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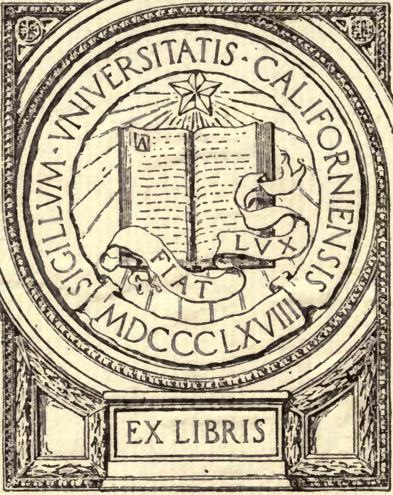
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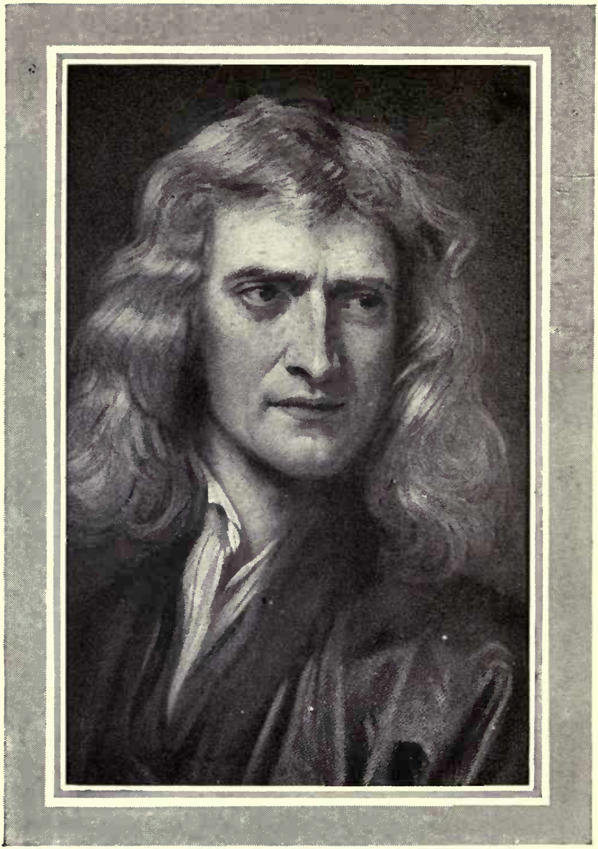

Sir Isaac Newton

From an engraving of a painting by Kneller, in the possession of Lord Portsmouth

BRITAIN'S HERITAGE OF SCIENCE

BY

ARTHUR SCHUSTER, F.R.S.

AND

ARTHUR E. SHIPLEY, F.R.S.

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ERRATA.

Page 70, line 5 from bottom:

for "Robert" *read* "Charles."

Page 286, line 10 from bottom:

for "Sir William Herschel" *read* "Sir William James Herschel, eldest son of Sir John Herschel."

for "Foulds" *read* "Faulds."

Page 291, line 11 from top:

for "Thompson" *read* "Thomson."

LIST OF PORTRAITS

Sir Isaac Newton - - - - - Frontispiece

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PREFACE

THIS book does not pretend to establish any thesis. Incidentally it may point a moral which different readers will interpret in different ways. Our main purpose was to give a plain account of Britain's great heritage of science; an heritage that—handed down through several centuries of distinguished achievements—will, if the signs speak true, be passed on to the coming age with untarnished brilliancy.

A limit had to be set to the extent to which contemporary science should be included, and some difficulty was felt in fixing that limit. It seemed desirable—for obvious reasons—to avoid discussing the work of living men; but no fixed rule could be enforced because that work is often too much interwoven with that of others who are no longer with us to be completely ignored. Sometimes, also, researches undertaken by our present leaders have led to results that are firmly established, and to have omitted them would have conveyed a false idea of the part which Great Britain has played in the recent progress of science. In such cases we had to use our discretion in breaking through a rule which—as a principle—we have tried to adhere to.

It was not intended to write a complete history of British science, but to lay stress mainly on its salient features, without overburdening our account with work which, though meritorious and perhaps precursory to a real advance, did not deal with fundamental matters. Our judgment probably was at fault in some cases, and accidental omissions have, no doubt, also occurred. It is to be expected that these will be most numerous in the chapter on technical applications, where it was found difficult to select from the extensive material those special instances which most clearly show the part that pure science has taken in the economic life of the country.

The subject naturally divides itself into two great groups, one dealing with the physical, the other with the biological sciences, and we are respectively responsible for the one and the other. Our thanks are due to Professor Seward, Master of Downing College, Cambridge, for kindly helping in the chapter on Botany; to Mr. H. H. Brindley, of St. John's College, Cambridge, for his assistance in the chapter on Zoology; and to Professor F. G. Hopkins for help in that on Physiology. The chapter on Geology was partly re-written and much increased in value by the late Professor McKenny Hughes, while Dr. Marr and Mr. R. E. Priestley have also assisted us with advice. Extensive use has been made of the "Dictionary of National Biography," and of some articles in the "Encyclopædia Britannica."

Part of the History of Biological Science has been taken, by kind permission of the Editors and of the authorities of the Cambridge University Press, from the "Cambridge History of English Literature." In that portion of the chapter on Zoology which deals with Charles Darwin considerable extracts have also been made from the Presidential Address to the Zoological Section of the Winnipeg Meeting of the British Association.

Our thanks are due to the Council of the Royal Society for permission to reproduce a number of portraits, and to the Editor of "Nature" for allowing the reproduction of the excellent engraving of Clerk Maxwell. The portraits which accompany the last five chapters were prepared from photographs kindly taken by the Rev. Alfred Rose, of Emanuel College, Cambridge, from various well-known prints. The excellent likeness of Joule, taken about 1875 by Lady Roscoe, now appears for the first time.

A. S.
A. E. S.

August 1917.

UNIV. OF CALIFORNIA

BRITAIN'S HERITAGE OF SCIENCE

CHAPTER I

The Ten Landmarks of Physical Science

(Roger Bacon, Gilbert, Napier, Newton, Dalton, Young, Faraday, Joule, William Thomson, Clerk Maxwell)

THE history of British Science begins with Roger Bacon, the Franciscan friar, who, cutting himself adrift from the scholastic philosophy of his time, rejected the traditional appeal to recognized authority, and urged with a powerful voice that a knowledge of Nature can only be attained through experimental research and by logical reasoning. Intellectually he stood high above the level of his contemporaries;[1] by his writings he set the true standard of scientific enquiry, and planted the first of the great landmarks along the path of British science.

> "There are two methods," he writes, "in which we acquire knowledge, argument and experiment. Argument allows us to draw conclusions, and may cause us to admit the conclusion; but it gives no proof, nor does it remove doubt, and cause the mind to rest in the conscious possession of truth, unless the truth is discovered by way of experience, *e.g.*, if any man who had never seen fire were to prove by satisfactory argument that fire burns and destroys things, the hearer's mind would not rest satisfied, nor would he avoid fire; until by putting his hand or some combustible thing into it, he proved by actual experiment what the argument laid down; but after the experiment had been made, his mind receives certainty and rests in the possession of truth, which could not be given by argument but

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[1] An interesting account of the general character of scientific speculations before Bacon's time has been given by Charles L. Barnes ("Manch. Lit. and Phil. Soc.," Vol X. 1896).

> only by experience. And this is the case even in mathematics, where there is the strongest demonstration. For let anyone have the clearest demonstration about an equilateral triangle without experience of it, his mind will never lay hold of the problem until he has actually before him the intersecting circles and the lines drawn from the point of section to the extremities of a straight line."[1]

In a more detailed discussion of experimental science, he points to three "prerogatives" which it has over other sciences. It tests the conclusions of these other sciences by experience, it attains to a knowledge of truth which could not be reached by the special sciences, and "it has no respect for these, but investigates on its own behalf the secrets of Nature, which consist in a knowledge of the future, the past and the present, and the inventing of instruments and machines of wonderful power."

We further note Bacon's repeated plea for the study of mathematics, which he judges to be "the key and door to the special sciences."

Roger Bacon was born about 1214, in the county of Dorset, of wealthy parents. Having completed his studies at Oxford, he seems very soon to have gained a reputation by lecturing, both at Oxford and Paris, where he went about 1236. He entered the Franciscan Order, and, though in bad health, continued his studies, devoting part of his time to optical experiments.

> "During the twenty years," he writes in 1267, "in which I have laboured specially in the study of wisdom, after abandoning the usual methods, I have spent more than £2,000 on secret books and various experiments and languages and instruments and mathematical tables, etc."

Bacon found a friend in Pope Clement IV., an enlightened Frenchman, who, having been a lawyer and judge, took orders after his wife's death and rapidly rose in the Church. In 1263 Clement was appointed papal legate in England, and it was probably then that he came to hear of Bacon's writings. When elected Pope, two years later, he asked for fair copies of Bacon's works, who, thinking that nothing he had yet written was good enough, set out on a more ambitious undertaking, of which the "Opus Majus" was the first instalment. In this work he displayed such independence of thought, and attacked the prevailing ideas so forcibly, that his opponents were converted into bitter enemies. They saw their opportunity—and used it—when Clement died. Accusations of heresy were raised, and Roger Bacon was condemned to prison by the General of the Franciscan Order in 1277. He remained in captivity till shortly before his death, which took place in 1292.

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[1] The translation (with a slight modification) is that given by Prof. R. Adamson (*see* "Commemoration Essays on Roger Bacon," edited by A. G. Settle, p. 18).

With Roger Bacon England took the lead in laying the foundation of modern science. While the scholastic tradition held the whole of Europe in bond he stood alone, fearlessly holding up the torch of enlightenment; but its rays fell on eyes that could or would not see. More than three barren centuries separated Bacon from the next great scientific figures, William Gilbert and John Napier.

Gilbert (1540–1603) has been called the father of electric and magnetic science. He belonged to an old Suffolk family, was born at Colchester, and after a distinguished career at Cambridge, spent three years in Italy and other parts of Europe. On his return he settled down in London as a medical practitioner, and soon gained a reputation which secured him many honours, and among them the appointment as physician to Queen Elizabeth. His chief work is described in a volume published in 1600 under the title of "De magnete, magnetisque corporibus et de magno magnete tellure."

It was known to the Greek philosophers that a certain mineral originally found in Magnesia had the power of attracting small pieces of iron. In the twelfth century the knowledge of the compass was brought to Europe. The Chinese, who had been familiar with it in very early times, already knew that the direction in which the needle points was a little to one side of North, and Columbus discovered that this deviation differed in different localities. Nearly a century later, Robert Norman, a British sailor, had observed that the force which acted on the needle was not, as had generally been assumed, directed upwards towards the pole star, but downwards, and in 1576 he measured the angle between the horizontal and the direction of the magnetic needle, which we now call the magnetic dip, and found it to be nearly 72° in London. Such was the knowledge at Gilbert's disposal when he began his celebrated researches. The word "loadstone" for the magnetic mineral, derived from lead-stone, indicates how the main interest in magnetic properties had been concentrated in their use for purposes of navigation. Gilbert's object, on the other hand, was chiefly scientific. The high position which he occupies in the history of science is not merely due to his discoveries, but to a great extent on his being the first man of science who gave effect to Roger Bacon's teaching, possessing the power and will to draw logical conclusions from his experiments, and to verify by new experiments the wider views suggested by these conclusions.

Mapping out the directions in which a freely suspended magnetic needle sets at different points on the earth's surface, it appears to us a simple matter to infer that the earth as a whole behaves like a huge magnet. A diagram seems to be all that is required to complete the deduction. But the world at the time was not accustomed to logical reasoning of this kind. It was necessary, therefore, to enforce conviction by corroborative evidence, which Gilbert supplied, showing that the earth, so far as could be tested, possessed all the properties of a magnet. He pointed out that rods of iron lying about become magnetic under its influence, just as when placed near magnetized iron, and he noted that the effect is the stronger the more nearly the direction of the rods coincides with the direction in which a suspended needle comes to rest. Gilbert further constructed a magnetic sphere, and suspending small magnets by thin fibres, he examined how these set in different directions at different points on the sphere. He could thus, on a small scale, reproduce a model of the earth as a magnet, and observing that the magnetic forces extend beyond the surface of his "terellum," was led to speculate on the possible action of terrestrial magnetism on the moon, and the mutual magnetic effects of planets on each other. We readily forgive him if in these cosmic speculations he travelled beyond the justifiable limits of his experimental facts.

In his electrical researches Gilbert had the same wide outlook. Amber, when excited by friction, was known to attract light bodies; why—he asked himself—should special properties be confined in one case to iron and in another to amber? He tried but failed to find a magnetic action on water and other bodies, but discovered that the property of amber was shared by a large number of substances, such as glass, sulphur, and the precious stones. He was the first to note that electric effects persist longer in dry air than in wet weather, that an electrified body loses its power when moistened with water or spirit, or when glowing coal is brought near to it. We also owe to him the word "electricity" (derived from "ἤλεκτρον", the Greek word for amber); though only in the form of the adjective. "Vim illam," he writes, "electricam nobis placet appellare, quæ ab humore provenit." In a posthumous work he declares himself to be an adherent of the Copernican doctrine, and shows a clear scientific perception, as when he explains that there is no intrinsic property of "levity," but that when light bodies are seen to ascend they do so under the influence of the pressure of the surrounding heavier bodies.

Galileo,[1] almost the only man of science born in the sixteenth century who stands on an intellectual level with Gilbert, appreciated his work. In the third of the famous "Dialogues" he gives an account of it, and Salviati, the imaginary person who is made to express Galileo's own views, mentions Gilbert's book, "which might not have come into my hands if a peripatetic philosopher had not presented it to me, for the reason, I believe, that he did not wish to contaminate his own library with it." After referring to some of Gilbert's experiments, Salviati further says:

> "I highly praise, admire, and envy this author for having formed such a stupendous conception on a

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[1] The name is given in its usual form, but it sounds rather like calling a man Thomas whose full name is Thomas Thomasson. Galileo's father was Vincenzio Galilei; his own full name Galileo Galilei.

> matter which has been treated by many sublime intellects, but solved by none; he appears to me also to deserve the highest praise for his many and true observations, putting to shame the lying and vain authors who write not only of what they know, but also of what they hear from the silly crowd, without satisfying themselves by experiment of what is true—perhaps, because they do not wish to shorten their books. What I should have desired in Gilbert is that he would have been a little more of a mathematician, and especially well schooled in geometry, the practice of which would have made him less inclined to accept, as conclusive proofs, what are only arguments in favour of the deductions he draws from his observations. . . . . . I do not doubt that in the course of time this new science will be perfected by new observations, and by true and cogent demonstrations. But the glory of the first inventor will not be diminished thereby; I do not esteem less, but, on the contrary, admire, the first inventor of the lyre (though probably his instrument was roughly constructed and more roughly played), much more than the hundred other players who, in the succeeding centuries, have brought his art to exquisite perfection."

Coming from Galileo this was high praise, indeed.

The next landmark was planted by a man of equal power but different type of intellect.

John Napier, of Merchiston, descended from a distinguished Scotch family, which, in the fifteenth century, included three Provosts of Edinburgh among its members. His father, Sir Archibald Napier, was Justice Deputy under the Earl of Argyll, and Master of the Mint. John was born at Merchiston Castle in 1550; after a short period of study at the University of St. Andrews, he probably spent some time in foreign travel, but returned to Scotland at the age of twenty-two. Though involved in the political and religious controversies of his age, he devoted his spare time to the study of mathematics, and, what to him seemed of greater importance, the writing of a book on the Apocalypse. This mathematical work culminated in the discovery of logarithms, and gave to the world a method by means of which multiplication is converted into addition, division into subtraction, and the extraction of square or cube root into a division by two or three respectively. The scientific merit of introducing logarithmic functions into the domain of mathematics is surpassed by the incalculable importance of assisting the complicated numerical calculations which were vital to the progress of astronomy and of other branches of science. Without explaining the objects which Napier primarily had in view, or the steps by which he arrived at his final results, we may justify the prominent position here given to him in the history of science by quoting a few passages from an article contributed by Dr. J. W. L. Glaisher to the "Napier Tercentenary Memorial Volume":

> "The process of multiplication is so fundamental and direct that, from an arithmetical point of view, it might well be thought to be incapable of simplification or transformation into an easier process, so that there would seem to be no hope of help except from an apparatus. But Napier, not contented with such aids, discovered by a most remarkable and memorable effort of genius that such a transformation of multiplication was possible, and he not only showed how the necessary table could be calculated, but he actually constructed it himself. That Napier at a time when algebra scarcely existed should have done this is most wonderful; he gave us the principle, the method of calculation, and the finished table.
>
> "The 'Canon Mirificus' is the first British contribution to the mathematical sciences, and next to Newton's 'Principia' it is the most important work in the history of the exact sciences that has been published in Great Britain, at all events until within the memory of living persons.
>
> "In whatever country the 'Canon Mirificus' had been produced, it would have occupied the same commanding position, for it announced one of the greatest scientific discoveries ever made."

Independently of his work on logarithms, Napier's contributions to spherical trigonometry would alone have secured him a high position among mathematicians.

The interval between the death of Gilbert in 1603 and that of Napier in 1617 marks the period of Galileo's astronomical discoveries and of Kepler's fundamental work on planetary orbits. The world was now waiting for a great generalization, but Kepler passed away and Galileo died an old and broken man before one was born who surpassed both in genius and power as much as they had excelled those who went before them.

From the seventeenth century onwards, British science has continuously advanced, sometimes rushing ahead with torrential energy, sometimes in a smooth and almost imperceptible flow; at one period chiefly concentrated in the universities; at others almost entirely kept alive by private enthusiasts; but taken as a whole never losing contact with past achievements or ceasing to foreshadow future conquests. To appreciate correctly the different stages of the advance, we must distinguish between the slow work of accumulating facts or proving and disproving theories and the generation of new ideas which suddenly alter the whole trend of scientific thought. Such creations form the seven landmarks which bring us to nearly the end of the nineteenth century: Newton's establishment of the law of gravitation, Dalton's atomic theory, Faraday's electric discoveries, Young's contribution to the wave-theory of light, Joule's foundation of the conservation of energy, Kelvin's demonstration of the dissipation of energy; finally, Maxwell's formulation of the electro-magnetic theory of light.

Roger Bacon made an acute remark to the effect that while in mathematics we can proceed from the simple to the more complicated, it is impossible to do so in other branches of science, because Nature does not, as a rule, present us with the simple phenomenon. The whole history of science shows how it is always struggling in search of the simple starting point with respect to which we are constantly driven to modify or even reverse our ideas. Thales believed *water* to be the elementary substance from which everything else could be derived, Anaximenes thought it was *air*, and Heraclitus substituted *fire*, while, according to Pythagoras, it was the relations between integer numbers which formed the foundation of all science.

Take the case of "rest" and "motion." At first sight it seems obvious that the former is the simpler phenomenon; but our trouble begins when we try to define "rest." Disregarding this difficulty, let us ask "What is the simplest kind of motion?" Every schoolboy now could give the answer: "A uniform motion in a straight line"; but he would be sorely puzzled if he were required to give an example of a body moving with uniform motion in a straight line, for such a thing does not exist. The Greek philosophers kept more in touch with realities when they considered motion in a circle to be the simplest of its kind, because they had observed that the stars describe circles in the sky, and they could artificially produce circular motion by tying a weight to a string and whirling it round. As astronomy advanced, and the motion of the planets were further investigated, it became more and more difficult to reduce everything to circular motion. All efforts to persevere in such attempts finally broke down when the laws regulating the fall of bodies from a height were discovered. The straight line motion—although never directly brought within the range of observation—then took its place as the simpler basic idea.

Sir Isaac Newton (1643–1727) formulated the laws of motion; they have formed ever since the foundation of physical science, and a few words must be said as to their significance. Our first idea of "force" is derived from muscular sensation. We push a body, and see it change its place, and are conscious that we can ourselves be made to move by an application of muscular force from outside. From this it is natural, though perhaps not altogether logical, to conclude that every change of motion which we observe in a body is due to some push or pull on that body. This imaginary push or pull we call a force. The first law, originally due to Galileo, asserts that absence of force does not necessarily imply that a body is at rest; it may be moving, but, if so, it continues to move in a straight line with unaltered velocity. The second law allows us to measure a force, and may be said to have been first applied by Huygens. The third law asserts that whenever we observe a change of motion in a body there must be an equal and opposite change of motion in another body or system of bodies. This is the law of "action and reaction," which has played so important a part in the history of science.

Having accurately defined what is meant by change of motion, Newton in his "Principia" establishes a number of propositions relating to the motion of a body acted on by a force directed to a fixed centre. The Copernican hypothesis that the earth and planets are in motion round the sun, replacing the older view which believed the earth to be the centre of the universe, was at that time generally accepted by scientific men, and Kepler had formulated three laws defining the orbits of the planets. Newton's propositions, applied to Kepler's laws, proved that the movements of the planets may be accounted for by imagining attracting forces to act between the sun and the planets diminishing in proportion to the squares of the distances. If this attraction be accepted, it is natural to identify it with the force that keeps the moon in its orbit round the earth, and finally with that which we observe directly when a body falls down from a height. But it had to be proved that the intensity of gravitation at the surface of the earth and that acting on the moon were related to each other according to the law deduced from the planetary motions; in other words, as the distance between the centres of the earth and moon is 60 times the earth's radius it had to be shown that the gravitational force at the surface of the earth is 3,600 times as great as that which keeps the moon in its orbit. The calculation is easily made if we know the length of the earth's diameter, and this having been ascertained with sufficient accuracy by Picard in France shortly before the publication of the "Principia," Newton had the satisfaction of finding an almost perfect agreement. His theory was confirmed, and it was definitely proved that the motion of the planetary system, as well as the behaviour of heavy bodies on the surface of the earth, could all be deduced from the general proposition that every particle of matter attracts every other particle with a force which varies in the inverse ratio of the square of the distance.

