blood-connection resembling the placenta of mammals. He had followed day by day the changes in the chick within the hen's egg, and observed the development of many other animals. In embryology also, he anticipated Harvey in appreciating the true nature of development as a process of gradual building, and not as the mere expansion of a previously formed germ. This doctrine, which is known under the name of epigenesis, was, as we shall see later, hotly contested in the eighteenth century, and has a modified application at the present time.

In reference to the structure of animals he had described the tissues, and in a rude way analyzed the organs into their component parts. It is known, furthermore, that he prepared plates of anatomical figures, but, unfortunately, these have been lost.

In estimating the contributions of ancient writers to science, it must be remembered that we have but fragments of their works to examine. It is, moreover, doubtful whether

the scientific writings ascribed to Aristotle were all from his hand. The work is so uneven that Huxlev has suggested that, since the ancient philosophers taught *viva voce*, what we have of his zoölogical writings may possibly be the notes of some of his students. While this is not known to be the case, that hypothesis enables us to understand the intimate mixture of profound observation with trivial matter and obvious errors that occur in the writings ascribed to him.

Hertwig says: "It is a matter for great regret that there have been preserved only parts of his three most important zoölogical works, '*Historia animalium*,' '*De partibus*,' and '*De generatione*,' works in which zoölogy is founded as a universal science, since anatomy and embryology, physiology and classification, find equal consideration."

Some Errors.—Dissections were little practised in his day, and it must be admitted that his observations embrace many errors. He supposed the brain to be bloodless, the arteries to carry air, etc., but he has been cleared by Huxley of the mistake so often attributed to him of supposing the heart of mammals to have only three chambers. It is alto gether probable that he is credited with a larger number of errors than is justified by the facts.

He must have had unusual gifts in the exposition of these technical subjects; indeed, he made his researches appear so important to his royal patron, Alexander, that he was aided in the preparation of his great Natural History bv a grant of 800 talents (equivalent to $200,000) and by numerous assistants and collectors. Thus in ancient times was anticipated the question that is being agitated to-day—that of the support and the endowment of research.

Personal Appearance.—Some idea of his looks may be gained from Fig. 1. This is a copy of a bas-relief found in the collection of Fulvius Ursinus (d. 1600), and was originally published by J. Faber. Its authenticity as a portrait is

attested (1811) by Visconti, who says that it has a perfect resemblance to the head of a small bust upon the base of which the name of Aristotle is engraved. Portrait busts and statues of Aristotle were common in ancient times. The picture of him most familiar to general readers is the copy of the head and shoulders of an ancient statue representing him with a draping over the left shoulder. This is an

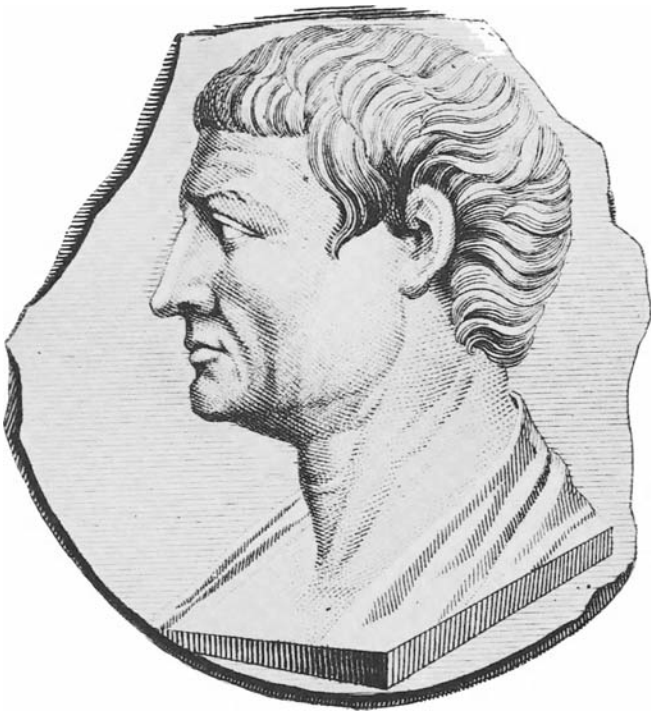

FIG. 1.—ARISTOTLE, 384–322 B.C.

attractive portrait, showing a face of strong intellectuality. Its authenticity, however, is not as well established as that of the picture shown here. Other pictures, believed to be those of Aristotle, represent him later in life with receding hair, and one exists in which his baldness is very extensive. He was described as short in stature, with spindling legs and small, penetrating eyes, and to have been, in his younger days, vain and showy in his dress.

He was early left an orphan with a considerable fortune; and there are stories of early excesses after coming into his property. These charges, however, lack trustworthy support, and are usually regarded as due mainly to that undermining gossip which follows one holding prominent place and enviable recognition. His habits seem to have been those of a diligent student with a zest in his work; he was an omnivorous reader, and Plato called him the mind of his school. His large private library and his manner of living bespeak the conserving of his property, rather than its waste in selfish indulgences.

His Influence.—The influence of Aristotle was in the right direction. He made a direct appeal to nature for his facts, and founded his Natural History only on observation of the structure, physiology, and development of animals. Unfortunately, the same cannot be said of his successors.

Galen, who is mentioned above in connection with Aristotle, was a medical writer and the greatest anatomist of antiquity. On account of the relation of his work to the growth of anatomy, however, the consideration of it is reserved for the chapter on Vesalius.

Soon after the period of Aristotle the center of scientific investigation was transferred to Alexandria, where Ptolemy had erected a great museum and founded a large public library. Here mathematics and geography flourished, but natural history was little cultivated.

In order to find the next famous naturalist of antiquity, it is necessary to look to Rome. Rome, although great in political power, never became a true culture center, characterized by originality. All that remains of their thought shows us that the Roman people were not creative. In the capital of the empire, the center of its life, there arose no great scientific investigator.

Pliny.—The situation is represented by Pliny the Elder

(23–79 A.D.), the Roman general and littérateur (Fig. 2). His works on natural history, filling thirty-seven volumes, have been preserved with greater completeness than those of other ancient writers. Their overwhelming bulk seems to have produced an impression upon those who, in the nineteenth century, heralded him as the greatest naturalist of

FIG. 2.—PLINY, 23–79 A.D.

antiquity. But an examination of his writings shows that he did nothing to deepen or broaden the knowledge of nature, and his Natural History marks a distinct retrograde movement. He was, at best, merely a compiler—"a collector of anecdotes"—who, forsaking observation, indiscriminately mixed fable, fact, and fancy taken from the writings of others. He emphasized the feature of classification which Aristotle had held in proper subordination, and he replaced the clas-

sification of Aristotle, founded on plan of organization, by a highly artificial one, founded on the incidental circumstance of the abodes of animals—either in air, water, or on the earth.

The Arrest of Inquiry and its Effects.—Thus, natural history, transferred from a Greek to a Roman center, was already on the decline in the time of Pliny; but it was destined to sink still lower. It is an old, oft-repeated story how, with the overthrow of ancient civilization, the torch of learning was nearly extinguished. Not only was there a complete political revolution; there was also a complete change in the mental interests of mankind. The situation is so complex that it is difficult to state it with clearness. So far as science is concerned, its extinction was due to a turning away from the external world, and a complete arrest of inquiry into the phenomena of nature. This was an important part of that somber change which came over all mental life.

One of the causes that played a considerable part in the cessation of scientific investigation was the rise of the Christian church and the dominance of the priesthood in all intellectual as well as in spiritual life. The world-shunning spirit, so scrupulously cultivated by the early Christians, prompted a spirit which was hostile to observation. The behest to shun the world was acted upon too literally. The eyes were closed to nature and the mind was directed toward spiritual matters, which truly seemed of higher importance. Presently, the observation of nature came to be looked upon as proceeding from a prying and impious curiosity.

Books were now scarcer than during the classical period; the schools of philosophy were reduced, and the dissemination of learning ceased. The priests who had access to the books assumed direction of intellectual life. But they were largely employed with the analysis of the supernatural, without the wholesome check of observation and experiment; mystical explanations were invented for natural phenomena,

while metaphysical speculation became the dominant form of mental activity.

Authority Declared the Source of Knowledge.—In this atmosphere controversies over trivial points were engendered, and the ancient writings were quoted as sustaining one side or the other. All this led to the referring of questions as to their truth or error to authority as the source of knowledge, and resulted in a complete eclipse of reason. Amusing illustrations of the situation are abundant; as when, in the Middle Ages, the question of the number of teeth in the horse was debated with great heat in many contentious writings. Apparently none of the contestants thought of the simple expedient of counting them, but tried only to sustain their position by reference to authority. Again, one who noticed spots on the sun became convinced of the error of his eyes because Aristotle had somewhere written "The face of the sun is immaculate."