Commentators on Newton's work frequently draw attention to the delay in publishing for ten years or more the results of his calculations, because when they were first completed there seemed to be a discrepancy of about 11 per cent. between the value of gravity at the surface of the earth as deduced from the moon's orbit, and that which can be observed directly. It has even been said that, for a time, he rejected the theory altogether, but there is reason for believing that the delay was due to one uncertain step in the argument which might have caused an error and accounted for the disagreement. Newton consequently deferred publication until he could satisfy himself with regard to this doubtful point. The attraction of the earth as a whole is made up of the attraction of its separate parts. When the attracted body is at a distance, no great error can be committed by assuming the earth's mass to be concentrated at its centre, but it might be otherwise, if it is near the surface. Ultimately, Newton proved that, when the law of attraction is that of the inverse square, we may indeed take the attraction of a sphere at all distances to be the same as that of an equal mass placed at its centre. The real cause of the disagreement was then found to be the inaccurate value originally adopted for the circumference of the earth. When the measurements of Picard became known the agreement was found to be complete.

The importance of Newton's discovery extended far beyond its immediate results; its wider and far-reaching effect lay in the demonstration it supplied that by means of a rigorous mathematical analysis the facts of Nature can be represented not only in the vague speculative manner which then was considered sufficient by the majority of philosophers, but definitely and quantitatively, allowing a numerical test to be applied. Apart from the philosophic value of a rigorous treatment, the human mind is always strongly (on occasions too strongly) impressed by numerical coincidences. Newton's investigation which enabled him to calculate the force of gravity at the earth's surface from the time of revolution of the moon therefore carried conviction, and was accepted by the majority of his countrymen; but it took some time before the continent of Europe gave its full assent, and the criticisms which were raised illustrate the danger of taking up too definite an attitude with regard to the ultimate starting point representing the simple phenomenon from which everything else should be derived. In France, at any rate, the influence of Descartes' philosophy was paramount, and Descartes had truly started from the beginning: "I think, therefore I exist," was to him the only justifiable *à priori* assertion to make; everything else was to be deduced from that proposition. With a most powerful and original intellect, he had developed an ingenious and in many ways logical and consistent system, in which there was no room for the motion of any body except that which was brought about by the impulse of another body which itself was in motion. If the planets revolve round the sun, it was to him, therefore, clear that they must be carried along by an invisible medium whirling round the sun. Hence his hypothesis of gigantic vortices filling all space. This is not the place to explain how all phenomena in Nature were supposed to be accounted for by such means, but it is clear that the hypothesis was elastic, and could be varied, added to, and infinitely extended, whenever some difficulty arose. What concerns us here is that it seemed to go to the foundation of things—the origin of motion—and to those trained up in the doctrine of vortices, the mere postulate of a universal attraction to account for one set of natural phenomena, disregarding all the rest, seemed to be a retrograde step. Hence very naturally arose considerable opposition, and it was mainly those who disagreed with Descartes and believed in the possibility of action at a distance, who inclined towards Newton. But this was really beside the point, because Newton expressly guards himself against the implication that his theory necessarily involved action at a distance, the origin of gravitational force being in no way prejudged by the affirmation of its existence. We have here an example of the often recurring struggle between a general but indefinite hypothesis which suggests many things, but cannot be submitted to a numerical test, and what is characteristic of the Cambridge school of investigation. This school, which had its period of triumph in the nineteenth century, clearly defines a problem, confining it to such limits, wide or narrow, as will convert it into a precise problem which can be formulated and submitted to mathematical analysis. There must always be a definite answer to a definite question, and, unless the mathematical difficulties are insuperable, the consequences of any assumption may be obtained in a form in which they can be tested, not only as to their general nature but also as to their numerical values. The result may not be far-reaching, but within its limited field it is definite. We may not have penetrated to the foundation of the building, but we shall have mapped out one of its apartments and perhaps reached a fresh starting point.

Two centuries and a quarter have now passed since the publication of Newton's "Principia," and during that time our astronomical measurements have become more and more accurate. Though the mathematical analysis has sometimes found it difficult to keep pace with the improved methods of observation, Newton's simple law of the inverse square has hitherto always been found sufficient to explain apparent irregularities in the motion of the celestial bodies, with perhaps the solitary exception of an irregularity in the motion of Mercury, which may ultimately be cleared up without calling in some other agency or perhaps is destined to open out an entirely new aspect of gravitation.

The most precious heritage bequeathed to us by Newton is this: He has given us the confidence that, complicated as the problems of Nature may be, they are soluble if we confine ourselves to a limited and definite range, and follow up by irrefragable logical or mathematical reasoning the consequences of clearly-defined premises.

By his laws of motion Newton laid the foundation of modern dynamics. The next great advance relates to the constitution of "matter." Common experience shows that each piece of matter may change in shape or volume; it even seemingly vanishes, as when water evaporates, or is freshly formed, as when dew is deposited on a blade of grass. If this be kept in mind, we are forced to concede, in opposition to the school which professes to reject all theories, that an introspective philosophy entirely detached from observation may lead to a truth hidden from the pure experimentalist. To perceive that matter in spite of all appearances is indestructible goes beyond the limits of our direct observation; and a science without imagination confining itself to that which it can see would have grown very slowly indeed. We owe that much to the Greek philosophers, that they took a wider view, and at any rate tried to evolve a system which would satisfy our sense of harmony in the perception and interpretation of Nature. Their imagination frequently led them astray, but as often prepared the way for the evolution of the correct view. The idea that all matter is composed of separate small particles which cannot further be subdivided appears very early among the Greek philosophers. Anaxagoras, in the fifth century before Christ, assumed the existence of indestructible and immutable elements of which all bodies are composed, and called them "seeds." Half a century later, Democritus first used the word "atom," but differed from Anaxagoras by ascribing the different properties of bodies not to a difference in kind, but merely to one in shape and arrangement. Aristotle rejected this hypothesis completely, and his unhappy doctrine, apparently borrowed from Indian sources, which treats matter as an embodiment of mixtures in different proportions of the imaginary elements, fire, earth, water, and air, had a most paralysing influence on the history of science. The atomic theory consequently remained through centuries the subject of metaphysical speculations and the plaything of philosophers; as the foundation of chemical science, it takes its place only in modern times. But one great obstacle had to be removed. The chemistry of the eighteenth century was entirely under the influence of an erroneous theory of combustion, according to which inflammable bodies contained an invisible substance—"phlogiston"—showing itself as a flame on being expelled, and no progress was possible until the true nature of combustion had been demonstrated by the eminent French chemist Lavoisier. His explanations were so simple and convincing that it is difficult to understand why the attitude taken up by English chemists with regard to them was entirely hostile. Cavendish, like Black and Priestley, adhered to the phlogiston theory, even when the latter, by his discovery of oxygen, had supplied the chief weapon by which it ultimately fell.

Robert Boyle (1627–1691) had clearly shown how a sharp distinction between elementary and compound bodies could be drawn, and even explained the difference between mixtures and chemical compounds. But it was only when phlogiston had been finally abandoned that the way was prepared for our present conception of the constitution of matter. This is indelibly connected with the name of John Dalton (1766–1844), who taught us that the material universe contains a certain number of elementary substances, each possessing, as its ultimate constituent, a distinctive atom which cannot be split up farther by chemical or physical means. There are, therefore, as many different kinds of atoms as there are elementary substances. The atoms of each element are alike in every respect, and have the same weight. When atoms of different elements enter into close union with each other, they form what Dalton called "compound atoms," or, according to our present nomenclature, "molecules"; these are the ultimate constituents of compound bodies.

Dalton's first scientific interests, which he preserved through life, were connected with meteorology. He was led to his chemical investigations through attempting to find a reason for the uniformity in the mixture of gases at different levels of the atmosphere, being much puzzled to know why the oxygen, nitrogen, and aqueous vapour did not arrange themselves in layers according to their density, as when oil rises to the top if mixed with water. His difficulty was mainly due to the peculiar ideas he had formed of the nature of a gas. For a time he seems to have adopted the correct view that all gases at the same temperature and pressure have the same number of ultimate particles in unit volume, but he abandoned it because it did not seem to him to lead to the observed intermingling of gases irrespective of their density. He then invented a rather fanciful hypothesis which drew a distinction between the density of an atom and its weight, and he tried to find some connexion between the two. This led him to investigate atomic weights. Dalton's temperament and methods of procedure were different from those of the other leaders of science whose work is under review. He is rightly considered to be the originator of the principle of multiple proportions, but he did not base his results so much on accurate measurements, as on the logical coherence of the system he advocated. In its simplest form, this principle means that if one atom of an element can combine with one, two, or more atoms of another, the weight of the compound molecules formed must increase by equal steps. But in the "New System of Chemical Philosophy" (first published in 1810), though examples are given in illustration, no systematic attempt is made to reach an accuracy sufficient to establish a proof. To Dalton the principle was obvious, and he was mainly interested in determining the relative atomic weights and showing, for a number of simple substances, how many atoms of each element are combined to form the compound molecule. The most important portion of the work deals with substances in which one or all of the combined elements are gaseous, and he depends a good deal on the measurement of volumes before and after combination. As the methods of drying and otherwise purifying gases were imperfectly understood at the time, the figures which he obtained were, according to our standard, very inaccurate; nevertheless, the power and success with which he treated the subject very soon convinced other chemists that the foundations of his system were correct.

Dalton's evidence was cumulative rather than individually decisive, and it may be said that he convinced the scientific world more by the strength of his own convictions than by the experimental proofs he supplied.

The total number of elements known in Dalton's time was twenty-three, but others were soon added, until, towards the middle of last century, over sixty elementary substances were recognized. At present we have reason to believe that the number is strictly limited.[1] Whatever opposition there was to Dalton's views it died out quickly, though some philosophers found much that was distasteful in the immediate result of his teaching. There is, indeed, at first sight, something repellent in the idea that there should be one number, whether it be sixty-three or ninety-two, raised in importance so far above all others that it

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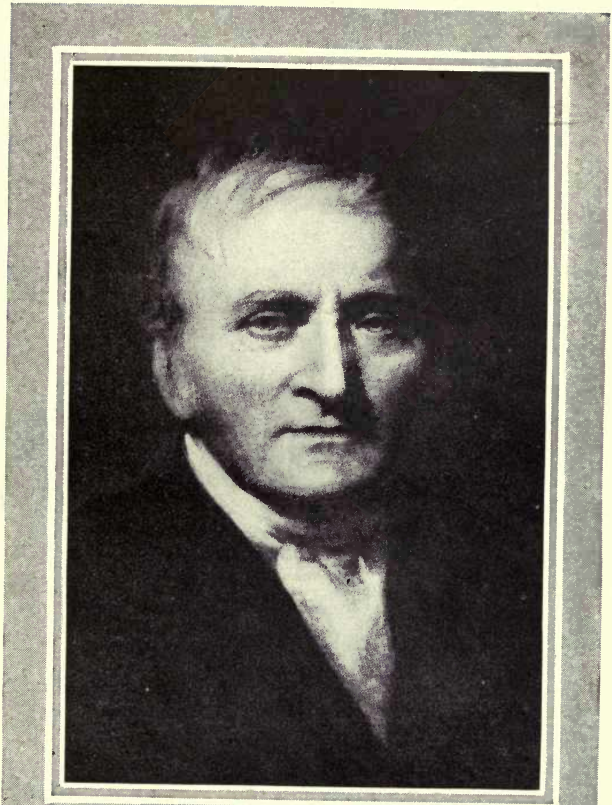
[1] *See* the result of Moseley's researches, page 185.



John Dalton

From a painting by R. R. Faulkner in the possession of the Royal Society

fixes the limits of creation, as regards the possible diversity of matter. But all such scruples must be set aside, for the atom of Dalton is only a stepping-stone to a higher level of knowledge. The chemist knows what he means by an atom, and when he is building up his compounds with them, he is not concerned with the question of their ultimate constitution; just as the builder who constructs a house with bricks need not trouble to enquire whether the substance of the bricks is continuous or made of up of molecules. The merit of Dalton's atomic theory, like that of the law of gravitation, is that it sets certain boundaries beyond which our imagination need not wander for the moment; it defines a limited problem and for the time solves it.

Speculations on the nature of light could not fail to attract the attention of the old philosophers; but, for our present purpose, we need not go farther back than to the rival theories of Newton and Huygens. The former—led, no doubt, by his predilection for an accurately definable starting point from which he could proceed to develop the consequence of a theory with mathematical precision—adopted the view (to be found already in the writings of Democritus), that light consists of small corpuscles emitted by the luminous body. The rectilinear propagation of light, and its bending as it passes from one transparent body to another, could easily be explained on this theory, and though it was incapable of dealing with the more complex properties of light, it received general support until the middle of last century.

It was apparently Hooke who first suggested that light was an undulatory motion in an all-pervading medium, but Huygens has the merit of showing how this hypothesis could explain luminous phenomena with a precision at least equal to that of the corpuscular theory. There being at that time no crucial test to decide between the rival theories, the cleavage of scientific opinion took place along the line of separation between metaphysical tendencies. Those who disliked the idea of a vacuum and action at a distance inclined towards Huygens, others towards Newton. Compromises have never been favoured by men of science, and as the theory of gravitation starts from an assumption implying action at a distance, those who were guided by Newton considered it to be almost a sacrilege to go further than the master. To them action at a distance became an universal dogma, and the undulatory theory had no chance until it could produce a conspicuous success by explaining experimental facts, which were not amenable to treatment by the more favoured hypothesis.

The analogy of light to sound attracted the attention of Thomas Young (1773–1829), and was emphasized by him in a paper published in the Philosophical Transactions of the Royal Society in 1800. Here, again, it was the detailed examination of one special aspect of the problem which led to the decisive advance. Some of the characteristic features of a wave motion may be illustrated by an examination of the waves passing over a sheet of water. Everyone is familiar with the circles spreading out from a centre when a stone is thrown into water; each point of the surface as the wave passes over it rising and falling alternately. If two stones are thrown, and enter the water at points near each other, each will start its own system of circles. These will overlap, and the question arises: how does the motion at any point of the surface of the water depend on the motion due to each wave separately? The question is so simple, and the answer seems so easy, that many must have passed it by as hardly worth recording; but Young saw that it was the key to the position: each wave produces its own effect without interference from the other. If, under the influence of one set of waves, a point were raised one inch above the undisturbed level, and the other set caused by itself alone an *elevation* of two inches, then the combined effect would be a rise of three inches. If the effect of the second wave at any time were a *depression* of two inches, the effect of the first being the same as before, the depression of two inches would overbalance the rise of one inch, and leave a depression amounting to one inch. If the rise due to one set of waves equals exactly the fall due to the other, there will be neither a rise nor a fall, but the point will remain at rest. This, in a few words, is the principle of "superposition of motions," which applies only approximately to water waves, but generally to all small displacements such as those we suppose to occur in the propagation of light. The important point to notice is, that two rays of light falling on the same point can neutralize each other's effect, so that there is darkness, where each ray separately produced illumination.

The colours of thin plates could not be explained on Newton's theory, unless the corpuscles of light were endowed with some peculiar attributes, and it occurred to Young that a more natural explanation presented itself by considering the overlapping of waves which occurs whenever two rays of light meet at a point. This led him to design new experiments in which two sets of light waves could be made to overlap in such a manner that the crest of one set falls exactly over the hollow of the other, so that the two waves neutralize each other. By measuring the distances of the dark regions from each other, he showed how the lengths of waves could be determined. All seemed simple and straightforward, when a formidable difficulty arose, through the discovery of a new property of light, now called polarization. This seems to have baffled Young to such an extent that he began to be doubtful of his theory. It was only when the French engineer, Fresnel (who rediscovered the cause of the "interference" of light and corrected Young's explanation of "diffraction"), had, in conjunction with Arago, formulated more precisely the experimental conditions under which polarized light may interfere, that the clue to the solution was found. In a letter to Arago, dated 12th of January 1817, Young suggested that the peculiarity of waves which gave rise to polarization might be due to the direction in which the motion takes place. In a wave of sound, each particle of air moves backward and forward in the direction in which the sound is propagated, so that if the sound spreads out from one point, the motion is directed everywhere to or from the centre. In a water wave propagated over a horizontal sheet of water, on the other hand, the direction is mainly up and down. It occurred to Young that if a wave of light resembled that spreading over a sheet of water, two disturbances propagated in the same direction might still show different effects, for if the wave comes straight towards us the direction of motion might be horizontal or vertical.

If the originality of a discovery can be gauged by the opposition it rouses, Young's work takes a high rank. In referring to his explanation of the interference of light—(*Edinburgh Review*, Vol. I., p. 450)—Lord Brougham expresses the opinion that it "contains nothing which deserves the name either of experiment or discovery," and concludes by "entreating the attention of the Royal Society, which has admitted of late so many hasty and unsubstantial papers into its Transactions."

As regards the suggestion of transverse vibrations, one might have imagined that the analogy of water waves would have secured its being more readily accepted, but the passage from two to three dimensions is by no means obvious, and its difficulties presented themselves with special force to mathematicians. When Fresnel had independently recognized that the experimental facts could not be explained except by accepting this transverse motion, he placed the wave theory of light on a new and firm basis; but he lost the collaboration and sympathy of his colleague Arago, who, up to the time of his death in 1853, would not recognize the possibility of a spherical wave in which the motion was not entirely radial. Even Laplace and Poisson were strongly antagonistic to the idea of spherical waves with transverse displacements; their difficulty was a very substantial one, solved only at a later date by the investigations of Stokes.

Of all men who have spent their lives in the search for experimental discoveries, no one has ever approached Michael Faraday (1791–1867) in the number, the variety, or the importance of the new facts disclosed by his labours. If we wish to select from among these discoveries one or two which have had a predominant influence in directing scientific efforts into new channels, we must give the first place to his researches on electro-magnetic induction. Starting from the discovery that an electric current suddenly generated or suddenly stopped caused an instantaneous current in a wire placed in its neighbourhood, he proceeded to show that a current passing through a wire which is made to move in the neighbourhood of another circuit induces similarly a current in the latter; and finally he extended these facts to the effects of moving magnets in place of electric currents. Faraday thus not only prepared the way for a consistent theory of electro-magnetic action, but proved that it was possible to convert electric energy into mechanical power, or, reciprocally, obtain electric energy by an expenditure of mechanical work. In other words, the whole of the present electric industry is based on his discoveries.

As a second example of Faraday's experimental genius, we may take his work on the chemical decomposition of a liquid when an electric current is sent through it. Though this process of electrolysis had been used with great success by Sir Humphry Davy, its laws were not fully understood. Faraday proved that the total quantity of the substance decomposed depends only on the total quantity of electricity which has passed, independently of whether it be a strong current acting for a short time, or a weak current acting for a correspondingly longer time. He also discovered a most important relation between the amount decomposed and the chemical constitution. In his own words: "If we adopt the atomic theory and phraseology, then the atoms of bodies which are equivalents to each other in their ordinary chemical action, have equal quantities of electricity naturally associated with them." How pregnant these words are as forerunners of the most recent researches in electricity will appear in due course.

During a long life Faraday piled his discoveries one upon another in almost continuous succession, yet they are united by a common thread of thought applied both consistently and persistently. New facts were brought to light, not through an omnivorous desire to penetrate into detached bits of unexplored regions, but by the wish to find a common link binding together all the forces which in each branch of Physics—gravity, electricity, magnetism and chemistry—had been treated as peculiar to that branch. His manner of looking at things was so different from that of other scientific men of his time, and in some ways so prophetic, that a few words must be said with regard to

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it, more especially as it was much more thorough-going than is generally represented.

Matter is only known to us through the forces which it exerts, and we cannot, therefore, reason about matter at all, but only about forces. This truth was so strongly impressed on Faraday's mind, that he warned scientific men against the use of the word "atom," because it fixed their attention on what he considered to be unessential. He could only conceive centres of force and lines of force emanating from these centres. Though all visible effects are perceived at the termination of the lines, his whole attention was fixed on the space which was filled by them. He objected to all materialistic conceptions and looked upon an all-pervading medium which had been invented to explain the phenomena of light as an unnecessary and objectionable imagination. He insisted that the lines of force which spread out from a centre cannot be conceived to be made of different stuff from the centres themselves, and that, therefore, the æther, if it exist at all, must itself be made up of lines of force emanating from separate centres. We may, perhaps, regard this view as a dim foreshadowing of the most recent and not yet firmly established views which have emerged from the so-called principle of relativity. The vibration of light Faraday tentatively suggested to be due to a vibration of the line of force emanating from a centre, and therefore forming an essential part of it. Each particle of matter in his mind sends out tentacles through space, and when two bits of matter seem to act on each other at a distance they only appear to do so because their tentacles are invisible to us. During the closing days of his fertile life he planned experiments—no doubt in connexion with his speculations on the nature of light—to test whether magnetic force requires time for its propagation.

Our belief in the conservation of energy now forms the foundation of our conception of nature, and we hold to it more firmly than to anything else that science has taught us. All the changes we witness in the material world are merely transformations of one form of energy into another, and these different forms can all be measured in the same units. The principle of conservation asserts that energy is never lost or gained in any of these transformations, the total quantity in the universe remaining the same. The simplest kind of energy is that of a body in motion, and is measured by half the product of the mass and the square of the velocity. If a heavy body be allowed to drop from a height, it increases its velocity as it falls, and strikes the ground with a certain amount of energy. If that energy has not been created, it must have existed already when the body was placed at the height from which it fell. Hence we must recognize some form of energy which depends on the gravitational attraction between the earth and the body. This potential energy, as we call it, is being transformed into the energy of motion (kinetic energy) as the body falls. These are the two great subdivisions of energy. If heat be not a substance, as was generally believed till the middle of last century, but a form of energy, a definite quantity of heat should be equivalent to a definite amount of energy; so that whatever the means by which we transform mechanical work into heat, we ought always to get the same amount. That this conclusion is correct was established by Joule's researches. It forms our first law of thermodynamics.

John Prescott Joule[1] (1818–1889) began his scientific career at the age of nineteen, and already six years later he had established his position as one of the greatest benefactors of the community. The characteristic quality of mind which enabled him without aid and without encouragement to accomplish so much was his ability to fix on the essential factors of a problem, and to verify his ideas by accurate measurements. Inspiration came to him from his own experiments; his first ideas were hesitating and sometimes wrong, but correcting them step by step, he was led almost automatically to the final great discovery. His cautious and strictly scientific procedure showed itself at an age when an abundance of energy and originality so often lead to ambitious speculations which are beyond the powers of inexperienced youth. Joule published his first results in a series of letters addressed to Sturgeon's "Annals of Electricity," and in the fourth of them he gives us the guiding motive of his research.

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[1] A valuable account of Joule's life and work, by Osborne Reynolds, will be found in the Joule volume of the Manchester Literary and Philosophical Society.

> "I can hardly doubt," he writes, "that electro-magnetism will ultimately be substituted for steam to propel machinery. If the power of the engine is in proportion to the attractive force of its magnets, and if this attraction is as the square of the electric force, the economy will be in the direct ratio of the quantity of electricity, and the cost of working the engine may be reduced *ad infinitum*. It is, however, yet to be determined how far the effects of magnetic electricity may disappoint these expectations."

Sturgeon's electro-magnetic engine which Joule tried to improve was a very primitive machine. His first attempt to render it more effective was not successful, as he admits; but what is remarkable is the strictly scientific manner in which he measured the power by the weight the engine could raise per minute. Joule next turned his attention to the measurement of the electric power absorbed. He designed and constructed a galvanometer for the purpose, and as a first result discovered an important law (subsequently shown to be only approximately true), which appeared to him to justify his belief in the future of the electro-magnetic engine. The passage—quoted above—in which he expresses this belief shows, however, that consideration of the conservation of energy had not crossed his mind at that time, and that he considered it possible to have an effective machine the cost of working which may be reduced *ad infinitum*. He had, nevertheless, some scruples about the effects of "magnetic electricity," which may disappoint his expectations. He therefore directed his attention to these effects. Referring to the impossibility of understanding experiments made by different investigators, "which is partly due to the arbitrary and vague numbers which are made to characterize the electric current," he adopted a system of units which can be reproduced anywhere, using the amount of water decomposed per hour as the standard of current, and the quantity of electricity delivered in one hour by the unit current as the unit quantity.

In a paper "On the Production of Heat by Voltaic Electricity," he announced the most important law, that heat generated in a circuit is proportional to the time, the resistance and the square of the current.

In the early stages of his investigations, Joule tacitly adopted the then accepted view that heat is a substance, which could not be generated or destroyed, but he soon altered his opinion. In 1843 he expressed himself as follows :—

> "The magnetic electrical machine enables us to convert mechanical power into heat by means of the electric currents which are induced by it. And I have little doubt that, by interposing an electro-magnetic engine in the circuit of a battery, a diminution of the heat evolved per equivalent of chemical change would be the consequence, and this in proportion to the mechanical power obtained."

It seems that Joule was not then aware of the previous experiments by Count Rumford, in which heat had been generated by means of mechanical work (*see* page 108).

He assumed a more decisive attitude in a subsequent paper, which is introduced with the words :—

> "It is pretty generally, I believe, taken for granted that the electric forces which are put into play by the magneto-electrical machine possess, throughout the whole circuit, the same calorific properties as currents arising from other sources. And indeed when we consider heat not as a *substance*, but as a *state of vibration*, there appears to be no reason why it should not be induced by an action of a simply mechanical character, such, for instance, as is presented in the revolution of a coil of wire before the poles of a permanent magnet. At the same time, it must be admitted that hitherto no experiments have been made decisive of this very interesting question; for all of them refer to a particular part of the circuit only, leaving it a matter of doubt whether the heat observed was *generated* or merely *transferred from the coils* in which the magneto-electricity was induced, the coils themselves becoming cold. The latter view did not appear untenable without further experiments. . . ."

The crucial experiment was performed by Joule with the result—again in his own words—"that we have therefore in magneto-electricity an agent capable by simple mechanical means of destroying or generating heat." The second part of the same paper, entitled "On the Mechanical Value of Heat," begins as follows:—

> "Having proved that heat is *generated* by the magneto-electrical machine, and that by means of the inductive power of magnetism we can *diminish* or *increase* at pleasure the *heat* due to chemical changes, it became an object of great interest to enquire whether a constant ratio existed between it and the mechanical power gained or lost. For this purpose it was only necessary to repeat some of the previous experiments and to ascertain, at the same time, the mechanical force necessary in order to turn the apparatus."

He thus finds that—

> "The quantity of heat capable of increasing the temperature of a pound of water by one degree of Fahrenheit's scale is equal to, and may be converted into, a mechanical force capable of raising 838 lbs. to the perpendicular height of one foot."

The particular method adopted to determine what we now call the mechanical equivalent of heat was beset with many experimental difficulties, and it is not therefore surprising that his first result was nearly 9 per cent. in error. Osborne Reynolds observed that the paragraph quoted really overstates the conclusions Joule was entitled to draw, because he has only shown that work could be converted into heat, but not the inverse process, and that, at that time, he had no clear ideas as to the conditions under which heat may be converted into work. In fact he had dealt only with the first law of thermodynamics, and it took some years before the second law could be formulated with precision. It must be remembered, however, that Joule was only twenty-five years old at the time of his great discovery, and that he was working alone, unsupported, and opposed by all the prejudices of the recognized authorities.

It is not necessary to refer here in detail to the skill with which Joule extended his investigations in many directions, generating heat by mechanical force in different manners, but always finding the same equivalent, until no vestige of doubt was left that all different forms of energy could be expressed in the same units. His measurements became more and more accurate, and such uncertainties as remained in the numerical value of the equivalent were, in great part, due to the difficulty of measuring the temperature with a glass thermometer; the accuracy obtained was indeed to some extent the result of the accidental excellence of his thermometers. A few years later the composition of glass became much less suitable for scientific use.

It has already been noted that while the conversion of mechanical work into heat was completely and satisfactorily dealt with by Joule, the converse transformation of heat into work involves further important considerations, into which it was necessary to enter. Sadi Carnot had, in 1824, published a work entitled "Réflexions sur la puissance motrice du feu, et sur les machines propres à développer cette puissance," in which the subject was treated with masterly perspicuity, but his reasoning was expressed in the language of the material theory of heat. He was, however, the first to point out that the mechanical production of an effect by a heat engine is always accompanied by a transference of heat from one body to another at a lower temperature. Relying on the axiom that a perpetual motion involving a continuous performance of work is impossible, he laid down the conditions for a thermodynamic engine which, with a given transference of heat, would do the maximum amount of work. The peculiarity of such an engine is, that whatever amount of work can be derived from a certain transference of heat, an equal reverse thermal effect will be produced if the same amount of work be spent in working it backwards. Further, the work done by a perfect heat-engine must be the same for the same transference of heat, whatever be the nature of the material used. If heat be a form of energy, and not a substance, it is clear that the amount which enters the cooler body of an engine must be less than that which leaves the hotter one, and that the difference is equivalent to the mechanical work done in the passage. The position of

Joule was, therefore, necessarily antagonistic to Carnot's assumption.

William Thomson (1824–1907), known to the present generation as Lord Kelvin, while studying in Regnault's laboratory in Paris, had become acquainted with the important conclusions that may be drawn from Carnot's thermodynamic cycle, and with the efforts which were being made in France to verify the relations between the thermal properties of substances which can be derived from it. Though at first reluctant to abandon so fertile a principle, and hesitating to give full assent to Joule's views, he soon discovered that Carnot's reasoning may be modified so as to bring it into harmony with the principle of the conservation of energy. The same solution had occurred to Clausius, who, anticipating Kelvin, was thus the first to give the correct theory of the heat engine; but we are here concerned only with the account of Kelvin's share in advancing the subject; and a very magnificent share it was. His great paper "On the Dynamical Theory of Heat," communicated to the Royal Society of Edinburgh in 1851, places the whole matter on a firm scientific basis, and establishes relations between the physical properties of substances which have all been verified experimentally. Full credit is given in the paper to those who have contributed to, and, in part, initiated, the ideas which led up to the final recognition of the conservation of energy as the most fundamental law of nature. What is called the second law of thermodynamics is really the adaptation to thermodynamics of the axiom expressing the impossibility of obtaining a perpetual motion by a heat-engine. As formulated by Lord Kelvin, it runs as follows: "It is impossible, by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest surrounding objects."

Considerations leading up to a complementary principle as important as that of the conservation of energy seem to have been in Kelvin's mind at an early stage. If we imagine a hot and a cold body, say, the boiler and condenser of a steam engine, we may, by transferring the heat from the first to the second, transform part of the thermal energy into work, but only a certain definite portion, exactly calculable in accordance with the second law and Carnot's principle. But if we bring the hot and cold bodies into actual contact with each other, and allow the heat to pass directly from one to the other, without doing mechanical work, their temperature will be equalized, and we shall have lost for ever the possibility of utilizing the thermal energy which has been transferred. There is, therefore, a fundamental difference between the transformation of mechanical work into heat and the inverse transformation. In the former case we may convert the whole mechanical energy into heat, as when we rub two bodies together and raise their temperature through friction, while, in the reverse operation, when heat is transformed into work, only part of that which leaves the source of heat is utilized. We must therefore distinguish in the energy of a body a part which is available for the performance of useful work, and another part which is unavailable, the thermal energy of a body containing only a definite proportion belonging to the first category. Moreover, it is only the ideally perfect engine that can utilize the whole of the available energy; in machines such as those we can construct there is always a further loss due to their imperfection. We must conclude that in the constantly occurring processes in which heat is allowed to pass from one piece of matter to another without doing useful work, the quantity of available energy stored in the universe is diminished. This leads us to the counterpart of the principle of *conservation*, which is that of the *dissipation* of energy. Among the wealth of achievements contained in the intellectual heritage left us by Kelvin, the discovery of this truth is pre-eminently the one which stands out as a landmark to future generations. It was first announced in 1852, and we may quote the main conclusions as then formulated.

1. There is at present in the material world a universal tendency to the dissipation of mechanical energy.

2. Any restoration of mechanical energy, without more than an equivalent dissipation, is impossible in inanimate material processes, and is probably never effected by means

of organized matter, either endowed with vegetable life, or subject to the will of an animated creature.

3. Within a finite period of time past, the Earth must have been, and within a finite period to come the Earth must again be, unfit for the habitation of man as at present constituted, unless operations have been, or are to be, performed, which are impossible under the laws to which the known operations going on at present in the material world are subject.

The third of these statements must necessarily apply not only to this earth but to the whole universe, and there is therefore no escape from the conclusion that the material universe, as we know it, is like a clockwork which is slowly but steadily running down.

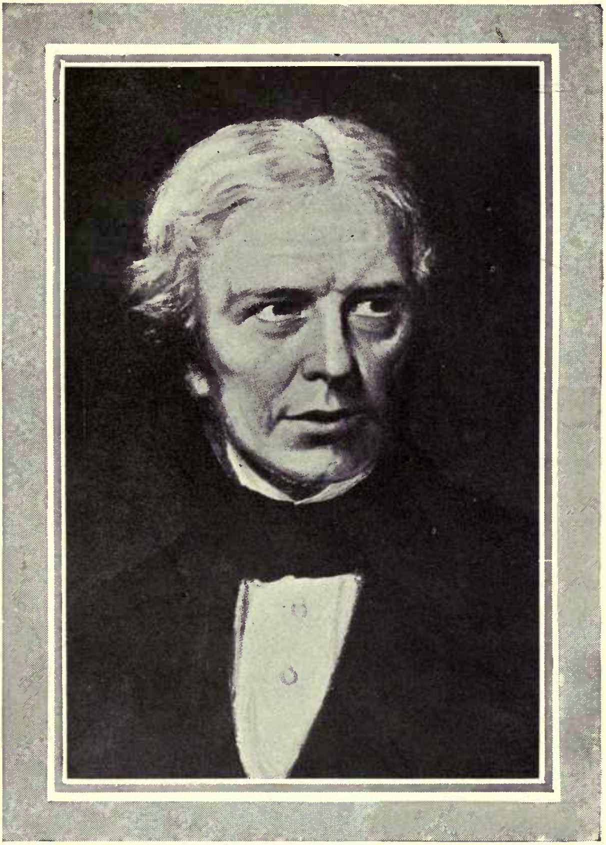
It was reserved to Clerk Maxwell to perceive the reason of our inability to check the gradual degradation of energy. Heat is essentially a disorderly motion, the particles of matter in a body which is apparently at rest moving irregularly in all directions. We are unable to convert this irregular into a regular motion, and it is this limitation of our powers which prevents our making full use of molecular energy as a source of mechanical work. Speaking of the second law of thermodynamics, Maxwell says: . . . . "it is undoubtedly true, as long as we can deal with bodies only in mass, and have no power of perceiving or handling the separate molecules of which they are made up. But if we conceive a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are still as essentially finite as our own, would be able to do what is at present impossible to us. For we have seen that the molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform, though the mean velocity of any great number of them, arbitrarily selected, is almost exactly uniform. Now let us suppose that such a vessel is divided into two portions, *A* and *B*, by a division in which there is a small hole, and that a being, who can see the individual molecules, opens and closes this hole so as to allow only the swifter molecules to pass from *A* to *B*, and only the slower ones to pass from *B* to *A*. He will thus, without expenditure of work, raise the temperature of *B* and lower that of *A*, in contradiction to the second law of thermodynamics."

In the history of electrical science Maxwell (1831–1879) stands in very much the same relative position to Faraday as Lord Kelvin occupied towards Joule in the domain of heat. They both brought pre-eminently mathematical minds to bear on the results of experimental discoveries, and saw more clearly than the original discoverers the important consequences which flowed from their researches. Neither Faraday nor Joule were experimentalists pure and simple, they were indeed guided mainly by theoretical considerations; but it lay beyond their object or powers to enter fully into the wider generalizations, though Faraday showed in the passages we have quoted that his imagination went far beyond his immediate experimental results.

The theory of electrostatics which deals with electric charges at rest, their distribution on conductors, and their mutual attractions or repulsions, is explained in the simplest manner by assuming the existence of two kinds of electricity, for which it is convenient to retain the old names, positive and negative electricity. The mechanical effects of the charges may be dealt with mathematically very much as we do in the case of gravitational attractions. There is also a formal analogy between magnetic and electric actions, so that independent magnetic fluids were sometimes introduced to facilitate the treatment of magnetic problems.

Faraday saw that, if we wish to grasp the relationship between the action of electric charges at rest and the electrodynamic effects produced by electricity in motion, and more especially, if we wish to include in the same field of enquiry the electric effects produced by moving magnets, we must take a more comprehensive view. We must cease to look at the centres or origin of the forces, and fix our attention on the medium between them. This, as has already been explained, was Faraday's outlook. Further, if the effects of light and electricity are both transmitted through a medium, our natural distaste to add unnecessarily to the number of hypotheses inclines us to the belief that the same medium serves both purposes. But here a formidable difficulty presented itself. The phenomena of light seemed to be explained in a satisfactory manner by giving to the æther the properties of ordinary incompressible elastic bodies, though certain circumstances might have roused the suspicion that we had not got hold of the whole truth. Yet the essential points seemed so well accounted for by the investigations of Green and Stokes, that there was every reason to believe that outstanding difficulties would be satisfactorily solved, without abandoning the substance of the theory. It was quite clear, nevertheless, that the medium invented to explain the properties of light, could not account for the electrical effects.

It is here that Maxwell's genius saw the solution: the problem had to be inverted. It was not the question of whether a medium adapted to account for the comparatively simple phenomena of light could explain electrical action, but whether a medium constructed so as to explain electrical action could also explain the phenomena of light. In formulating the essential properties of the medium which could produce the electrical effects, Maxwell had to fit a mathematical mantle on the somewhat crude skeleton of Faraday's creation. The task was formidable, and the manner in which it was carried through stands unequalled by any achievement in the whole range of scientific history, both as regards its intellectual effort and its final results. Only one of its successes need here be recorded. A quantity of electricity may be measured either by its electrostatic, when it is at rest, or by its electrodynamic effect, when it is in motion. Looking separately at the two manifestations of electricity, we are led to two different units in which it can be measured, the so-called electrostatic and electromagnetic units. The time of propagation of an electrodynamic effect through space was proved by Maxwell to be equal to the ratio of these two units. It could be calculated, therefore, from purely electric measurements, and it turned out to be exactly equal to the velocity of light. Hence luminous and electrodynamic disturbances are propagated with the same velocity, and we must conclude that their nature is identical. There was, after the publication of Maxwell's work, really nothing more to be said for the older



Michael Faraday

From a painting by A. Blakeley, in the possession of the Royal Society

view which gave to the æther the properties of elastic solids.

Brought up in a school of physicists which based the explanation of natural phenomena on perfectly defined conceptions, and required, therefore, always a mechanical model to represent properties of matter and force, Maxwell in his first efforts tried to outline the mechanical construction of the æther necessary to explain the electrical effects. He conceived this æther, the ultimate elements of which retained the properties of the cruder forms of matter, to be composed of cells, each of which enclosed a gyrostatic nucleus. Gradually, however, he abandoned these attempts at finding a mechanical model for the æther, and was satisfied to rely mainly on the mathematical formulæ which expressed its properties in the simplest way. In this he followed, or, to be strictly accurate, helped to initiate, the modern tendency of refusing to go beyond the immediate results of observation, relegating tacitly all questions of interpretation to the domain of metaphysics; which means disregarding them altogether. Maxwell's electrical work has revolutionized the whole aspect of science; and though undertaken in the purest spirit of philosophic enquiry, it has led directly to the great practical results which we see in the present applications of wireless telegraphy.

It is seldom that it is given to one man to open out new paths of thought in more than one direction. Newton's theory of gravitation and his optical work is an example of such a rare success, and there is perhaps no other equally marked except that supplied by Maxwell. Though his work on the constitution of gases may not have been as far-reaching in its results as the monumental researches we have already noted, it has introduced a new and original idea into the treatment of the properties of matter.

Towards the middle of last century, Herapath had revived the theory originally proposed by Daniel Bernoulli, according to which the pressure of a gas is due to the impact of its molecules against the sides of the vessel which contains it, and Joule, adopting this view, had calculated the velocity of the molecules of a gas from its known density and pressure. Such calculations can only give us the measure of an average. Through mutual collisions or otherwise, each particle constantly changes its velocity both in magnitude and direction, and it becomes important to determine the law regulating the distribution of velocities. Maxwell's classical investigation of this difficult problem has since been modified in detail and extended, but the manner in which he attacked it introduced an entirely novel method of applying mathematical reasoning to physical phenomena. Its results were decisive, and led to the discovery of new experimental facts connected with the internal friction of gases. When a metal disc is suspended from a wire passing through its centre so that the plane of the disc is horizontal, a twist imposed on the wire will cause the disc to perform oscillations in its own plane, which diminish in magnitude and gradually disappear owing to the internal friction of the gas surrounding it. Maxwell's calculations led to the unexpected result that this retarding effect should be the same whatever the pressure of the gas, so that air at a pressure of a few millimetres should diminish the motion of the disc as rapidly as when it is at atmospheric pressure. This surprising result was tested experimentally and found to be correct.

We are naturally interested in the personal history of those who have initiated new departures in science, and it is more especially instructive to record the character of their early education and the conditions under which they accomplished their work. Without entering into biographical details, we may briefly state, so far as they have not already been given, the essential facts in the lives of the great men whose achievements have formed the subject of this chapter.

Isaac Newton, the posthumous son of a small freehold farmer in Lincolnshire, is reported to have been—like Kepler—a seven months' child. While attending school at Grantham, he showed little disposition towards book learning, but great aptitude for mechanical contrivances, and he amused himself with the construction of windmills, water clocks, and kites. Not being considered fit to be a farmer, he was sent to the University of Cambridge in 1661, on the recommendation of an uncle who was a graduate of Trinity College. He does not seem to have received much inspiration from his teachers, but pursued his reading according to his own choice, and it was Descartes' "Geometry" that inspired his love for mathematics. In 1665, at the age of twenty-five, he left Cambridge on account of the Plague, and it seems that in this year the method of "fluxions," which contains the germ of the differential calculus, first occurred to him. Returning to Cambridge, he began his optical and chemical experiments, and continued his mathematical researches at the same time. In the year 1669, he was elected Lucasian Professor of Mathematics, and chose Optics as the subject of his first series of lectures. He continued his studies at Cambridge, the "Principia" being published in 1687. As a sign of national gratitude, Montague (afterwards Earl of Halifax), then Chancellor of the Exchequer and at the same time President of the Royal Society (1695–1698), offered Newton the post of Warden of the Mint in 1695, and this was followed five years later by his appointment to the Mastership, which was then worth between £1,200 and £1,500 per annum. Newton continued, however, to discharge his professorial duties at Cambridge until 1701. From 1703 onwards until his death, twenty-five years later, he held the Presidency of the Royal Society.

One is tempted to look upon the quiet life of the old Universities as being specially conducive to study and research, but the times of active progress in the Universities coincided rather with the periods when political disturbances were sufficiently intense to penetrate these havens of rest. Such a time was the end of the seventeenth century, when the interference of James II. into University affairs was a source of trouble both at Oxford and Cambridge. Newton himself took an active part in defending the prerogatives of the University. On a previous occasion he had taken the side of the Senate against the Heads of Colleges in a dispute about the Public Oratorship, and when in 1687 the King issued a mandate that a certain Benedictine monk should be admitted a Master of Arts without taking the oaths of allegiance and supremacy, Newton was one of the deputies appointed by the Senate to make representations to the High Commissioners' Court at Westminster.

In recognition of the services rendered to the University, he was elected on two occasions as their representative in Parliament. The interest which Newton displayed in University politics illustrates his intellectual vigour, and is inseparable from those qualities to which he owes his commanding position in the history of science. While it is, therefore, useless to speculate whether he was wise to allow his attention to be diverted from his more serious work, it is much to be regretted that his mind should have been disturbed by discussions about priority which affected his nervous system and damaged his health. These discussions were forced upon him, and he would gladly have avoided the bitter controversies with Hooke and, in later years, with Leibnitz.