This was a barren period not only for science, but also for ecclesiastical advance. Notwithstanding the fact that for more than a thousand years the only new works were written by professional theologians, there was no substantial advance in their field, and we cannot escape the reflection that the reciprocal action of free inquiry is essential to the growth of theology as of other departments of learning.

In the period from the downfall of Rome to the revival of learning, one eminent theologian, St. Augustine, stands in relief for the openness of his mind to new truth and for his expressions upon the relation of revelation in the Scriptures to the observation of nature. His position will be more clearly indicated in the chapter dealing with the rise of evolutionary thought.

Perhaps it has been the disposition of historians to paint the Middle Ages in too dark colors in order to provide a background on which fitly to portray the subsequent awak-

ening. It was a remolding period through which it was necessary to pass after the overthrow of ancient civilization and the mixture of the less advanced people of the North with those of the South. The opportunities for advance were greatly circumscribed; the scarcity of books and the lack of facilities for travel prevented any general dissemination of learning, while the irresponsible method of the time, of appealing to authority on all questions, threw a barrier across the stream of progress. Intellectuality was not, however, entirely crushed during the prevalence of these conditions. The medieval philosophers were masters of the metaphysical method of argument, and their mentality was by no means dull. While some branches of learning might make a little advance, the study of nature suffered the most, for the knowledge of natural phenomena necessitates a mind turned outward in direct observation of the phenomena of the natural and physical universe.

Renewal of Observation.—It was an epoch of great importance, therefore, when men began again to observe, and to attempt, even in an unskilful way, hampered by intellectual inheritance and habit, to unravel the mysteries of nature and to trace the relation between causes and effects in the universe. This new movement was a revolt of the intellect against existing conditions. In it were locked up all the benefits that have accrued from the development of modern science. Just as the decline had been due to many causes, so also the general revival was complex. The invention of printing, the voyages of mariners, the rise of universities, and the circulation of ideas consequent upon the Crusades, all helped to disseminate the intellectual ferment. These generic influences aided in molding the environment, but, just as the pause in science had been due to the turning away from nature and to new mental interests, so the revival was a return to nature and to the method of science. The pio-

neers had to be men of determined independence; they labored against self-interest as well as opposition from the church and the priesthood, and they withstood the terrors of the Inquisition and the loss of recognition and support.

In this uncongenial atmosphere men like Galileo, Descartes, and Vesalius established the new movement and overthrew the reign of authority. With the coming of Vesalius the new era of biological progress was opened, but its growth was a slow one; a growth of which we are now to be concerned in tracing the main features.

The Epochs in Biological History

It will be helpful to outline the great epochs of biological progress before taking them up for fuller consideration. The foundation of progress was the renewal of observation in which, as already stated, all modern science was locked up.

It was an epoch in biological history when Vesalius overthrew the authority of Galen, and studied at first hand the organization of the human body.

It was an epoch when William Harvey, by adding experiment to observation, demonstrated the circulation of the blood and created a new physiology. The two coördinate branches of biology were thus early outlined.

The introduction of the microscope, mainly through the labors of Grew, Hooke, Malpighi, and Leeuwenhoek, opened a new world to the investigator, and the work of these men marks an epoch in the progress of independent inquiry.

Linnæus, by introducing short descriptions and uniform names for animals and plants, greatly advanced the subject of natural history.

Cuvier, by founding the school of comparative anatomy, so furthered the knowledge of the organization of animals that he created an epoch.

Bichat, his great contemporary, created another by laying the foundation of our knowledge of the structure of animal tissues.

Von Baer, bv his studies of the development of animal life, supplied what was lacking in the work of Cuvier and Bichat and originated modern embryology.

Haller, in the eighteenth, and Johannes Müller in the nineteenth century, so added to the ground work of Harvey that physiology was made an independent subject and was established on modern lines.

With Buffon, Erasmus Darwin, and Lamarck began an epoch in evolutionary thought which had its culminating point in the work of Charles Darwin.

After Cuvier and Bichat came the establishing of the cell-theory, which created an epoch and influenced all further progress.

Finally, through the discovery of protoplasm and the recognition that it is the seat of all vital activity, arrived the epoch which brought us to the threshold of the biology of the present day.