No two men could differ more in temperament or outlook than Newton and John Dalton. To Newton the accurate numerical agreement between the results of observation and those of theory was of paramount importance, while in Dalton's experiments, numerical results were mainly used as illustrations of a theory which to him did not admit of any doubt. John Dalton was the second son of a weaver in poor circumstances living in Cumberland. In 1778, when only twelve years old, he started teaching at the Quaker School in Eaglesfield, where he himself had obtained his first instruction. In this he was not successful, and after a brief attempt at earning his living as a farmer, he left his native village in 1781, in order to assist a cousin who kept a school at Kendal. In 1793 he moved to Manchester, where he spent the remainder of his life as a teacher of mathematics and natural philosophy, first in "New College" (which ultimately was transferred to Oxford as "Manchester College"), and later privately. As early as 1787 he began to keep a meteorological diary, which he continued to the time of his death fifty-seven years later. He led the quiet life of a student, interrupted by occasional visits to the Lake District. In 1822 Dalton paid a short visit to Paris; of London he remarked that it was "the most disagreeable place on earth, for one of a contemplative turn, to reside in constantly" In addition to the work which gained him immortality, he foreshadowed several subsequent discoveries, and enunciated the correct law of expansion of gases some months before Gay Lussac, without, however, ever giving the numerical measurements required to prove the law. He was affected by colour-blindness, and first examined that defect scientifically. Dalton died in 1844, being then seventy-eight years old.

Thomas Young was probably, next to Leonardo da Vinci, the most versatile genius in history. He was descended from a Quaker family of Milverton, Somerset, and at the age of fourteen was acquainted with Latin, Greek, French, Italian, Hebrew, Persian and Arabic. He studied medicine in London, Edinburgh and Göttingen, and subsequently entered Emmanuel College, Cambridge. In 1799, at the age of twenty-six, he established himself as a physician in London. Subsequently he held for two years the Professorship of Physics at the Royal Institution, but resigned, fearing that his duties might interfere with his medical practice; during the tenure of his Professorship he delivered many lectures, which were subsequently published, and contain numerous anticipations of later theories. In 1804 he was elected Foreign Secretary of the Royal Society, and held that position for twenty-six years. In 1811 he became physician to St. George's Hospital, and Superintendent of the Nautical Almanac. His efforts to decipher Egyptian hieroglyphic inscriptions were among the first that were attended with success. His share in establishing the undulatory theory of light has already been described, and his claims as the founder of physiological optics will be discussed in another chapter (p. 299). Thomas Young was a man of private means, and not dependent on his medical practice for a living. He died in London in the year 1829. To quote Helmholtz:

> "He was one of the most clear-sighted of men who ever lived, but he had the misfortune to be too greatly superior in sagacity to his contemporaries. They gazed at him in astonishment, but could not always follow the bold flights of his intellect."

Michael Faraday, the son of a working blacksmith, was brought up in humble circumstances, and had but a scanty school education. In 1804, at the age of thirteen, he became an errand boy to a bookseller and stationer in

London, part of his duties being to carry round the newspapers in the morning. After a year of probation he was formally apprenticed to learn the art of bookbinding. It was by reading some of the books that passed through his hands that his mind was first attracted to science. Noticing an advertisement in the streets announcing evening lectures in Natural Philosophy with an admission fee of one shilling, he obtained his master's permission to attend the lectures. The account of his first connexion with the Royal Institution may be given in his own words:

> "When I was a bookseller's apprentice I was very fond of experiment and very averse to trade. It happened that a gentleman, a member of the Royal Institution, took me to hear some of Sir H. Davy's lectures in Albemarle Street. I took notes, and afterwards wrote them out more fairly in a quarto volume.
>
> "My desire to escape from Trade, which I thought vicious and selfish, and to enter into the service of Science, which I imagined made its pursuers amiable and liberal, induced me at last to take the bold and simple step of writing to Sir H. Davy, expressing my wishes, and a hope that, if an opportunity came in his way, he would favour my views; at the same time, I sent the notes I had taken of his lectures. . . . This took place at the end of the year 1812, and early in 1813 he requested to see me, and told me of the situation of assistant in the laboratory of the Royal Institution, just then vacant.
>
> "At the same time that he thus gratified my desires as to scientific employment, he still advised me not to give up the prospects I had before me, telling me that Science was a harsh mistress; and in a pecuniary point of view but poorly rewarding those who devoted themselves to her service. He smiled at my notion of the superior moral feelings of philosophic men, and said he would leave me to the experience of a few years to set me right on that matter.
>
> "Finally, through his good efforts, I went to the Royal Institution early in March of 1813 as assistant in the laboratory; and in October of the same year went with him abroad as his assistant in experiments and

> writing. I returned with him in April 1815, resumed my studies in the Royal Institution, and have, as you know, ever since remained there."

The journey abroad was a great event in Faraday's life, as he became acquainted with many famous men of science. Unfortunately his position was an unpleasant one. At the last moment, Sir Humphry Davy's valet had refused to leave the country, and Faraday had undertaken to replace him until he could engage a substitute at Paris; but no suitable person being found there, Faraday had to continue in the menial work which did not form part of the duties for which he was engaged. "I should have little to complain of," wrote Faraday, in connexion with this matter, "were I travelling with Sir Humphry alone, or were Lady Davy like him." An interesting incident took place during their stay at Geneva in the summer of 1814. During a shooting expedition, Faraday accompanied the party in order to load Davy's gun, and De La Rive, their host, accidentally entering into conversation with him, found that the boy who had been dining with his domestics was an intelligent man of science; accordingly he invited Faraday to dine at his table. To this Lady Davy strongly objected, and matters had to be compromised by dinner being served for Faraday in a separate room.

On his return home, after an absence of eighteen months, Faraday was again engaged as an assistant at the Royal Institution, and obtained some practice in lecturing at the "City Philosophical Society." His independent scientific work began in 1816, and was continued without interruption until 1860. In 1827 Mr. Brande, who had succeeded Davy as Professor of Chemistry at the Royal Institution, resigned his position and Faraday was elected in his place, having already, since 1825, occupied the position of Director of the Laboratory. Faraday's emoluments were insufficient even for his modest requirements, so that he had to supplement them by undertaking private practice in chemical analysis and expert work in the law courts; but though the income which he thus secured was very substantial, he soon gave it up, as he found it interfered with his scientific work.

In its place he accepted a lectureship at the Royal Academy of Woolwich with a salary of £200. Subsequently, he was made scientific adviser to Trinity House. At a later period he was granted a Civil List pension of £300. Unselfish, high-minded, and modest, Faraday enjoyed the confidence of his friends, and declined all official honours. His outstanding quality was his irrepressible enthusiasm for experimental research. Foreign visitors to the laboratory relate how, after a demonstration of one or other of his discoveries, "his eyes lit up with fire," or how, when in their turn, they showed him a striking experiment, he danced around, and wished he could always live "under the arches of light he had witnessed." Though interested in all practical applications of science, he preferred to leave their development to others.

> "I have rather," he is reported to have said, "been desirous of discovering new facts and new relations dependent on magnetoelectric induction than of exalting the force of those already obtained; being assured that the latter would find their full development hereafter."

The importance of the electrical industries to-day prove how brilliantly this assurance has been justified.

Joule's name appears to be derived from "Youlgrave," a village in Derbyshire where his family originally resided; but his grandfather migrated to Salford and acquired wealth as a brewer. When Joule was ten years old, his father sent him, together with his elder brother, to study chemistry under Dalton, who, however, during two years confined his instruction entirely to elementary mathematics, and before they could proceed to chemistry, Dalton was struck by paralysis, and had to give up work. It has already been explained how Joule was led to his final discoveries, starting from the desire to utilize the power of electrodynamic machines, which were then not more than interesting toys. Towards the end of 1840, when Joule was only twenty-two years of age, he forwarded a paper to the Royal Society in which he announced the correct law indicating how the heat developed in a wire through which a current of electricity passes depends on the intensity of the current. That paper was published in abstract in the Proceedings of the Royal

Society, but full publication in the Transactions was declined. A worse fate befell a later paper: "On the Changes of Temperature produced by the Rarefaction and Condensation of Air," read on June 20th, 1844, but not printed by the Society even in abstract. Joule must have felt severely disappointed at the time, but his disposition was so amiable and indulgent to human failings that, at any rate in his later years, he did not show any resentment. "I can quite understand," he once remarked, "how it came about that the authorities of the Royal Society refused my papers. They lived in London; I lived in Manchester; and they naturally said: What good can come out of a town where they dine in the middle of the day?"

Joule had not, however, to wait long for recognition; he was elected a Fellow of the Royal Society in 1850, a year before the same honour fell to Lord Kelvin and Stokes. The turning point in his life came with the meeting of the British Association at Oxford in June 1847, where he described his experiments. According to Joule's account that communication would have passed without comment if a young man had not risen, and by his intelligent observations created a lively interest in the new theory of heat. That man was William Thomson, afterwards Lord Kelvin, whose recollection of the meeting differs, however, from that of Joule.

> "I heard," he writes some years later, "his paper read at the sections, and felt strongly impelled to rise and say that it must be wrong . . . . . but as I listened on and on, I saw that Joule has certainly a great truth and a great discovery and a most important measurement to bring forward. So, instead of rising with my objection to the meeting, I waited till it was over, and said my say to Joule himself at the end of the meeting."

Whichever version of the incident be the correct one, it led to a lifelong friendship, and marks the date at which opposition to Joule's views began to break down. Faraday was also present at the meeting, and was impressed by Joule's work.

On the whole, Joule's life ran a smooth course. The independent means of his father allowed him to devote his whole time to scientific researches. He never took an active share in the management of the brewery, but the record of his observations of the pressure and temperature of the air are often entered on the blank pages of the books in which the stocks of barrels were kept. After his father's death, unfortunate investments materially diminished his income, and he was unable to undertake the heavy expenditure involved in the prosecution of his researches without some assistance from scientific societies with funds available for research purposes. The grant of a pension of £200 from the Civil List released him in 1878 from further anxieties. In private life Joule often expressed his opinions strongly, but the kindness of his character impressed all who came into contact with him, and the modesty of the man who, as much as any one, has placed experimental science in this country in the commanding position it occupies, is typically illustrated by the remark he made about himself two years before his death: "I believe I have done two or three little things, but nothing to make a fuss about."

William Thomson, born in 1824, was the second son of James Thomson, who, at the time of his marriage, was Professor of Mathematics in the "Academical Institution," Belfast. He was eight years old when his father took over the Professorship in the same subject at the University of Glasgow, and matriculated at that University at the early age of ten. He entered as an undergraduate at Cambridge in October, 1841, his first paper "On Fourier's Expansions of Functions in Trigonometrical Series" having already been published in the Cambridge Mathematical Journal in May of the same year. The paper was apparently written during a journey to Germany in the previous summer. No less than thirteen additional papers were published by him in the same journal during his undergraduate career, which ended in 1845 with his graduation as second wrangler. In the following year he was appointed Professor of Natural Philosophy at Glasgow, a position which he held during fifty-four years. From an early period he was recognized as one of the greatest scientific intellects of his time, surpassed in power by none, in originality perhaps only by Maxwell. Well merited honours came to him in rapid succession. He was created a knight in 1866, General Commander of the Victorian Order in 1896, and a Peer of Great Britain as Lord Kelvin in 1892. The Royal Society awarded to him the Copley Medal—their highest distinction—in 1883, and he occupied their Presidential Chair between 1890 and 1895. He was one of the original members of the Order of Merit, which was founded in 1902, and in the same year was made a Privy Councillor. He was buried in Westminster Abbey by the side of Newton.

Lord Kelvin's powers of work were prodigious and his memory unequalled. He claimed to be able to take up at any time the thread of an investigation which he had left unfinished ten years previously. His brain was uninterruptedly active; his notebook handy on every railway journey, and he could work till the late hours of an evening without risking a sleepless night.

Everyone interested in the history of science must often have asked himself the question how far its progress would have been retarded if a particular brain had never been called into existence. With few exceptions the answer arrived at would be that, though discoveries might have been delayed and reached by different roads, and the work of one man divided between two and three, the effect in the long run would have been small and perhaps insignificant; but it is difficult to believe that science would stand where it does to-day if Maxwell had never lived. Faraday's way of looking at things was perhaps equally distinctive, but Faraday's originality lay in the manner in which he was led to perform the experiments which brought new facts to light, and the same experiments might have suggested themselves to others in a different manner. Maxwell's originality of thought, on the other hand, was the essential factor in the investigation, and it is almost impossible to see how his results could have been arrived at by a different road from that which he took. He also possessed another power not always given to great intellects. A mind that excels in originality is frequently unable or, at any rate, unwilling to follow other men's lines of reasoning, and thereby loses much of its power of fructifying contemporary thought. But in Maxwell it was not only his originality, but also his receptivity that was exceptional. No one was less imitative, either in the manner of expression or in the direction of his thoughts; but he always knew how his own way of looking at things was related to that of others.

We possess a good account of Maxwell's life,[1] rendered specially valuable by the number of his letters which are reproduced; these allow us to get a glimpse of the attractive quaintness with which he could illuminate every subject, but the barest outline of his career must here suffice.

His powers of observation showed themselves at a very early age. In a letter, written when he was not yet three years old, his mother relates that "Show me how it does" was never out of his mouth, and that he investigated the hidden courses of streams and bell wires. At school, he did not at first take a very high place, and his schoolfellows so much misunderstood the character of the reserved, dreamy boy, that they gave him the nickname of "Dafty." He soon, however, grew interested in his work, and all his letters home breathe a healthy playful spirit. When fourteen years old he was taken by his father to attend some of the meetings of the Royal Society of Edinburgh, and a year later wrote a paper "On the Description of Oval Curves," which, on the recommendation of Professors Kelland and Forbes, was published by that Society. At that time he was already repeating for his own instruction experiments on light and magnetism. He entered the University of Edinburgh in 1847 at the age of sixteen, and after remaining three years entered Peterhouse at Cambridge, from which college, however, he soon migrated to Trinity, graduating as second wrangler in 1854. While still an undergraduate he published a number of papers in the Cambridge and Dublin Mathematical Journal; from that time onwards his scientific activity never ceased and gradually spread over a wider and wider range of subjects.

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[1] "Life of James Clerk Maxwell," by Lewis Campbell and William Garnett (Macmillan, 1882).

In November 1856 Maxwell was appointed Professor of Natural Philosophy at Marischal College, Aberdeen, a chair which was abolished in 1860 in consequence of the fusion of the two colleges in that town. Among many characteristic remarks which occur in his letters of that period we may quote the following: "I found it useful at Aberdeen to tell the students what parts of the subject they were *not* to remember, but to get up and forget at once as being rudimentary notions necessary to development, but requiring to be sloughed off before maturity." Between 1860 and 1865 Clerk Maxwell taught Physics at King's College, London. His duties there were exacting and he suffered from two serious illnesses. He may have realized that his powers of teaching did not lie in the direction of making matters easy to students, many of whom were not over anxious to learn, but it was probably mainly for reasons of health that he resigned his chair and settled down at Glenlair, the house built by his father on the family estate in Dumfriesshire. A few years later he was, however, persuaded with some difficulty to take over the newly-established Professorship of Experimental Physics at Cambridge. The Cavendish Laboratory was built in that University by the VIIth Duke of Devonshire for the prosecution of experimental research in Physics; it was opened in 1870, and there probably never has been a benefaction more fruitful in its results. The laboratory has, indeed, had a brilliant history; its immediate result was to allow Clerk Maxwell to spend the closing years of his life among old friends and new pupils. He died after a short but painful illness in November 1879, at the age of forty-eight. Those who knew him will hold his memory in affectionate remembrance, and to all who turn to his writings for a knowledge of his work he will always remain a source of inspiration.

CHAPTER II

(Physical Science)

THE HERITAGE OF THE UNIVERSITIES

during the Seventeenth and Eighteenth Centuries

THE range of activity covered by University teaching in the sixteenth century is indicated by the subjects assigned to the five Regius Professorships founded in 1546 at Oxford and Cambridge by King Henry VIII. These were Divinity, Hebrew, Greek, Civil Law, and Medicine, the latter subject forming the only point of contact with science. The practical demands of navigation were, however, beginning to stimulate the study of mathematics and astronomy, and when Gresham College was founded in 1575, separate professorships in these subjects were provided for. A few years later (1583), Edinburgh appointed professors of mathematics and natural philosophy, and Oxford followed with the endowment of the Sedleian Professorship of Natural Philosophy (1621), the Savilian Professorship of Geometry (1619), the Savilian Professorship of Astronomy (1621), and a Professorship of Botany (1669). During the seventeenth century, Cambridge could only claim the Lucasian Chair of Mathematics (1663), but it was the first University with a Chair of Chemistry, endowed in 1702. Its two Professorships of Astronomy were founded in 1704 and 1749 respectively. Chemistry and Botany being mainly introduced as adjuncts to medicine, it appears that science at the Universities may be said to have been confined to the application of mathematics first to Astronomy, and subsequently to other subjects, which, as they became more definite began to supply material for the exercise of mathematical skill. Experimental science for its own sake began to be taught at the Universities only in comparatively recent times. On the other hand, it is well to dispose at once of the erroneous impression that the British Universities were bodies which confined themselves to the academic discussion of abstruse subjects unrelated to the ordinary interests of the community. The Universities trained the medical men, who kept the flag of science flying in the eighteenth century, and the study of astronomy was pursued in great part for the sake of its value in finding the position of ships at sea, and in the measurement of time. The problems dealt with by mathematicians were, at first, generally suggested by practical requirements, and only gradually became detached from them. In fact, science began to be taught as a means towards a practical end.

If Gresham College had developed—as it ought to have done—into a University of London, it might have affected the higher education of England at a critical time in a manner which it is difficult now to estimate. Its founder, Sir Thomas Gresham, had studied at Cambridge, and was a man of exceptional abilities. He was admitted to the Mercers' Company at the age of twenty-four, and soon afterwards went to the Netherlands, where his father, a leading London merchant, had business interests. By his management of affairs in Amsterdam he helped King Edward VI. over his private financial difficulties, and received valuable grants of land as a reward. Under Queen Elizabeth he continued to act as financial agent of the Crown, and was knighted previous to his departure on a mission to the Count of Parma. Having realized the utility of the "Bourse" of Amsterdam during his residence in Holland, he offered to build at his own expense what afterwards became the Royal Exchange in London, if a suitable plot of land were placed at his disposal. This was done, and, in the upper part of the building erected, shops were established, the rental for which was handed over to Gresham. He then conceived the idea of converting his own mansion in Bishopsgate into a seat of learning, and endowing it with the revenues arising from the Royal Exchange. Some correspondence about this scheme took place in 1575, and after his death in 1579 it was found that —subject to the life interest of his wife—he had provided in his will for the foundation of a college. The first lectures were given in 1597, each professor receiving the stipend of £50, a sum somewhat larger than the revenue of the Regius Professors at Oxford and Cambridge, which was £40. The building contained residential quarters for the professors, an observatory, a reading hall, and some almshouses. It ultimately proved to be too expensive to be maintained with the available funds, and in 1768 was handed over to the Crown; the lectures were then held in the Royal Exchange until 1843, when the present building was erected.

The appointment of the professors was, by Gresham's will, vested in the Mayor and Corporation of London, who in their first selection consulted the Universities of Oxford and Cambridge, requesting them to nominate two candidates for each of the seven professorships; the final selection included three graduates of Oxford, three of Cambridge, and one who was a graduate of both Universities. The first Professor of Geometry at Gresham College was Henry Briggs (1561–1631), who, after the discovery of logarithms by Napier, calculated complete tables, and thus made their general use possible He also introduced the present notation of decimal fractions, one of the most important advances in the history of arithmetic. The last twelve years of his life were spent at Oxford, where he held the newly-founded Savilian Professorship of Geometry.

Edward Wright (1560–1615), a mathematician closely associated with Napier and Briggs, translated into English the Latin original of the work which contains the first account of logarithms, but his name deserves chiefly to be remembered in connexion with navigation, to which science he rendered conspicuous service by laying the scientific foundation of the method of constructing maps known as "Mercator's Projection." Wright studied at Cambridge, was elected to a fellowship of Caius College, and became a teacher of mathematics in the service of the East India Company.

Among those who, during the seventeenth century, held professorships at Gresham College, we note John Greaves, Isaac Barrow, Robert Hooke, Edward Gunter, Henry Gillibrand, and Christopher Wren. Their work now calls for consideration.

John Greaves (1602–1652), who held also for a time the Savilian Professorship of Astronomy at Oxford, from which position he was dismissed on political grounds in 1646, must be considered to be the earliest scientific metrologist. He determined with fair accuracy the relation between the Roman and English foot, and also carried out some investigations on Roman weights. One of his successors at Oxford, Edward Bernard (1638–1697), followed up this work, and published a treatise on ancient weights and measures.[1]

The mathematics of the time, as has already been noted, was under the influence of Descartes, who had invented the method of analytical geometry, in which the position of a point is defined by its distance from two lines at right angles to each other, and which represents a curve in the form of an equation as an algebraic relationship between these distances. When this is done, many problems suggest themselves, such as that of forming the equation to its tangent at any point, or calculating the area bounded by the curve. The solution of such problems led naturally to the conceptions from which the differential calculus emerged. Isaac Barrow (1630–1677), working along the lines indicated by Fermat and Pascal, succeeded in finding the correct expression for the tangents of a number of curves. A successful lecturer and writer of books, rather than an independent discoverer, he was, nevertheless, an interesting figure in the history of science. The son of a linendraper in London, educated at Charterhouse, he proceeded to study medical subjects as well as literature and astronomy at Cambridge, where he took his degree and obtained a Fellowship at Trinity College. Having been driven out of the University by the persecution of the Independents, he travelled in France and Italy, proceeding thence to Smyrna and Constantinople. After spending a year in Turkey, he returned home through Germany and Holland in 1659. In the following year, he was appointed to the Chair of Greek at

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[1] *See* "Report of the Smithsonian Institution, 1890," "The Art of Weighing and Measuring," by William Harkness.

Cambridge, and subsequently was elected Professor of Astronomy at Gresham College. He returned to his Alma Mater in 1663 to take up the newly-founded Lucasian Professorship of Mathematics. Perhaps he performed his most noteworthy scientific act when he resigned his chair in favour of his pupil Newton.

John Wallis (1616–1703) is another example of a University Professor who took an active share in the national life. After passing through Cambridge, where—like Barrow—he studied medicine, he took Holy Orders in 1641, but became involved in politics; he attained considerable facility in deciphering intercepted despatches of the Royalists, and thereby rendered considerable service to the Puritan party. After holding several livings in succession, he was appointed Savilian Professor of Geometry in 1649, in spite of the opposition of the Independents, who resented his having signed the protest against the execution of Charles I. John Wallis was one of the foremost mathematicians of his time. His work dealt chiefly with applications of Descartes' analytical geometry; but he also published a book on algebra. He seems to have been the first to conceive the idea of representing geometrically the square root of a negative quantity, and is the originator of the sign ∞ for infinity. Other writings of his dealt with the tides. His efforts to teach deaf mutes to speak, which are said to have been successful, were the first attempts in that direction. Wallis was also interested in investigations on sound, and in a paper published in the Philosophical Transactions he communicated some interesting experiments made by William Noble, fellow of Merton College, and Thomas Pigot, Fellow of Wadham, which contain important investigations on the phenomenon of resonance in sound. Light bodies were placed as riders to investigate the vibrations of stretched wires, and it was shown that when these wires responded to a higher harmonic, the riders were not set in motion if placed at what we now call the nodal points.

Associated with the group of mathematicians who were contemporaries of Newton, Lord Brouncker (1620–1684) takes an intermediate place between the professional and non-academic class. The title descended to him from his father, who had been elevated to the peerage by Charles I. Brouncker, after obtaining the degree of Doctor of Physic in the University of Oxford, devoted himself to the study of mathematics, and acquired a great reputation at home and abroad by his investigations, which take a high rank in the history of the subject. He made extensive use of approximation by infinite series, and though he is not the originator of continued fractions, he first used them effectively. He was one of the original promoters of the Royal Society, and was named as its President in the Charter. He occupied that position for fifteen years, during which he assiduously devoted himself to its duties. The first years of the Society were necessarily critical ones, and much credit for the judicious and successful direction of its affairs is due to his distinguished services.

Christopher Wren (1632–1723), though known to fame mainly as a great architect, distinguished himself at Oxford as a mathematician. He had, independently of Newton, suggested the existence of a universal attraction as the cause which retained planets in their orbits, and is highly spoken of in the "Principia." He also was the first to calculate the length of the curve called the cycloid.

In 1657 he became Professor of Astronomy at Gresham College, and three years later took over the Savilian Professorship at Oxford. Wren's contributions to science were substantial. When the Royal Society expressed a wish that mathematicians should investigate the laws of impact, Huygens, Wallis and Wren sent in independent investigations. All these contained a correct appreciation of the principle of conservation of momentum. The great architect's solution was correct so far as perfectly elastic bodies were concerned. Wallis began with the consideration of inelastic bodies, but ultimately treated the problem in the most general manner, including both perfect and imperfect elasticity.

A most striking instance of a family, who in many successive generations reached distinction in the academic world, may here be recorded. James Gregory (1638–1675), educated at Aberdeen, published, at the age of twenty-five, a treatise on optics, containing the invention of the reflecting telescope which goes by his name, but he had no opportunity of actually constructing an instrument. He was also the first to show how the distance of the sun could be deduced by observations of the passage of Venus across the disc of the sun. After a period of study at Padua he became Professor of Mathematics at St. Andrews and subsequently at Edinburgh. His elder brother, David Gregory (1627–1720), was privately engaged in scientific pursuits, and having used a barometer to predict the weather, paid the penalty of his success by being accused of witchcraft. David had three sons, the eldest of whom (1661–1708) successively held the Chair of Mathematics at Edinburgh and the Savilian Professorship of Astronomy at Oxford; the second son succeeded his elder brother in the Chair of Mathematics at Edinburgh, and the third (Charles) was Professor of Mathematics at St. Andrews. The eldest son of David, the Savilian Professor, was Dean of Christ Church and Professor of Modern History at Oxford.

Among the descendants of James Gregory we find in three generations four distinguished medical men, all of whom held professorships in the subject, and in the fourth generation, two brothers, the elder of whom, William (1803–1858), became Professor of Chemistry at the Andersonian University in Glasgow, at King's College in Aberdeen, and finally at Edinburgh University. His younger brother, Duncan Farquharson Gregory, entered Trinity College, Cambridge, assisted for a time the Professor of Chemistry, but ultimately devoted his attention to mathematics, and founded the Cambridge Mathematical Journal.

The scientific activity of the Universities in the second half of the seventeenth century was naturally dominated by the influence of Newton's work. His dynamical investigations, leading up to the explanation of the observed motions in the solar system, have already been described, and it is interesting to trace the historical connexion between those discoveries and others which remain to be mentioned. Fortunately his own words describing the succession of ideas as they occurred to him have been preserved:

> "In the beginning of the year 1665 I found the method of approximating series and the rule for deducing

> any dignity of any binomial into such a series. The same year, in May, I found the method of tangents of Gregory and Slusius, and in November had the direct method of fluxions, and the next year, in January, had the theory of colours, and in May following I had entrance into the inverse method of fluxions. And the same year I began to think of gravity extending to the orb of the moon, and having found out how to estimate the force with which a globe revolving within a sphere presses the surface of the sphere, from Kepler's rule of the periodical times of the planets being in a sesquialterate proportion of their distances from the centres of their orbs, I deduced that the forces which keep the planets in their orbs must be reciprocally as the squares of their distances from the centres about which they revolve; and thereby compared the force requisite to keep the moon in her orb with the force of gravity at the surface of the earth, and found them answer pretty nearly. All this was in the two Plague years of 1665 and 1666, for in those days I was in the prime of my age for invention, and minded mathematics and philosophy more than at any time since."[1]

In explanation of this passage it may be noted that the "method of fluxions" was the foundation of the differential calculus, and the "inverse method of fluxions" that of the integral calculus.

Newton's attention was probably drawn to the study of optics by Barrow. The change of direction of a ray of light on entering a transparent body obliquely had been a favourite subject of investigation in many countries, and the law regulating it was first correctly formulated by Snell (1591–1626), Professor of Mathematics at the University of Leiden. It was reserved to Newton to show that ordinary white light, such as sunlight, consisted of a mixture of different rays. When transmitted through a prism it spreads out into a band of coloured light called the spectrum, because the different rays are deviated to a different degree. With the same transparent material, the measure of the deviation, or the refrangibility, as we should now call it, is perfectly definite for each ray, and is intimately connected with its colour. Having once separated a ray of definite colour, no further refraction will alter that colour, and it will continue to retain the same properties. As one of the results of this discovery it became apparent that a lens cannot form a perfect image of an object, because different colours are not brought together at the same focus. This appeared to Newton to be such a serious and irremediable defect of telescopes with glass objectives, that he set himself to construct an instrument in which the principal lens is replaced by a mirror. At the request of the Royal Society, who had heard of his telescope, Newton forwarded the instrument to its secretary in December, 1671, with the result that in January of the succeeding year he was elected a Fellow of the Society. The idea of reflecting telescopes had, as already mentioned, previously occurred to Gregory, whose proposal differed, however, essentially from that of Newton in the manner in which the rays were ultimately brought to the observer's eye.

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[1] From a MS. among the Portsmouth Papers, quoted in the preface to the "Catalogue of the Portsmouth Papers."

Newton's name is attached to the coloured rings seen when two slightly curved surfaces of glass are brought together, so that there is a thin circular wedge of air formed near the point of contact. The explanation of these rings presented considerable difficulties, especially with the theory of light adopted by Newton. Though cognisant of the wave-theory of light, which, as shown by Huygens, could explain its propagation and refraction, Newton had good grounds for not accepting it. He saw that the analogy of sound which had been invoked in its favour broke down when applied to the formation of shadows. Sound after passing through an opening spreads in all directions, while light apparently follows a straight course. In other words, sound can turn a corner, while light seems unable to do so. More than a century later, Fresnel gave the correct explanation of the apparent discrepancy, showing that when the experimental conditions were made to correspond, the analogy was maintained. It is necessary for the purpose that the relation between the size of the aperture and the length of the wave should be the same, and as the waves of light are very short, either the aperture through which the light is made to enter has to be very small, or the opening allowing the sound to be transmitted must be large. In the latter case we get "sound shadows," in the former the light spreads out just as the sound does. But such refined considerations only matured in the nineteenth century. In the meantime, the ordinary laws of refraction and reflexion of light could be satisfactorily explained by the corpuscular theory, which seemed better able to cope with the formation of shadows, and Newton therefore preferred the simpler theory. It is unfortunate that an error of judgment, arising really from superior knowledge, paralysed the progress of optics for the time being, but this is the price which had to be paid for the many benefits which accrued to science through the confidence which Newton's work had inspired, and which in all other cases proved to be justified.

Newton's work on light brought him into controversy with Robert Hooke (1635–1703), a man of great genius but unpleasant temperament, who, for a time, held the Chair of Geometry at Gresham College. Hooke graduated at Oxford and there came into contact with John Wilkins, Thomas Wilkins and Robert Boyle. With an extraordinarily prolific mind he touched on many subjects, insisting on his priority in almost every new idea that was brought forward by others.

In his "Micrographia" Hooke described important observations on the nature of combustion and of flames. Almost identical experiments were conducted by John Mayow (1640–1679), a fellow of All Souls College, Oxford, and it is impossible now to ascertain to whom they were originally due. Mayow, who was also a distinguished physiologist (*see* p. 296, Chapter XI.), interpreted these experiments with remarkable foresight. He truly recognized that there must be a common element in air and in such bodies as nitre, which readily give up their oxygen, and showed that the air contains some constituent which is consumed in combustion; he thus came very near anticipating by more than a century Lavoisier's great discovery.

Hooke was the first who conceived the idea of regulating watches by the balance wheel and spiral spring, and this alone would give him a high place among discoverers. He first constructed a spirit level, but others had anticipated him in the use of the Vernier. He was the first to use light powders to study the vibration of sounding bodies, and invented an instrument to measure the depth of the sea. His more theoretical speculations always showed acuteness, and might have led to great things if he had been more persevering. In 1674 he published views on a universal gravitation which was to explain the planetary motions; with the exception of the law of the inverse square, these contained the main principles of the theory which Newton had then already worked out, though not published. In optics, Hooke favoured the undulatory theory, and even expressed the idea that the motion of the particles of the medium which transmitted light was transverse to the direction of propagation, differing in this respect from the waves of sound. Newton, who disliked controversies, is said to have delayed the publication of his book on optics until after Hooke's death for fear of rousing an acrimonious discussion.

The second edition of Newton's "Principia" was published in 1713 by Cotes (1682–1716), a distinguished and promising mathematician, who died at the early age of thirty-four, having held during the last ten years of his life the newly-founded Plumian Professorship at Cambridge.

Among the professional representatives of mathematics during the eighteenth century, it must suffice to name Maclaurin (1698–1746), Professor of Mathematics at Aberdeen; Matthew Stewart (1717–1785), who succeeded him in the Professorship, and Thomas Simpson, the son of a grocer, who ultimately became Professor of Mathematics at the Royal Woolwich Academy.

After Newton had placed astronomy on a sound dynamical foundation, a vast field was opened out to further research. It had still to be proved that the law of gravitation was sufficient to account for every detail of the motions of celestial bodies, and was not only a first approximation to be supplemented by other effects. Hence it became necessary to increase the accuracy of astronomical observations, and to extend the theoretical investigations, based on the laws of gravity, so as to include the mutual action of planets on each other. We have now to consider the work of some of the great men occupied in this task.

Flamsteed (1646–1720) does not strictly belong to the academic circle, but as he was the first official representative of astronomy in this country it is convenient to speak of his work at this stage. Flamsteed began at an early age to take an interest in astronomical observations. He entered Jesus College, Cambridge, apparently with the object of taking holy orders, but after obtaining his degree, influential friends procured him an appointment as "King's astronomer." About the same time, a Frenchman, called Le Sieur de S. Pierre, visited England with proposals for improved methods of determining longitudes at sea, and Flamsteed in a report expressed the opinion that the project was impracticable, because the position of the stars were not known with sufficient accuracy. According to some manuscripts kept at the Greenwich Observatory, when this came to the ears of King Charles II, "he was startled at the assertion of the fixed stars places being false in the catalogue, and said, with some vehemence, he must have them anew observed, examined and corrected, for the use of his seamen." This incident was the immediate cause of the foundation of Greenwich Observatory, the warrant for its building being issued on June 12th, 1675. When it was completed, Flamsteed set to work to form an improved star catalogue. Up to that time, only observations with the naked eye had been used to determine the positions of the stars, though the cross wire and measuring micrometer had already been invented by Gascoigne. Flamsteed realized the advantages of applying the telescope in combination with a clock. But he had to struggle against great disadvantages; his salary was £100 a year, and he was provided by the Government with neither assistants nor instruments. The latter had to be provided by friends, or made at his own expense. In spite of these difficulties he produced as a result of his labour a star catalogue three times as extensive as, and six times more accurate than, that of Tycho Brahe, which up till then had been in use. Altogether he recorded the positions of 3,000 stars.

Flamsteed was succeeded at Greenwich by Edmund

Halley (1656–1742), who plays an important and interesting part in the history of science. The son of a soap-boiler, and educated at St. Paul's School and Queen's College, Oxford, Halley, at the early age of nineteen, invented an improved method for determining the elements of planetary orbits. Finding that more accurate measurements of the positions of fixed stars were necessary to the progress of astronomy, and that this task was being satisfactorily carried out at Greenwich for the northern heavens, he planned a journey to catalogue some of the southern stars. Through the good offices of the East India Company he obtained a passage to St. Helena, but disappointed with the weather conditions, he returned to England after having registered the positions of about 300 stars. He was an ardent supporter of Newton, and it was in great part due to Halley's efforts that the "Principia" were published.

Halley was the first to take a comprehensive view of the subject of Terrestrial Magnetism. Some advances had been made in that subject since Gilbert's time, notably by Edward Gunter (1581–1621), one of the early professors of astronomy at Gresham College, who had taken regular observations of the angle between the direction in which the magnetic needle sets and the geographical north, and found a progressive change in its amount. When the first observation was taken in England, the needle pointed to the east of north; in 1657 it pointed due north, and the declination then gradually increased towards the west. Henry Gellibrand (1597–1637) continued and extended these observations.

In order to explain these slow changes called "the secular variation of terrestrial magnetism," Halley formed the theory that the earth is divided into an outer crust and an inner nucleus, each part possessing its own independent magnetic poles. A fluid layer was supposed to separate the shell and the core, and Halley imagined the latter to revolve with a slightly smaller velocity than the former about a common axis. It is easy to see that if we accept the premises, a suitable adjustment of the magnetic axes of the inner and outer parts of the earth would lead to a slow revolution of the resulting magnetic axis. This theory was recently renewed and extended by Henry

Wilde, and, though not generally accepted, it shows that Halley recognized that the study of terrestrial magnetism could yield important information on the constitution of the earth and that he looked upon the subject from a wider point of view than that of its mere application to the purposes of navigation. The observations he took in two journeys specially undertaken for the purpose of determining the magnetic declination in different parts of the world, are invaluable to us as historical records.

Halley's most important discoveries in astronomy were the secular acceleration of the moon's mean motion, the proper motion of the stars, and the periodicity of comets. Comparing the dates at which certain total eclipses of the sun had occurred, Halley could fix the times of the new moon with sufficient accuracy to ascertain that the length of the month was diminishing by about one-thirtieth of a second per century. This implied that the moon's orbital velocity is increasing and may be explained in accordance with Newton's principles, partly as a result of an indirect effect on the earth's orbit round the sun due to the attraction of planets, and partly by friction between the tides and the solid parts of the earth, which increases the length of the day, and indirectly reacts on the moon.

In all three of the discoveries mentioned, Halley made extensive use of old records; it was by comparing the observed distances of well-known stars from the ecliptic with the observations of the Greek astronomers, that he discovered their independent motions, and, similarly by calculating the orbits of comets observed in previous centuries, he found that some of them pursued nearly identical paths. He concluded that though these were registered each time as new intruders into the solar systems, they might only be reappearances of the same body. As an example, he took the comet which had been observed at intervals of about seventy-six years, and had last been seen in 1682. He predicted that it would be seen again in 1758. Halley did not live to see his prophecy come true: the comet was actually observed on Christmas Day of that year, and is now recognized as a permanent member of the Solar System.

Halley succeeded Waller as Professor of Geometry at Oxford in 1678, and Flamsteed as Astronomer Royal in 1720. When he arrived at Greenwich, he found most of the instruments removed, being the private property of his predecessor. He procured some new ones, and began the series of observations of the moon, the continuance and improvement of which has always been the special care of the Royal Observatory. But the age at which he took over his duties prevented his making much progress.

Halley's activity covered a large range of subjects, and proved him to be a man of extensive knowledge and great versatility. He investigated, independently of Mariotte, the diminution of the pressure of air as we rise above the surface of the earth, and gave the correct formula for calculating differences in altitude from the barometric records; he observed the aurora borealis, and connected it with terrestrial magnetism by noting that the highest point of the arch lies in the magnetic meridian. He gave the generally accepted explanation of the cause of the trade winds, but was less successful in his attempts to improve the construction of thermometers; he was the first to give the formula which connects the position of objects and images formed by lenses; he formed an estimate of the quantity of water vapour which enters the atmosphere by the action of solar heat on the oceans; he wrote on the effect of the refraction of air on astronomical observations, worked out the method of deducing the distance of the sun from observations on the transit of Venus, and made valuable contributions to the method of calculating logarithms. He improved the construction of diving bells, and was the originator of "life statistics." There are few men who can show a finer record of scientific activity.

Halley was succeeded at Greenwich by Bradley (1692–1762), to whom, according to the astronomer Delambre, we owe the accuracy of modern astronomy. Bradley was a nephew of John Pond (1669–1724), a clergyman who had erected an astronomical observatory at his rectory of Wanstead in Essex, and done some meritorious work on the satellites of Saturn and Jupiter. After graduating at Oxford, Bradley went to reside with his uncle, and became interested in astronomical work. His observational skill soon secured results of sufficient importance to justify his election to the fellowship of the Royal Society in 1718, and the appointment to the Savilian Chair of Astronomy in 1721. He, however, continued to live in Wanstead even after the death of his uncle, visiting Oxford only for the delivery of his lectures.

It was known to Robert Hooke that the distance of the stars might be ascertained by noting their change of position at different times of the year, for as the earth revolves round the sun, we look upon each star from a slightly different point of view according to the position of the earth in its orbit. The more remote the stars, the smaller will be the displacement, and no one could tell beforehand whether any of them were sufficiently near to show a measurable effect. Hooke himself, with his accustomed impetuosity, had tried the method, and using a star which for particular reasons was specially fitted for the purpose, believed that he had observed a comparatively large displacement. Samuel Molyneux (*see* page 90) had erected a suitable telescope at his house in Kew Green, for the purpose of verifying Hooke's observations, and observed the same star on a series of evenings during the early part of December, 1725, but no material change of position was noted. At this stage Bradley, a friend of Molyneux, began to take part in the investigation. On visiting the Observatory at Kew on December 17th, curiosity tempted him to take an observation, and he noted that the star had slightly increased in declination. To his surprise, however, the displacement was found to be in a direction opposite to that to be expected if it were due to the proximity of the star. The apparent movement was then continuously watched, and the star was found to describe a closed curve, returning at the end of a year's observation very nearly to its original position. Bradley, much puzzled by the result, at first thought that the displacement might be due to a periodic change in the inclination of the earth's axis. In order to test this idea, it was necessary to observe stars in different parts of the sky, and Bradley set up a new instrument at his home in Wanstead for the purpose. He found, indeed, that every star examined described an elliptic curve similar to that observed with Molyneux's telescope, but the differences in size and shape did not agree with the hypothesis he had formed. At last the true explanation occurred to him.

Owing to the fact that light is not transmitted instantaneously, a star is not actually seen in the direction in which it would appear if light took no time in its passage to the earth. The cause of this curious effect may be illustrated by a familiar analogy. A person driving in a carriage during a shower of rain on a windless day, though the drops fall down vertically will feel them striking against his face, as if he were meeting the wind. Hence, holding up an umbrella to shield himself, he would have to tilt it forwards and if he were unaware of his own motion, he would believe that the drops fall at an angle slightly inclined to the vertical. Substituting Newton's corpuscles of light for the drops of rain, it becomes clear that the velocity of the earth affects the angle at which the light coming from a star *seems* to reach us. This effect is called the "aberration of light." As the earth's velocity changes in direction while it revolves round the sun, a star, though stationary, will appear to describe a closed curve. From the known velocity of the earth, and the extent of a star's apparent motion, the velocity of light may be calculated, and Bradley found it to agree closely with that which had been calculated by Roemer from the eclipses of Jupiter's satellites. The accuracy of Bradley's observations may be appreciated by noting that if the star's position in the sky be such that it appears, owing to the aberration of light, to describe a circle, the angular diameter of the circle is about that of a halfpenny piece placed at a distance of 420 feet; the dimensions of the curve described by the star were measured by Bradley with an accuracy of about two per cent.

After Bradley had established himself at Greenwich Observatory, he continued his observations, and found that the stars after a year's interval did not return to the same position, as they ought to do if the aberration of light were the only cause of their apparent displacement. Returning to his original idea of a small change in the inclination of the earth's axis, he then found it to account satisfactorily for this residual effect. He thus discovered the "nutation" of the earth's axis, which is caused by an attractive effect of the sun on the equatorial protuberance of the earth, which is not an exact sphere, but a spheroid with a larger equatorial than polar diameter.