Step by step naturalists have been led from the obvious and superficial facts about living organisms to the deep-lying basis of all vital manifestations.

CHAPTER II

VESALIUS AND THE OVERTHROW OF AUTHORITY IN SCIENCE

VESALIUS, although an anatomist, is to be recognized in a broad sense as one of the founders of biology. When one is attempting to investigate animal and plant life, not only must he become acquainted with the external appearance of living organisms, but also must acquire early a knowledge of their structure, without which other facts relating to their lives can not be disclosed. Anatomy, which is the science of the structure of organized beings, is therefore so fundamental that we find ourselves involved in tracing the history of its rise as one part of the story of biology. But it is not enough to know how animals and plants are constructed; we must also know something about the purpose of the structures and of the life that courses through them, and, accordingly, after considering the rise of anatomy, we must take a similar view of its counterpart, physiology.

The great importance of Vesalius in the history of science lies in the fact that he overthrew adherence to authority as the method of ascertaining truth, and substituted therefor observation and reason. Several of his forerunners had tried to accomplish the same end, but they had failed. He was indebted to them as every man is indebted to his forebears, but at the same time we can not fail to see that Vesalius was worthy of the victory. He was more resolute and forceful than any of his predecessors. He was one of those rare

spirits who see new truth with clearness, and have the bravery to force their thoughts on an unsympathetic public.

The Beginning of Anatomy.—In order to appreciate his service it is necessary to give a brief account of his predecessors, and of the condition of anatomy in his time. Remembering that anatomy embraces a knowledge of the architecture of all animals and plants, we can, nevertheless, see why in early times its hould have had more narrow boundaries. The medical men were the first to take an interest in the structure of the human body, because a knowledge of it is necessary for medicine and surgery. It thus happens that the earliest observations in anatomy were directed toward making known the structure of the human body and that of animals somewhat closely related to man in point of structure. Anatomical studies, therefore, began with the more complex animals instead of the simpler ones, and, later, when comparative anatomy began to be studied, this led to many misunderstandings; since the structure of man became the type to which all others were referred, while, on account of his derivation, his structure presents the greatest modification of the vertebrate type.

It was so difficult in the early days to get an opportunity to study the human body that the pioneer anatomists were obliged to gain their knowledge by dissections of animals, as the dog, and occasionally the monkey. In this way Aristotle and his forerunners learned much about anatomy. About 300 B.C., the dissection of the human body was legalized in the Alexandrian school, the bodies of condemned criminals being devoted to that purpose. But this did not become general even for medical practitioners, and anatomy continued to be studied mainly from brute animals.

Galen.—The anatomist of antiquity who outshines all others was Galen (Claudius Galenus, 130–200 A.D.), who lived some time in Pergamos, and for five years in Rome, during

the second century of the Christian era. He was a man of much talent, both as an observer and as a writer. His descriptions were clear and forceful, and for twelve centuries his works exerted the greatest influence of those of all scientific writers. In his writings was gathered all the anatomical knowledge of his predecessors, to which he had added observations of his own. He was a man of originality, but not having the human body for dissection, he erred in expounding its structure "on the faith of observations made on lower animals." He used the right method in arriving at his facts. Huxley says: "No one can read Galen's works without being impressed with the marvelous extent and diversity of his knowledge, and by his clear grasp of those experimental methods by which alone physiology can be advanced."

Anatomy in the Middle Ages.—But now we shall see how the arrest of inquiry already spoken of operated in the field of anatomy. The condition of anatomy in the Middle Ages was the condition of all science in the same period. From its practical importance anatomy had to be taught to medical men, while physics and chemistry, biology and comparative anatomy remained in an undeveloped state. The way in which this science was taught is a feature which characterizes the intellectual life of the Middle Ages. Instead of having anatomy taught by observations, the writings of Galen were expounded from the desk, frequently without demonstrations of any kind. Thus his work came to be set up as the one unfailing authority on anatomical knowledge. This was in accord with the dominant ecclesiastical influence of the time. Reference to authority was the method of the theologians, and by analogy it became the method of all learning. As the Scriptures were accepted as the unfailing guide to spiritual truth, so Galen and other ancient writers were made the guides to scientific truth and thought. The baneful effects of this in stifling inquiry and in reducing knowledge

FIG. 3.—GALEN, 131–200.

From *Acta Medicorum Berolinensium*, 1715.