When it is considered that every measurement of a star's position has to be corrected so as to eliminate the effects of aberration and nutation before its true position is ascertained, Delambre's judgment that the accuracy of astronomical observations owes everything to Bradley cannot be gainsaid, and we shall also probably agree with the same author[1] that "ce double service assure à son auteur la place la plus distinguée après celle de Hipparque et de Képler, et au-dessus des plus grands astronomes de tousles âges et de tous les pays."

After Bradley's death, Nathaniel Bliss, Savilian Professor of Geometry at Oxford, was appointed Astronomer Royal, but he only held the position for two years. Nevile Maskelyne (1732–1811), a man of much greater ability, next had charge of Greenwich Observatory. He graduated as seventh wrangler at Cambridge in 1754, and twelve years later was appointed to the post of Astronomer Royal, the duties of which he discharged successfully during forty-six years. His mind was first turned to astronomy as a boy of sixteen by watching a solar eclipse. During a voyage undertaken to observe the Transit of Venus, in 1761, he became interested in a process for determining longitudes by measuring the distances of selected stars from the moon, and he ultimately succeeded in introducing this method as a regular practice in navigation. The importance of the procedure consisted in its being independent of timekeepers, and it consequently retained its place until recently, when the construction of chronometers improved so much that it lost its practical value.

In order to make the tabulations of the position of the moon and of the selected stars readily accessible to navigators, Maskelyne persuaded the Government to issue an annual publication. This was the origin of the Nautical

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[1] Delambre, "Histoire de l'Astronomie au dix huitième siècle."

Almanac, which has proved to be of immeasurable value to all seamen. Maskelyne remained its editor until his death. He also re-organized in many ways the work and instrumental equipment of the Greenwich Observatory, and instituted an important research which led to the first determination of the density of the earth. To appreciate the importance of this experiment, we must remember that by noting the rate of fall of a body we can measure the force with which the earth attracts it, but not knowing the total mass of the earth, we cannot tell how much one pound of matter would attract another pound at a given distance. That can only be ascertained by measuring the attraction between masses both of which are known. From the result of such a measurement the mass of the earth may be calculated, and as its dimensions are known, we can deduce its mean density. The problem of finding the density of the earth is, therefore, identical with that of finding the gravitational attraction between known masses, and herein lies its chief value. Maskelyne's method consisted in determining the deflexion of a plumb line in the neighbourhood of a mountain. As this deflexion cannot be observed directly, we must have recourse to an indirect method; but this presents no difficulties. If the latitudes of two places, one to the north and the other to the south of a mountain, be determined astronomically, and their distances directly measured, the discrepancy between the observed and measured differences of latitude gives us the data we want for calculating the gravitational effect of the mountain. The method cannot give very accurate results, as the density of the material composing the mountain must be taken into account, and this requires a geological survey and complicated calculations. Maskelyne was assisted in his measurements, which were conducted in the neighbourhood of the mountain Schehallien in Perthshire, by Charles Hutton (1737–1823), Professor of Mathematics at the Military Academy, Woolwich; the figures they obtained showed that bulk for bulk the material of the earth is on the average between 4·48 and 5·38 times heavier than water.

While learning at Oxford and Cambridge rapidly declined after the first impulse of Newton's discoveries had died away, the reputation of academic science in the eighteenth century is retrieved by the splendid record of the Scotch Universities, and notably of Edinburgh. It was indeed a brilliant period in which Black originated quantitative chemistry, Hutton founded the science of geology, Robert Simpson taught mathematics, and John Robison, natural philosophy, while Watt worked out his inventions, and in other branches of knowledge Adam Smith and David Hume added to the fame of their Universities.

William Cullen (1710–1790), who may be said to be the founder of the Scotch school of chemists, studied at the University of Glasgow, and at the age of nineteen obtained, through the influence of friends, a post as surgeon on a merchant ship sailing to the West Indies. On his return home he became a medical practitioner in his native town, Hamilton, but a small legacy enabled him to spend two years at Edinburgh, in order to pass through a regular course of study. After a period of activity in Glasgow, during which he occupied the Chair of Medicine, and assisted in founding the medical school in that university, he returned to Edinburgh as Professor of Chemistry. Cullen was the discoverer of the lowering of temperature which takes place when a liquid evaporates, or a solid dissolves in a liquid. He also experimented on the heat generated in chemical transformations.

It was no doubt these researches on heat which directed Joseph Black's attention to that subject. Black (1728–1799) was the son of a Scotch wine merchant living at Bordeaux. He was educated at Belfast, Glasgow and Edinburgh, studied medicine at the latter University, and presented to it at the age of twenty-six an inaugural dissertation containing discoveries of fundamental importance to chemistry. Limestone, which forms so important a portion of the earth's surface layers, was at that time considered to be an elementary substance. It was known, of course, that at a high temperature its properties are changed; it becomes quicklime, which gives off a great amount of heat when brought into contact with water. This was explained at the time by supposing that the limestone absorbed, when heated, an imaginary thermal or caustic substance which it gave out again when brought into contact with water. The corresponding compound of magnesia behaved similarly, and was not clearly distinguished from the calcium salt. Magnesia had then already some importance as a drug, and the title of Black's dissertation "De humoro acido a cibis orto et magnesia alba" indicates that it was the medical aspect that led him to the research. Black proved that the current explanation was wrong, and that, instead of absorbing anything, limestone, on heating, lost in weight, and gave out a gas, which he collected and identified with Helmont's "gas sylvestre." He definitely proved that this gas, now known as carbonic acid, differed from air, because it could combine with caustic soda and potash, which air could not; he also showed that atmospheric air always contained small quantities of it. Black further established the essential differences between the behaviour of calcium and magnesium compounds. His use of the balance in these researches justifies the claim that has been made on his behalf of being the father of quantitative chemistry.

In his researches on heat, Black showed an equal power of selecting the fundamentally important questions, and of treating them with experimental skill and scientific precision. His results were explained in his lectures, but many of them remained unpublished until after his death It is, therefore, not always easy to fix the dates at which his discoveries were communicated to his students, so as to compare them with similar results arrived at in other countries, notably by Wilcke at Stockholm, and Deluc, who, born in 1727 at Geneva, left his native town at the age of forty-three and after various travels settled down in England, and died at Windsor in 1817. There is no doubt, however, that Black was the discoverer of latent heat. Deluc had noted the slow melting of ice, and made the observation that when a mixture of ice and water is heated, the temperature of the water remains constant until all the ice is melted, but Black went a good deal further, and not only measured the heat required to melt the ice, but showed it to be the same in amount as that which was set free in freezing the water. He applied the term "latent heat," which is still in use, and his measurements were correct to two per cent. The corresponding phenomenon was observed when water was converted into steam, but, owing to the greater experimental difficulties, the numerical value obtained was not so accurate. Black also had clear ideas on the differences in the amounts of heat required to raise different substances through the same range of temperature; but handed over this part of the subject to his pupil Irvine.

An interesting paper by Black on "The supposed effect of boiling on water in disposing it to freeze more readily, ascertained by experiments" (Phil. Trans. 1775) is worth reading as an example of clear thinking, lucid description, and good experimenting. It is still to-day the common belief of plumbers, and those who derive their knowledge of science from plumbers, that hot-water pipes freeze more readily in winter than cold ones. This belief seems to have had its origin in the report, made on good authority, that when water is exposed at night in the dry atmosphere of the Indian winter, in order to convert it into ice through the loss of heat by radiation, it is essential to boil it previously. In order to find the reason for this, Black exposed two similar cups, one filled with boiled and the other with unboiled water, to a temperature below the freezing point, and saw, indeed, ice crystals appearing on the surface of the former, while the latter remained clear. But on introducing thermometers, he discovered that the temperature of the unboiled water had fallen below the freezing point, without being converted into ice, which, however, formed as soon as the water was stirred. Black was aware of Fahrenheit's observation that water, when kept perfectly quiescent, could be cooled considerably below the normal temperature of freezing. The question that remained to be solved was, therefore, this: why should the unboiled water be more easily undercooled than that which had been boiled? The only effect that boiling can have on the water is to expel the absorbed air, and one might be tempted to reason from the above experiment that the absorbed air favours the undercooling. But this explanation is negatived by the circumstance that Fahrenheit's experiments were conducted in a vessel from which the air had been removed by the air pump. Black, realizing, therefore, that water deprived of its air could be undercooled as well as ordinary water, concluded that the cause of the difference lay in the act of re-absorbing the air. He suggested that the absorption caused (possibly through minute differences of temperature or density) sufficient circulation, or, as he expressed it, "agitation" to prevent the undercooling. It is remarkable that the subject has never been examined further, but Black's explanation finds some support in the experiments made by Thomas Graham, who showed that the admission of air into a previously boiled and undercooled solution of Glauber salt, set the crystallization going, and this was traced to a slight diminution of the solubility of the salt in water which contains air.

To Black must also be given a place in the history of aeronautics, as he was the first to make the attempt to fill a balloon with hydrogen; this was as early as 1767, two years before Montgolfier made his first balloon ascent.

Black practised as a medical man; he held for a time the Chair of Anatomy and Chemistry at Glasgow, but distrustful of his qualifications as a chemist, exchanged it for that of Medicine. In 1766 he succeeded Cullen in the Professorship of Medicine and Chemistry at Edinburgh. In private life he was fond of painting; the weakness of his health is probably responsible for a certain lack of energy which sometimes led him to abandon his work when half finished, and to leave many of his researches unpublished. "No man had less nonsense in his head," said Adam Smith, "than Black."

One further contribution of the Scotch Universities to chemistry remains to be noticed. Rutherford (1749–1819), a medical man who occupied the Chair of Botany at Edinburgh, was the first to isolate the gas nitrogen in 1772, by burning substances in an enclosed volume of air, and absorbing the carbonic acid formed in the combustion.

Black's lectures were edited after his death by John Robison (1739–1805), a man of great intellectual powers, who, like so many other men of science of the time, led an eventful life. After a brief period of study at Glasgow, he became tutor to the son of Admiral Knowles, who as a midshipman was about to accompany General Wolfe to

Quebec. Robison took part in the war, and after his return home was charged by the Board of Longitude to undertake a journey to the West Indies for the purpose of testing a chronometer constructed by John Harrison. A few years later Robison accompanied, as private secretary, Admiral Knowles to Petrograd, on his appointment as President of the Russian Board of Admiralty. For a time he also held the mathematical professorship attached to the cadet corps of nobles at Petrograd. Before he went to Russia Robison had occupied during four years the Chair of Chemistry at Glasgow, and after his return home in 1773 he became Professor of Natural Philosophy at Edinburgh. When the Royal Society of Edinburgh received its charter in 1783 he was elected secretary, and held this position until within a few years of his death, which took place in 1805.

Robison enjoyed a high reputation among his contemporaries, but we cannot assign any great advance in science to him. He was a man of great learning and published researches, which only just fell short of marking a distinct step. He deserves to be remembered even if it were only for his connexion with James Watt, who owed him much assistance and encouragement. Robison was always interested in steam, and had, before Watt's improvement of the steam engine, conceived the idea of applying the power of steam to the propulsion of vehicles.

David Brewster collated some of the manuscripts left by Robison, and published them in a work of four volumes: "Elements of Mechanical Philosophy."

It appears from this work that Robison undertook several researches, which he omitted to publish. Among them was an experimental investigation on the law of action of electrical forces. This, he states, was communicated to a "public society" in 1769, some years before Cavendish and Coulomb discovered the law of the inverse square. The experiments which are described in the published work, lead unmistakably to that law, but it is not stated whether they were the original ones or were repeated and improved upon later. Robison makes no claim in this respect, but refers to Cavendish as having "with singular sagacity and address, employed his mathematical knowledge in a way that opened the road to a much further and more scientific prosecution of the discovery, if it can be called by that name," and finally adopts Coulomb's measurements as conclusive. It seems, however, to have escaped notice hitherto that Robison in his experiments used what must be considered to be the first absolute electrometer, the electric force being balanced by the action of gravity, and therefore reducible to its value in terms of dynamical units.

Robison was a strong adherent of Boscovich, the Italian philosopher, who tried to dispose of the difficulties inherent in the definition of matter by considering atoms to be merely centres of forces without extension. Boscovich had applied his theory to the effects of ponderable matter on the transmission of light, and Robison took up this subject and treated it in a paper (Ed. Phil. Trans., Vol. II., 1790), which in many ways is remarkable. Its title, " On the motion of light as affected by refracting and reflecting substances which are in motion," shows that it deals with one of the most puzzling and difficult problems of physics. It was the phenomenon of aberration of light discovered by Bradley which gave practical importance to the subject, and, without entering into details, it deserves to be recorded that Robison had the idea of applying telescopes filled with water to clear up experimentally some of the obscure points, which up to our own times have puzzled mathematicians. This idea was revived and successfully applied later by Airy, but Robison failed on account of the difficulty of obtaining water that was sufficiently transparent. Although his ideas are now superseded, the paper gives us some idea of the powers of the man of whom Watt wrote : " He was a man of the clearest head and the most science of anybody I have ever known."

Robison's successor, both in the Chair of Physics and as Secretary of the Royal Society of Edinburgh, was John Playfair (1748–1819), previously Professor of Mathematics, who had taken part in the geological survey connected with the Schehallien experiment of Maskelyne and Robert Hutton. His first work was a book on " Hutton's Theory of the Earth," which had considerable influence in making James Hutton's geological theories known and appreciated. His mathematical contribution to science is mainly confined to a publication "On the Arithmetic of Impossible Quantities."

Though but little work of importance was produced at Oxford and Cambridge in the eighteenth century, science was kept alive. John Theophilus Desaguliers (1683–1744), the son of a French Protestant clergyman, who left his country on the revocation of the Edict of Nantes, was brought to England while an infant. He studied at Oxford and acted as Professor of Physics in that University. He settled in London in 1712, and ultimately became Chaplain to the Prince of Wales. After leaving Oxford, he became a voluminous writer on many subjects. In his first paper he describes a new method of building chimneys so as to prevent their smoking. He invented a machine for measuring the depth of the sea and other mechanical contrivances. He is best remembered by his electrical work in which he clearly defined the nature of a conductor as distinguished from bodies which could be electrified by friction without being attached to insulating handles. He enjoyed a great reputation, being consulted by men of science, and notably by James Watt in connexion with steam engines, having himself introduced some improvements in their construction.

At Cambridge, Robert Smith (1689–1768), as Plumian Professor, made some valuable contributions to acoustics, published in a separate volume—"Harmonics." His great treatise on light contains a wealth of information, and still possesses considerable historical interest. It had a great influence at the time, stimulating the study of optics, more especially with regard to its practical applications in the construction of optical instruments.

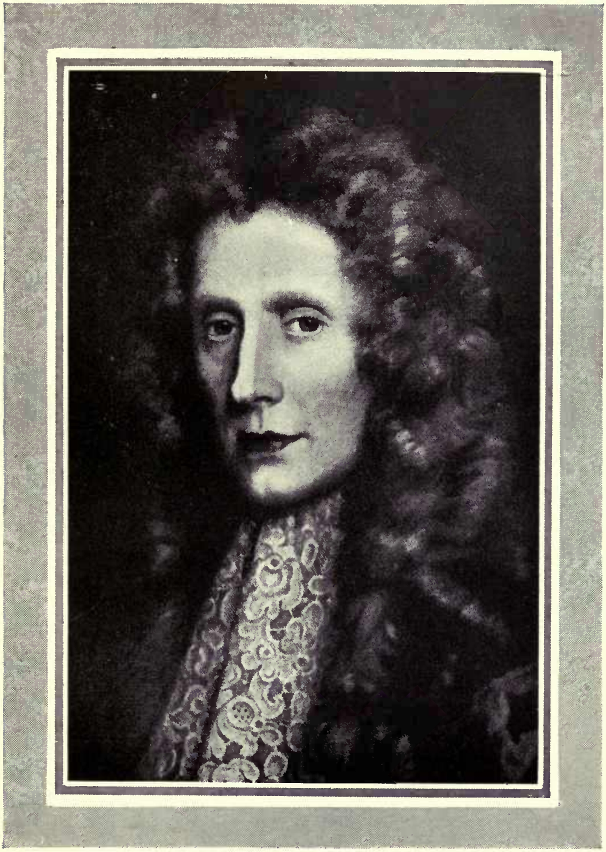
CHAPTER III

(Physical Science)

THE NON-ACADEMIC HERITAGE

during the Seventeenth and Eighteenth Centuries

THE scientific investigator should be endowed with knowledge, critical judgment, and inventive power. For the first two attributes we must look mainly to professional men, who have gone through a recognized training and are engaged in teaching or research. Such men, brought up under the compelling influence of accepted currents of thought, though well prepared to advance their subject and even to make new discoveries along the paths opened out by their predecessors, are heavily handicapped when the time has come for a revolution of fundamental ideas. Often they have risen to the occasion, and thrown antiquated doctrines overboard, but sometimes the academic tradition is strong enough to prevail. The advantage, then, lies with those who are not burdened by the weight of inherited opinions, and great opportunities are offered to the inexperienced youth or the enthusiastic amateur. What constitutes an amateur? All efforts to define the term must fail, because we cannot define what is not definite. The word in its literal sense denotes a man who pursues a subject for the love of it, but it carries a suggestion of weakness, or rather a suspicion, associated more particularly with amateurs in art, that they have not completely mastered their craft. So far as the actual work of research is concerned the difference between the amateur and professional man is not always pronounced, and is frequently obliterated; some University professors have retained through life the characteristic attributes of free lances of science, and



The Hon. Robert Boyle

From a painting by F. Kerseboom in

amateurs have occasionally rivalled professional scholars in profundity of knowledge and academic conservatism.

The essential distinction—and it is an important one—lies in the wider range of subjects which the professional man of science has to cover. He may have to lecture or advise students on matters which are outside his own researches, or he may have to direct an institution burdened with a quantity of routine work which cannot be neglected. He both gains and loses by the exigencies of his duties; while his compulsory reading may supply him with analogies which are frequently fertile in valuable suggestions, he is often drawn away to side issues, and is tempted to adopt a dogmatic attitude on those portions of his subject which he teaches or directs, but is not much interested in.

The non-academic class of workers are free from any routine which they do not impose on themselves and, as might be expected, present less uniformity in their aims and modes of working. What greater contrast could, indeed, be found than that between the three men whose work forms the main subject of this chapter: Robert Boyle, the indefatigable experimenter and voluminous writer, who, though refusing a peerage and the Presidency of the Royal Society, found his chief pleasure in intercourse with other men of science: Henry Cavendish, the taciturn recluse, who disliked contact with the ordinary affairs of life, and was remiss even in publishing his revolutionizing researches; William Herschel, the poor Hanoverian oboist, who had to earn his living as a teacher of music, and fight his way up until, with telescopes constructed by his own hands, he attained unrivalled pre-eminence as an astronomer.

Robert Boyle (1627–1691) belonged to an old Herefordshire family, whose name is mentioned in Domesday Book as Biuville. His father, Richard, described by Thomas Birch as one of the greatest men of his age, passed through a course of study at Cambridge, and having spent some time in London as a student of the Middle Temple, went to Ireland to make his fortune, married a rich wife, and ultimately became Baron of Youghall, Viscount of Dungarvan and Earl of Cork. He was married twice and had fifteen children. Robert, the last but one of them, received his education partly at Eton, and then privately at his father's newly-purchased property near Stalbridge in Dorsetshire. At the age of eleven he was sent on a lengthy journey to the continent, accompanied by an elder brother and a French tutor, Marcombes; they reached Geneva, where they stayed nearly two years before proceeding to Italy. At Florence, Boyle became acquainted with the works of Galileo, and one can imagine the impression the death of that great man, which occurred during his stay, must have made on his youthful mind. The party proceeded to Rome, and ultimately set out on their return journey, but found themselves at Marseilles without means, as a remittance from Boyle's father had been stolen by the messenger. Almost penniless, they made their way back to Geneva, M. Marcombes' native place, and ultimately the two brothers reached England in the summer of 1644. They found their father dead, and the country in such confusion that it was nearly four months before Robert Boyle, who inherited the manor at Stalbridge, could make his way thither.[1] In London, Robert Boyle made the acquaintance of John Wallis, Christopher Wren, and other distinguished men, whose weekly meetings were destined to lead to the foundation of the Royal Society. Though his scientific studies were interrupted by an enforced visit to his disordered Irish estates, which extended over two years, he settled down in 1654 at Oxford, where, during the following fourteen years, he devoted himself entirely to scientific research. He spent the remainder of his life in London, taking an active part in the affairs of the Royal Society until two years before his death. Boyle had strong religious views; but he refused to take orders on the ground that he felt no inner call, and thereby lost the appointment as Provost of Eton. He so strictly interpreted the command of the New Testament not to swear "neither by heaven, nor by earth, nor by any other oath," that he refused the Presidency of the Royal Society, because the Charter prescribed the taking of an oath on his accession to office. By his will he founded the "Boyle Lectures" for the defence of Christianity. He was never strong in health; weak eyesight troubled him throughout life, and a painful disease caused him much suffering in later years.

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[1] "Dictionary of National Biography."

His scientific work is distinguished by great experimental skill, and a determination to remain free from the bias of preconceived notions. In his travels he had become proficient in several languages, and he continued to keep himself informed of what was being done on the continent of Europe. Having read an account of Guericke's air-pump (or, as Boyle calls it, "wind-pump"), he set to work to construct one, and with the help of Robert Hooke, who appears to have acted as his assistant at that period, succeeded in effecting considerable improvements. With this pump a large number of experiments were performed, all devised to prove some definite point, such as comparing the weight of air with that of water, or investigating what he calls the spring of air. He showed that flames are extinguished and hot coal ceases to glow in a partial vacuum. He proved that magnetic and electric actions persist in his exhausted receiver, and that warm water begins to boil under reduced pressure. The action of the pump in removing air from a vessel suggested the inverse process of increasing the pressure, and this led to the construction of the compression pump. In his measurements he attained considerable accuracy; the specific gravity of mercury was correctly determined to one half per cent., that of air to about 20 per cent.

Boyle's name is associated with the important law connecting the density of air with its pressure. The proof of the law is contained in a long paper entitled "Defence of the doctrine touching the spring and weight of air," published in 1662. The range of pressures covered by the experiments extended from four atmospheres (involving the use of glass tubes ten feet long) down to 1¼ inches of mercury; the agreement between observed pressures and those calculated from the changes of volume, assuming that density and pressure are proportional, was quite sufficient to prove the correctness of the law. The often repeated assertion that it was Townley who first drew Boyle's attention to the significance of these observations and formulated the law is not justified, and is founded apparently on some misconception of a passage in Boyle's account of his experiments.

We owe to Boyle the use of the term "barometer," and he constructed an instrument in which the mercury is replaced by a short column of water with sufficient air above to counter-balance the atmospheric pressure. When no temperature changes interfere, such an instrument would be considerably more sensitive than an ordinary barometer. With it Boyle could observe the difference of pressure between the roof and floor of Westminster Abbey, thus confirming Pascal's experiment without having to ascend a mountain.

In his optical experiments Boyle showed that colours are produced by a modification of the light which takes place at the surface of the coloured body. The connexion between radiant heat and light was illustrated by covering half of a tile with black and the other half with white paint, when he found that in sunlight the black paint becomes hot while the white remains cold. He also first drew attention to the colours of thin films such as soap bubbles. He investigated freezing mixtures and discovered that when salt is added to snow or ice the observed cooling is connected with the liquefaction of the salt. Boyle invented the hydrometer and showed how to determine by means of it specific gravities not only of liquids but also of solids. He made extensive chemical experiments, and correctly explained a chemical reaction as being due to the substitution of an atom of one kind for an atom of another kind in the original compound.

Boyle's completed works occupy six folio volumes; he is somewhat prolix in his discussions, but his descriptions are always clear and interesting. By the manner in which he allows himself to be led from one experiment to another he almost reminds one of Faraday, though his indiscriminate mixing of what is important with what is of minor value partakes a little of the weakness of the dilettante. He was highly esteemed by his contemporaries, and Newton, as well as many other eminent men of science, showed, in their correspondence, that they attached great value to his opinions.

It is comparatively rare to find an eminent mathematician among amateurs, but a noteworthy example is furnished by Brooke Taylor (1685–1731), a wealthy man who, having completed his studies, soon acquired a reputation by his researches, and was elected into the Royal Society in 1712; two years later, he became one of the secretaries of that body. Taylor's theorem is known to every student of mathematics; in the subject of mathematical physics we owe to him the formula which connects the period of vibration of a stretched string with its length, cross-section and tension.

The meetings of the Royal Society in the early days of its activity were only partly occupied by the reading of papers. Experiments were shown and discussed, and new subjects were proposed for investigation; particular questions were occasionally assigned to individual Fellows for enquiry and report. In this manner scientific research was organized more successfully than has ever since been possible. To assist the Society's work, a curator was appointed, whose special duties consisted in preparing the experiments for the meetings. A wide range of subjects was therefore brought to the notice of the meetings in an attractive form, and we find that many Fellows extended their researches in consequence of the stimulus received at the meetings. The inducement to do so was more especially strong with those who acted as curators, and this may be one of the reasons why Robert Hooke, the first who occupied that position, touched upon such a variety of subjects in widely different fields of enquiry. Among those who were employed at the beginning of the eighteenth century to prepare experiments, though he does not seem to have received the title of curator, was Francis Hauksbee, to whom we owe many interesting observations. Passing a strong current of air over the reservoir of a barometer, he found that the height of the column of mercury diminished by two inches, thus proving the reduction of pressure accompanying the increase of kinetic energy in fluid motion. He connected this observation with the fall of the barometer during a gale of wind. He was the first who investigated the transmission of sound through water, and made some interesting experiments on the intensity of sound transmitted through air of different densities.

Hauksbee deserves, perhaps, most to be remembered by his researches in electricity. Frequent references occur in the publications of the time to the curious luminosity in the partial vacuum above the barometer column which occasionally appears when the mercury is made to oscillate in the dark. Hauksbee had the idea that the luminosity was connected with some electrical action. To test this, he mounted a spherical glass vessel so that it could be made to rotate round a central axis. The vessel was exhausted, and, being set in motion, became highly electrified by friction when the hand was placed against it. At the same time the remnant of air in the vessel became luminous, and Hauksbee rightly concluded that the luminosity was of the same nature as that observed in the barometer; in the latter case, of course, the friction is produced internally between the moving mercury and the glass. Incidentally it may be mentioned that the first record of an electric spark occurs in Hauksbee's writing; it was produced by approaching the finger towards the electrified glass vessel, and is said to have been an inch long.

Very little is known about the life of Hauksbee, or of that of Stephen Gray and Granville Wheler, two other important contributors to our knowledge of electricity. Gray, elected a Fellow of the Royal Society in 1732, was the first to point out the effects of conductivity in electrical experiments, classifying bodies as conductors or insulators. He had been led to this fundamental distinction by experimenting with a glass tube which was closed at one end by a cork, and noting that, when the glass was excited by friction, the cork attracted light bodies, thus showing that it had become electrified. When a rod several feet in length carrying an ivory sphere at its further end was inserted in the cork, the sphere also became electrified. When other experiments did not give the expected result, Gray seems to have consulted another Fellow of the Royal Society, Granville Wheler, a clergyman, who suggested to him that the cause of the failure was likely to be due to the difficulty of supporting the bodies experimented upon in such a manner that the electricity could not escape to earth. He advised the use of silk threads, as owing to their thinness they were likely not to conduct so well. This proved to be successful, not for the reason given but because silk is an excellent non-conductor. Besides silk, other substances like glass and resins were recognized as insulators, and the range of experimentation was thereby much enlarged.

There was at the time considerable confusion owing to the capricious manner in which electrical forces showed themselves, sometimes by attraction and sometimes by repulsion. No progress could be made in this respect until Dufay, a Captain in the French army, showed in the year 1733 that these apparently contradictory effects could be explained by assuming the existence of two kinds of electricity, which he called vitreous and resinous, terms which in our own time Lord Kelvin used in preference to the more common nomenclature of positive and negative electricity. Dufay's experiments attracted little attention, and Franklin, two years later, formed independently a theory, which admitted only one kind, but distinguished between an excess and defect of that kind. Bodies were called positively and negatively electrified according as they contained an excess or deficiency.

Another Fellow of the Royal Society, Robert Symmer, also apparently unaware of Dufay's work, revived in 1759 the theory of two separate kinds of electricity with opposite properties, and he was for some time supposed to be its first originator. He did much to promote clear and definite notions on electrical matters and the merit of his investigations cannot be called in question. Though the controversies between the followers of Franklin and those of Dufay and Symmer lasted until quite recent times, they could not lead to any substantial result because there is no fundamental difference between the two views. Both emphasize the distinction between two opposite electrical states, and our preference for one or other alternative depends mainly on the ideas which we unconsciously attach to forms of expression which suggest more than they are intended to do. As a matter of convenience, we may think of positive and negative electricity without committing ourselves to any definite theory as to their ultimate nature.

When the primary phenomena of static electricity had been established, the further progress took its natural and regular course. Experimental appliances had to be improved, and instruments constructed suitable for quantitative measurements. In this work John Canton (1718–1772), a private schoolmaster, took an active and successful part. He increased the efficiency of electrical machines by coating the friction cushion, which was pressed against the glass cylinder, with an amalgam of mercury. For the coarser indicators of electricity, such as that which Gray had used, Canton substituted two small spheres of pith or cork, suspended from threads, which diverged when the spheres became electrified.

Canton was also successful in other fields of science; we owe to him the first experimental demonstration that water is compressible, and the discovery of a new phosphorescent body which he prepared by the action of sulphur on oyster shells. William Henley, a linen-draper residing in London, who reached sufficient distinction to be admitted to the fellowship of the Royal Society, also constructed an electroscope intended for quantitative measurements. He was chiefly interested in thunderstorms and atmospheric electricity generally, and noted the positive electrification of the air in a dry fog. Greater importance is to be attached to Abraham Bennett (1756–1799), a clergyman residing in the Midland counties, who introduced the gold-leaf electroscope, the most sensitive instrument invented up to that time for the detection of small quantities of electricity. Simultaneously with Volta, he showed how the electric condensers could be used in conjunction with electrometers so as to increase their effectiveness. This led him to invent an instrument called a duplicator which in principle is identical with Lord Kelvin's replenisher; but as it contained conductors covered with shellac for purposes of insulation, irregularities in its action interfered with the experiments. In spite of these defects it was the embryo of our modern "influence" machine. William Nicholson (1753–1815), to whom further reference will be made (p. 107), cured most of the defects of Bennett's doubler and converted it into an instrument which ought to have come into more extensive use.

William Watson (1715–1787), who started life as an apothecary, but reached sufficient distinction as a medical man to obtain the honour of knighthood, improved the Leyden jar by substituting tin-foil for the liquid which till then had formed the inner coating. In his experiments with these jars he was much assisted by Dr. John Bevis (1695–1771), another medical man, who was, however, mainly interested in astronomical work, and also deserves to be mentioned as being the first to make a glass containing borax, and to note that its refractive power was thereby increased. Dr. Ingenhouse, a Dutch doctor settled in England, conducted many electrical experiments, and claimed to have been the first to replace the glass cylinder used in electrical machines by a disc. The same claim is, however, made by others both in France and Germany, and, among Englishmen, by Jesse Ramsden, the optician and instrument maker, of whom more will have to be said presently, and who certainly first brought glass-plate machines into general use.

On a higher plane stand the researches of Henry Cavendish which now demand our consideration. A paper published in the "Philosophical Transactions" contains the foundation of the mathematical theory of electrostatics. There were probably but few mathematicians at the time interested in the subject, and the experimental part of the enquiry, which might have directed more general attention to the importance of the work, was not published until a century later. The mathematical investigation showed that if the whole of the electricity communicated to a body collects at its surface, none entering the interior, it necessarily follows that the repulsion between two quantities of electricity must diminish with increasing distance according to the same law as that of gravitation. No other law would lead to the same result. Robison appreciated the importance of this investigation (*see* p. 69), but, like others, he was ignorant of the unpublished experiments which Cavendish had actually made on the subject. These verified with a sufficient degree of accuracy that the charge of a body in electrostatic equilibrium resides at the surface, and that if any part of it penetrates into the interior, it can only be a small fraction. Fortunately the manuscripts of Cavendish's electrical experiments have been preserved, and were placed in the hands of Clerk Maxwell when he took over the Professorship of Experimental Physics at Cambridge. Their subsequent publication throws quite a new light on Cavendish's importance as a physicist, giving evidence of a wonderfully balanced combination of theoretical power and experimental skill. Adverting to the many instances in which Cavendish neglected to publish results of importance, Maxwell[1] remarks :

> "Cavendish cared more for investigation than for publication. He would undertake the most laborious researches in order to clear up a difficulty which no one but himself could appreciate, or was even aware of, and we cannot doubt that the result of his enquiries, when successful, gave him a certain degree of satisfaction. But it did not excite in him that desire to communicate the discovery to others which, in the case of ordinary men of science, generally ensures the publication of their results. How completely these researches of Cavendish remained unknown to other men of science is shown by the external history of electricity."

This is not the place to enter into the details of the various researches which were edited by Maxwell in 1879. Suffice it to say that Cavendish measured experimentally the electrostatic capacity of bodies, anticipating Faraday in the discovery of the difference of the inductive capacities of various substances, and Ohm in showing that the electric current is proportional to the electromotive force. He also compared the electric resistance of iron with that of rain water and of different salt solutions. All this was done by means of a rough electroscope and without a galvanometer. He converted, in fact, his nervous system into a galvanometer, by comparing the electric shocks received when Leyden jars were discharged through various conductors, altering the length of the conductors until the shocks were estimated to be equal. He obtained astonishingly accurate results with such simple and almost primitive means.

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[1] "The Electrical Researches of the Hon. Henry Cavendish," Introduction, p. xlv.

The second of the two electrical papers which Cavendish communicated to the Royal Society attracted considerable attention, and though it does not deal with any matter which we should now consider of fundamental importance, it shows how far Cavendish was in advance of his time in appreciating electrical matters correctly. The shocks which certain fishes, such as the torpedo,[1] are capable of giving to those who touch them had been known for some time, and John Walsh, a Member of Parliament and Fellow of the Royal Society, had described some experiments showing the conditions under which the shocks were received. He suggested that they were of an electrical character. The idea was not generally accepted, and was even laughed at on the ground that a fish immersed in sea water, which conducts electricity, could not be electrically charged. In answer to this objection, Cavendish actually constructed an imitation torpedo and demonstrated to an assembly of scientific friends the possibility of obtaining shocks even when it was immersed in salt water.

Maxwell remarks that this is the only recorded occasion on which Cavendish admitted visitors to his laboratory.

Henry Cavendish was born in 1731; he entered Peterhouse, Cambridge, in 1749, and left that University four years later without taking his degree. He was elected a Fellow of the Royal Society in 1760 and died in 1810. His father, Lord Charles Cavendish, third son of William, second Duke of Devonshire, was interested in scientific subjects and published a paper on the capillary depression of mercury in glass tubes, which was highly spoken of by Franklin; he was also the first to construct maximum and minimum thermometers, and received the Copley medal of the Royal Society for the invention of these useful instruments. We may infer that the mind of Henry Cavendish was first directed towards science by his father's example. He lived on an allowance of £500 until he was about forty years of age, when through the death of an uncle he acquired a fortune which made him one of the richest men of his time, without altering the simple mode of life to which he had become accustomed. It has been said of him that his chief object in life was to avoid the attention of his fellows; "his dinner was ordered daily by a note placed on the hall-table, and his women servants were instructed to keep out of his sight on pain of dismissal."[1]

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[1] The word "torpedo" comes from the Italian, and is derived from "torpor;" the name was given to the fish on account of the numbness caused by the electric shock felt on touching it. The torpedo is not now generally associated with torpor.

There is some evidence, however, that in his intercourse with scientific men he was not equally reticent. He attended the meetings of the Royal Society regularly, dined nearly every Thursday with the Philosophical Club, composed of some of the Fellows, and in 1772 was an energetic member of a committee formed to consider the best means of securing a powder magazine against the danger of lightning.

Some of Cavendish's most remarkable results were derived from experiments on gases. Such investigations then tested the skill of an experimenter to a degree which is not easily realized at present. To the difficulties of isolating, purifying, and examining the chemical properties of these invisible substances was added the mystifying belief in the imaginary body, phlogiston, which was supposed to be expelled in every act of combustion, and to account for flame and fire.

From the purely experimental point of view a great advance was made when gases were collected over mercury instead of over water, which had been the usual practice. The credit of this is due to Joseph Priestley (1733–1804), a Nonconformist minister, who, having renounced his early Calvinism and become a Unitarian, was then in charge of Mill Hill Chapel, Leeds; subsequently he moved to Birmingham. Priestley held strong political views, which he expressed freely, and these, together with his unorthodox opinions, frequently got him into trouble. He wrote against England's attitude towards the American colonies, and sympathized with the French revolutionists. When he attended a dinner arranged to celebrate the anniversary of the taking of the Bastille, the mob burned his chapel and sacked his house. He then went to live in London for a few years, but ultimately emigrated to America. We owe to Priestley the discovery of a number of gases, and he first prepared oxygen by heating oxide of mercury with a burning glass. He obtained hydrochloric acid by heating spirits of salt, sulphur di-oxide by the action of sulphuric acid on mercury, and ammonia by heating spirits of hartshorn. Cavendish's attention was attracted by an observation of Waltire, who worked with Priestley, that when a mixture of hydrogen and common air was fired, dew appeared on the walls of the glass tubes. This was explained as being a condensation of water which had been present as vapour in the original gases. But Cavendish was able to prove that the water formed was really the result of the combustion of oxygen and hydrogen. In order to interpret correctly the language in which chemists expressed their results at the time we must remember that oxygen was referred to as "dephlogisticated air," nitrogen as "phlogisticated air," and hydrogen as "phlogiston." Cavendish therefore expresses his result by saying "that water consisted of dephlogisticated air united with phlogiston." The conclusion embodies the discovery of the composition of water, which till then was unknown.

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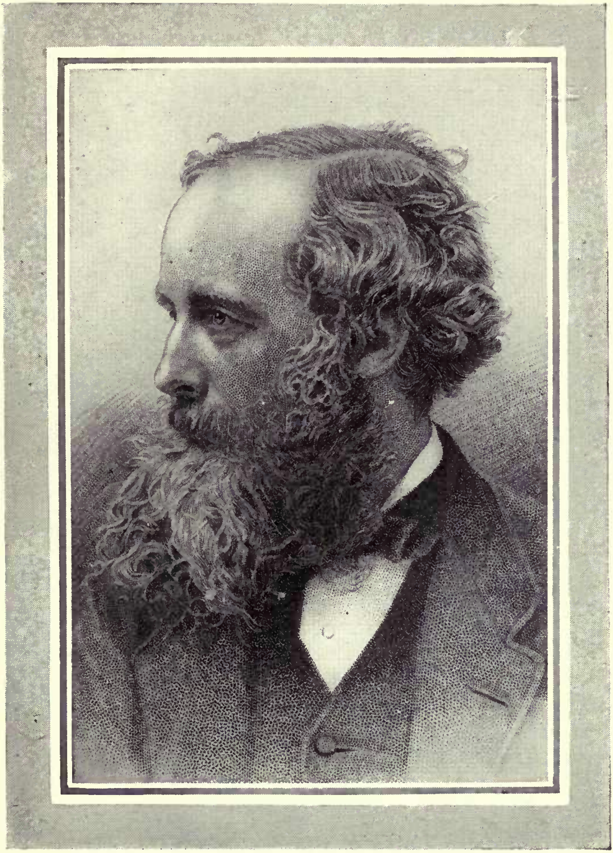
[1] "Encyclopædia Britannica."

Similar experiments seem to have been made by James Watt, who subsequently claimed priority, but we need not here enter into the discussions to which the dispute gave rise, and which passed without interfering with the subsequent friendly intercourse between Cavendish and Watt.

A remarkable research originated in the interest which Cavendish took in the composition of the terrestrial atmosphere. By burning various bodies in measured volumes of air, he satisfied himself that the amount of oxygen present was the same in all the samples experimented upon. He noticed, however, that in one of the experiments in which a mixture of hydrogen and oxygen was fired by an electric spark, the resulting water contained nitric acid. This, Cavendish attributed to a remnant of atmospheric nitrogen in the oxygen used, and, following up the matter, showed that nitrogen and oxygen actually did combine under the influence of an electric spark. Absorbing the nitric acid formed, he could observe a shrinkage of volume when sparks were passed through mixtures of nitrogen and oxygen. He then put himself the question, "whether there are not in reality many different substances compounded together by us under the name of phlogisticated air?" and to satisfy himself on that point, he investigated whether the whole of the air could be transformed into nitric acid by combination with oxygen. He found that there was, indeed, a small portion, estimated by him as $\frac{1}{120}$ of the whole, which resisted the change. This remnant undoubtedly consisted of argon, a separate gas, identified as a new element only in our own times. The amount of argon actually present in the air agrees remarkably well with Cavendish's estimate of his residual gas.

There are many investigations on heat, unpublished at the time, by which Cavendish anticipated Black in the discovery of latent heat; he also determined the specific heats of a number of bodies. Another important research remains to be noted. A Yorkshire clergyman, John Michell, had conceived the brilliant and ambitious idea of measuring directly the gravitational attraction between two spheres of lead. It has already been remarked, in connexion with the Schehallien experiment of Maskelyne and Hutton, that the average density of the earth may be derived from such a measurement, but quite apart from this application, the attempt to demonstrate Newton's gravitational force within the four walls of a room constitutes an effort of heroic ambition and remarkable foresight. John Michell had constructed all the necessary apparatus, including the torsion balance, which he had invented for the purpose. Infirmities of age prevented his carrying out the work, and at his death the apparatus fell into the hands of another distinguished clergyman, Francis John Hyde Wollaston (brother of the celebrated chemist), who, at the time, held the Jacksonian Professorship at Cambridge. Wollaston deserves considerable credit for handing over the execution of the experiment to the one living man who was capable of bringing it to a successful issue. The original torsion balance consisted of a wooden beam about two yards long, weighing 5½ ounces, and carrying at each of its ends a leaden sphere two inches in diameter. Cavendish substituted for the beam a metal rod



John Clerk Maxwell

From an engraving in "Nature"
by G. J. Stodart of a photograph
by Fergus of Glasgow

strengthened by a copper wire which acted as a tie to prevent bending, and was attached to a vertical suspension.

On being slightly displaced from its position of equilibrium the torsion of the wire by which it was suspended would tend to bring the horizontal beam back and make it oscillate slowly in a horizontal plane. Two larger leaden spheres eight inches in diameter could be brought near the ends of the beam, so that their gravitational attraction on the spheres attached to the beam would displace it, with the result that it would oscillate about the new position of equilibrium. By bringing the larger spheres round to the other side of the beam the displacement in the opposite direction could be observed and the gravitational effect measured. Cavendish fully realized the difficulties he would have to encounter in consequence of almost unavoidable air currents. Even when the apparatus was enclosed in a box the slightest difference in temperature would cause convection currents and, consequently, irregular movements of the beam. He, therefore, had to plan out a scheme which would allow him to conduct the whole of the experiments without entering the room in which the apparatus was placed. The observations were taken, and the large leaden spheres moved one side of the beam to the other from outside. No more delicate measurement had ever been successfully carried out. From the average of the number of observations, Cavendish deduced the value of 5·48 for the density of the earth, a number in fair agreement with, though slightly larger than, that obtained by Maskelyne and Hutton. The extreme difficulty and great charm of the experiment has still in our times attracted the most skilled physicists, and the introduction of quartz fibres by Mr. Vernon Boys has enabled us to increase its accuracy considerably. The final value for the average density of the earth as determined by Mr. Boys is 5·5270, so that Cavendish was correct to within one per cent.

John Michell (1724–1793), whose name has been mentioned above as the inventor of that most useful and delicate appliance, the torsion balance, has also in other directions given evidence of great originality of mind. He contributed an important paper entitled "Conjectures concerning the cause and observations upon the phenomena of earthquakes" to the Philosophical Transactions of the Royal Society, and was the first to suggest that double stars were more likely to be systems of physically connected bodies than accidental coincidences in the directions of two stars which might be at great distances one behind the other. This, as will presently appear, was subsequently proved by William Herschel to be the case.

It is not surprising that astronomy has always been a favourite study of men of leisure, with a scientific turn of mind. As Tyndall, in one of his lectures, said, we are most impressed by what is either exceptionally large or exceptionally small; and the feeling that in examining the heavens, our laboratory, no longer confined to a few cubic feet, extends through the universe, fascinates the human mind. Added to this, useful work can be carried on in astronomy with comparatively simple though sometimes expensive appliances, and to the painstaking, but not perhaps, mathematically inclined enthusiast, special problems are often ready to hand, which depend on accurate registration rather than on extensive knowledge. When, as not infrequently happens, the power of dealing with the observations is added to the aptitude for observation, the amateur can rise to the level of the professional more easily than in most other subjects.

It is impossible to say what position Jeremiah Horrocks (1619–1641) might have attained had his life not been cut short so early. He died at the age of twenty-two, with a remarkable record to his credit. After passing through Emmanuel College, Cambridge, as a sizar, he earned his living as a teacher at his native place, Toxteth Park, near Liverpool. Through William Crabtree, a wealthy draper of Manchester, whose acquaintance he had made, he became interested in astronomy, and on his advice studied the works of Kepler. Having tested and corrected the tables giving the positions of planets which had been published by that astronomer, he formed the conclusion that a transit of Venus would occur on the 24th November 1639. This happened to be a Sunday, and Horrocks being at that time a curate at Hoole was afraid that clerical duties would prevent his observing the transit. He, therefore, asked his friend Crabtree to watch independently for the appearance of Venus on the solar disc. Fortunately, Horrocks was set free before the planet had crossed the sun, and he could follow its passage until the time of sunset. This was the first time that human eye had witnessed this rare occurrence. Among the frescoes by Madox Brown in the Town Hall of Manchester one represents this transit of Venus. Unfortunately, the pictures being intended to commemorate events in the history of Manchester, the scene is laid in that city, and Crabtree is made to be the central figure, conveying a wrong impression of a great historical event.

The papers left by Horrocks were preserved by Crabtree and ultimately published. They show that he had the making of a great man of science in him. Before he was twenty, he showed how Kepler's laws had to be modified in order to fit the motion of the moon, and he suspected that these modifications were due to some disturbing cause emanating from the sun, as Newton afterwards proved was actually the case. He also discovered certain irregularities in the motions of Jupiter and Saturn, now known to be due to their mutual attractions.

The name of Molyneux first appears in this country at the time of the Norman Conquest through William de Moline, from whom the Earls of Sefton are descended. Another family of the same name is derived from Sir Thomas Molyneux, who came over from France, settled in Ireland, and became Irish Chancellor of the Exchequer. One of his great grandsons was Sir Thomas Molyneux, physician and zoologist, another William Molyneux, a philosopher, politician, and astronomer. Several of his papers were published in the Transactions of the Royal Society. They deal with the erecting eyepiece of terrestrial telescopes, the tides and the causes of winds; he also pointed out errors which occurred in surveying through neglecting to take account of the secular variation of the magnetic declination.

Samuel Molyneux (1689–1728), the son of William, followed in his father's footsteps as astronomer, and built himself an observatory at Kew. It was here that the observations which led to the discovery by Bradley of the aberration of light were carried out. Molyneux has not received sufficient credit for the design of the instrument and of the measuring appliances on which the successful prosecution of the research depended. The idea of testing Hooke's method of measuring the so-called "parallax" of stars seems to have been due to Molyneux. He worked assiduously at the construction of telescopes, one of which he presented to the King of Portugal, and left an unpublished MS. on optics, which was made use of by Robert Smith in the preparation of his treatise.

The work of William Herschel (1738–1822) brings us into touch with modern astronomy. His father was a musician in the Hanoverian Army, though the family originally came from Moravia. At the age of fourteen he accompanied, as an oboe player, a Hanoverian band on a visit to England, but only settled finally in this country in 1757, his health not being strong enough to take part in the Seven Years' War. He ultimately went to live in Bath as a teacher of music, and became director of the musical entertainments in that fashionable resort. His turn for reading serious books led him to the study of Ferguson's astronomy and Smith's harmonics, followed by the optics of the same writer. He then decided to take up astronomy more seriously; he bought a small Gregorian telescope, but not content with this, and, unable to obtain a larger instrument with the means at his disposal, he set to work with his own hands, and having succeeded in polishing a mirror of six-foot focal length mounted it as a reflecting telescope. A frequently quoted passage from one of his letters, written in 1783, shows the object he had in view:

> "I determined to accept nothing on faith, but to see with my own eyes what others had seen before me. I finally succeeded in completing a so-called Newtonian instrument, seven feet in length. From this, I advanced to one of ten feet, and at last to one of twenty, for I had fully made up my mind to carry on the improvement of my telescopes as far as it could be done. When I

> had carefully and thoroughly perfected the great instrument in all its parts, I made systematic use of it in my observations of the heavens, first forming a determination never to pass by any, the smallest, portion of them without due investigation."

Even the largest of the instruments, mentioned in this letter, did not satisfy him, and he determined to improve upon it by constructing one of twice its size. This was finally mounted at Slough, where he had settled with his sister in 1782. The polishing of concave mirrors was at that time a serious business. On one occasion he kept the tool on the mirror continuously for sixteen hours, and with both hands engaged had to be fed by his sister, Caroline, who then kept house for him. His desire to obtain larger and larger instruments did not, however, prevent Herschel from making good use of those he had completed. Surveying systematically the whole of the heavens he was soon rewarded by a brilliant discovery.

Struck by the peculiar appearance of a star that crossed his field of view, he examined it with higher magnifying powers, and found its apparent disc increased. Two days later, a slight change of position could be detected. At first it was thought to be a comet, but, ultimately, Saron, at Paris, and Lexell, at Petrograd, found that its path indicated an orbit round the sun of a nearly circular shape. It then took its place as a new planet, the first that had been discovered in historic times. The name "Georgium Sidus," suggested by Herschel, was not generally accepted, and was subsequently replaced by "Uranus." The discovery was a fortunate one for Herschel, as it established his reputation, and, what was more important, led George III. to appoint him his private astronomer, with a salary which, though modest, set him free to give up his professional work and devote his entire energies to astronomy. For a time, he increased his income by making and selling telescope mirrors, but this ceased to be necessary when, a few years later, he married a lady of independent means.

The leading feature of Herschel's work was his strong faith in the unity of design which he tried to trace in the structure of the Universe. He looked upon the assemblage of stars as an organic whole, and endeavoured to find regularities in their distribution or arrangement. He thus opened out an entirely new branch of enquiry.

If stars were scattered at random, we should find on the average an equal number in all parts of the sky. In order to avoid the enormous and practically impossible labour of actually counting the total number of stars visible in his telescope, Herschel devised a method of gauging the heavens, which gave him sufficiently good average results. This consists in taking specimens, by counting the stars which appear in a number of single fields of view near together, and taking the average number of stars recorded as an index of the density in this particular region of the heavens. It is obvious that the number of stars is vastly greater in the Milky Way than anywhere else, and the question arose whether that dense conglomeration had any relation to the rest of the stellar universe. It was, therefore, a discovery of the greatest interest and importance to find that the stars throughout the heavens increase in density as we approach the region of the Milky Way, thus demonstrating that the visible universe is not an accidental jumble, but possesses an organized structure.

Results, of equal interest, were obtained from the close investigations on double stars, of which about forty were known when Herschel began his work. Having added nearly 400 to this number, he set out to measure the relative positions of the two components of each doublet, and, repeating the measurements from time to time, discovered, after twenty years of work, that some of these double stars are physically connected, consisting of two huge and luminous masses which revolve round each other.

The organic bond which connects the separate units of the universe revealed itself in a striking manner, by Halley's discovery already referred to, that many of the stars are apparently moving through space with considerable velocities. Examining the direction and magnitude of the observed shifts, Herschel noticed that if the average motion be taken in any one region, that average is nearly the same in different parts of the sky. As our observations can only indicate a motion relative to the earth, we must conclude that if we consider the system of stars as a whole to be at rest, our sun with its planetary system moves towards a definite point in the heavens. If, on the other hand, we consider the solar system to be at rest, then the great majority of stars are drifting in nearly parallel directions, and whatever view we may take it is certain that the star velocities are not entirely independent of each other. The subject is one that has received renewed attention in recent years; it has now been demonstrated that there is more than one star-drift, and Herschel's work is likely to develop into an important department of astronomy.

One further discovery of considerable interest and importance but belonging to the domain of physics, remains to be noted. In order to compare the heating effects of the coloured rays of which, as Newton taught us, solar light is composed, Herschel placed thermometers in the different portions of a spectrum obtained by means of a prism. He noted that the heating powers of the rays continuously increased from the blue through the green and yellow to the red. He then discovered that the thermometer rose highest when placed outside the red, proving that the solar spectrum contains invisible rays less refrangible than the red. These rays, though they do not affect our eye, become apparent by means of their heating effect. Herschel satisfied himself that these invisible rays were refracted and reflected according to the ordinary laws.

The idea of invisible radiations, refrangible like light at the surface of transparent bodies was at that time entirely novel, and must have appeared almost as surprising as the discovery of Roentgen rays in our own time. The heat radiations were at first looked upon with scepticism, and met with opposition in some quarters, even when Wollaston soon afterwards proved the existence of other rays beyond the violet end of the spectrum which showed themselves by their chemical effects.

The success of experimental investigation depends so much on the use of scientific instruments and appliances that the important share contributed to the progress of science by the designers and makers of instruments deserves to be emphasized. Improvements in the design of an instrument lead not only to increased accuracy but also to the saving of time and labour, which is frequently of equal importance; and in this connexion we need not necessarily think of the construction of the costly instruments which the astronomer now requires, nor of the elaborate appliances to be found in a modern physical laboratory. The most effective instrumental improvements have frequently been of the simplest kind, and a handy appliance, such as the slide rule, saves an amount of time which in the aggregate may sum up to an astonishing figure. The slide rule was introduced at a surprisingly early time. Almost immediately following the introduction of logarithms, Gunter constructed a rod with logarithmic divisions engraved on it, but its use involved the application of a pair of dividers. The sliding arrangement which is the essential feature of the appliance was first used by Oughtred (1575–1660), a mathematically inclined clergyman, who incidentally introduced the × sign for multiplication and the symbol : : for proportion.

There is no department of science that depends on instrumental appliances more than astronomy. The construction of mirrors and lenses, the improvement of clocks and the accurate angular division of measuring circles all require skilled labour of the highest kind, while the requirements of navigation severely test the ingenuity of the inventor, who has to simplify the instruments and make their working independent of that firm support which may be obtained on dry land, but is not available on board ship.

As an instrument of precision the telescope was almost useless until some measuring arrangement was introduced. A micrometer eyepiece consisting of two metallic edges, the distance between which could be altered and measured by a screw, was invented by a young astronomer, William Gascoigne, a friend of Jeremiah Horrocks and Crabtree, born about 1612, and killed in the battle of Marston Moor. The Gascoignes are first mentioned in English history when Sir William Gascoigne acted as Chief Justice in the reign of Henry IV., and his son, George, acquired the reputation of a poet, but it is not known whether the astronomer descended from them. Crabtree mentions the invention of the micrometer in a letter to Horrocks, and the instrument itself was exhibited by Townley at a meeting of the Royal Society in 1667. Unfortunately it escaped the notice of astronomers until Huygens had constructed a similar but less perfect appliance, and Adrien Angout had produced a micrometer in which Gascoigne's edges were replaced by silk fibres.

If one had to select the instrument which combines the greatest simplicity with the highest precision, there is little doubt that one's choice would fall on the sextant, the most perfect appliance that has ever been invented. It is mainly used on board ship, but it has been successfully employed in the United States for accurate surveys on land. No one who has not held a sextant in his hand, and seen how, after a few days' practice, he could determine the local time to the tenth part of a second, and the latitude to a few hundred yards, can realize the beauty of the instrument and the sense of power it gives to its user. The inventor, John Hadley, was an instrument maker about whose life very little is known, though the Royal Society recognized his merits by electing him to their Fellowship, and ultimately made him a Vice-President. His instrument, the circle of which only covered 45°, and which therefore ought more properly to be called an "octant," was first shown to the Royal Society in 1744. Hadley also revived the use of reflecting telescopes; the construction of which had shown little progress since Newton's time.

The accuracy of astronomical observations depends in many cases on the excellence of the timekeepers employed to record the instant at which a star passes the centre of the telescopic field of view. Clocks used for the purpose are regulated by the swing of a pendulum acting through a mechanism called an escapement. The first efficient appliance of its kind, the anchor escapement, was invented by Robert Hooke, and improved upon by George Graham (1675–1751), an ingenious clockmaker who was generally interested in scientific matters. We owe to him, *e.g.*, the discovery of the diurnal variation of terrestrial magnetism. In the construction of clocks he introduced an important improvement. Owing to the expansion and contraction of ordinary materials when the temperature rises or falls, the time of oscillation of an ordinary pendulum alters with every change of temperature; but by properly combining different materials, the difficulty may be overcome. Graham attached a cylindrical vessel partly filled with mercury to the bob of the pendulum; when the rod of the pendulum expands the support of the mercury vessel descends, but the mercury in the vessel also expands, which tends to raise the centre of gravity of the whole arrangement. The expansion of the mercury being considerably greater than that of the pendulum rod, its volume may be adjusted so that the two actions counterbalance each other, and the pendulum may be made independent of moderate changes of temperature. Another arrangement, the "gridiron" pendulum, was introduced by John Harrison (1693–1776), the son of a Yorkshire carpenter, who became a surveyor, and settled down in London as a watchmaker. His pendulum compensation has been very extensively used, but Harrison will chiefly be remembered as the inventor of the chronometer.

The demand for accurate timekeepers suitable for use on board ship had become so urgent a question at the time, that the Government had offered a reward of £20,000 to anyone who would produce an instrument which satisfied certain requirements. Harrison soon supplied a "time-measurer" or "chronometer" which promised so well that the Government helped him with grants of money and facilities for testing his instrument on sea journeys. But it took him twenty-six years of continued labour before he obtained the full reward, producing a chronometer which, on a journey to Jamaica and back, showed an accumulated error of less than two minutes; this satisfied the required conditions, and the prize was awarded to him. One of the features of Harrison's chronometer, showing great ingenuity and manipulative skill, consisted in the temperature compensation which was applied to the balance wheel.

Next to accurately going clocks, the astronomer requires well-divided circles for the measurement of angles. Three English instrument makers secured considerable reputation in this work during the eighteenth century. The first of these, Graham, whose name has already been mentioned in connexion with clocks, worked for Halley and Bradley at Greenwich, and supplied an instrument to the Paris Academy of Sciences. The second, John Bird (1709–1776), divided a number of quadrants for several public observatories, and his method of working was considered so good that the Government purchased the right of employing it.

Further improvements were introduced by Jesse Ramsden (1735–1800), the son-in-law of John Dollond, who designed an engine for dividing mathematical instruments and received a premium for £315 from the Government for this invention. Ramsden was a remarkable man. The son of an innkeeper at Halifax, he became a clerk in a clothmaker's warehouse, after having completed a three years' apprenticeship. Two years later, when twenty-three years old, he again apprenticed himself, this time with a mathematical instrument maker, and afterwards established himself independently. His shop, first opened in 1762, in the Haymarket, was transferred later to Piccadilly. He soon acquired fame for the excellence of his workmanship, and we are told that, though ultimately sixty workmen were employed by him, the demand from all parts of Europe for his instruments was greater than could be satisfied. He was highly successful in constructing a new equatorial mounting for telescopes and a clockwork which drove the mirror of a siderostat so accurately that a star could be followed for twelve hours; but it was his skill in dividing circles to which he mainly owed his great reputation. There can be no doubt that his practice of substituting entire circles for the usual quadrants and sectors was sound in principle and contributed much to his success. Every student of optics knows "Ramsden's eyepiece," and he also invented a double image micrometer. The Royal Society recognized his work by awarding him the Copley medal in 1795.

While clocks and divided circles are necessary parts of an astronomer's equipment, he depends primarily on the optical performance of his telescopes. Newton had used mirrors to focus the beams of light, as he considered it to be impossible to do so accurately by means of lenses, because rays of different colours, being refracted to a different degree in their passage through a lens, come to a focus at different points. Hence the images formed by simple lenses of glass are coloured. Though the possibility of combining several lenses made of different materials had occurred to Newton, he had come to the conclusion that the dispersive power of substances (which is the power to separate different colours), is proportional to their refractive power, and if this were really the case, it would indeed be impossible to construct a lens which could bring different coloured rays to the same focus. The succeeding history of the subject is interesting. Euler asserted that notwithstanding Newton's experiments, which he accepted, it should be possible to produce achromatism, *i.e.*, images without coloration, by means of a combination of lenses. David Gregory had already in 1695 expressed similar ideas, and their argument depended on the belief that the images formed by the human eye are not deteriorated by any colour-dispersion. As the rays entering the eye are concentrated on the retina by successive refraction through different media, such as the cornea, the crystalline lens and the vitreous humour, it was argued that it should be possible to produce achromatic images by properly combining lenses of different materials. Euler's belief that the optical arrangement of the eye pointed the way to the construction of achromatic lenses was shared by others, and ultimately led to the solution of the problem; but the curious point is, that the premise on which the whole argument depends is wrong, the eye not being achromatic at all, but subject to the same defects as a simple lens.

A Swedish mathematician, Klingenstjerna, seems to have been the first to repeat Newton's experiments with sufficient care, when it appeared that the relationship between refractive and dispersive powers, which Newton thought he had established, did not hold accurately. John Dollond (1706–1761), a son of one of the many French refugees who came to England after the revocation of the Edict of Nantes, had started life as a silk weaver in Spitalfields, but relinquished this occupation and established a workshop for optical instruments. Having heard of Klingenstjerna's observation, he entered into an independent investigation on the optical properties of different kinds of glass, and had the satisfaction of solving, at last, this most important problem. By combining two lenses of different kinds of glass, he could produce images in which the colour defect was, though not entirely abolished, yet very materially diminished. In this discovery he was, however, anticipated by Chester More Hall of More Hall in Essex, a barrister, who, in 1833, had ? 17 already succeeded in constructing an achromatic lens. Dollond's patent was subsequently challenged on the ground of anticipation, but the judgment was upheld in favour of Dollond on the ground—containing much common sense—that "it was not the person who locked his invention in his scrutoire that ought to profit from such invention, but he who brought it forth for the benefit of mankind."

The improvements effected in electrical appliances by Canton, Henley, Bennett and others have already been described, and we may therefore pass on to the more direct applications of scientific principles to the utilization of power. The early steam engines—we should hardly call them by that name now—were little more than toys, useful, perhaps, for the special purpose for which they were designed, but wasteful and costly in their working. It was only when James Watt came to apply the scientific methods acquired in his intercourse with Joseph Black and John Robison that an efficient machine could be evolved.

We may begin our account of the history of steam engines with Edward Somerset, Marquis of Worcester, whose romantic personality and tragic history form an interesting study. He claims to have accomplished some wonderful things in a publication that bears the eccentric title: "A century of the names and skantlings of such inventions as at present I can call to mind to have tried and perfected, which, my former notes being lost, I have at the instance of a powerful friend endeavoured, now in the year 1655, to set down in such a way as may sufficiently instruct me to put any of them in practice." But his descriptions are so fantastic and vague that doubts have been raised whether he had ever gone beyond the forming of plans and making of projects, leaving the rest to his imagination, which had ample scope to exercise itself during a six years' confinement in the Tower of London.

We possess, however, the testimony of an eye-witness who had seen near Vauxhall one of Worcester's machines raise water through a height of forty feet. Engines were chiefly wanted at the time for the pumping of water, more especially to clear the mines, and it is therefore, not surprising that the first practical application of the pressure provided by steam should have been made by a miner. Thomas Savery's (1650 ?–1702) machine probably resembled that of Worcester, and it is immaterial whether it was an independent invention or not. A short description may serve to illustrate its mode of work. A cylindrical vessel has three tubes leading out of it, each capable of being opened and closed by a stopcock. The first tube joining the upper end of the cylinder is connected with a boiler; the second (the inlet tube) leads from the bottom of the cylinder vertically downwards to a reservoir of water, and the third (the outlet tube), also connected to the bottom of the cylinder, is bent round so as to lead vertically upwards. To start the machine, the cylinder is filled with water, and the stopcock of the inlet tube closed, while the two others are opened. Steam is then admitted, and the water expelled through the outlet tube. When the whole cylinder is filled with steam the boiler and outlet tubes are closed, and the inlet tube opened. The cylinder is cooled and the vacuum formed by the condensation of the steam draws a supply of water from the reservoir upwards into the cylinder. When the cylinder is filled, the stopcock of the inlet tube is closed, and the process repeated. The height to which the water may be raised in this manner depends on the pressure of steam employed, which in Savery's engine reached up to eight or ten atmospheres, corresponding to a height of about 250 feet of water. It will be seen that this machine contains no piston such as we associate now with steam engines, and there is no mechanical transmission of motion. Its sole object is the raising of a weight of water by the pressure of steam.

Papin (1647–1714), a French Calvinist who had to leave his country on account of his religious opinions, lived in England for some time, but ultimately accepted a professorship in a German University. He suggested the use of a piston, but abandoned the idea in favour of a modified form of Savery's engine.

During his stay in England, Papin took an active part in the Proceedings of the Royal Society, and in 1684 was appointed temporary curator of that body with a salary of £30, in consideration of which he was required to produce an experiment at each meeting of the Society. He had invented a so-called "bone-digester," to which Evelyn in his diary refers in these terms: "The hardest bones of beef itself and mutton were made as soft as cheese, without water or other liquor, and with less than eight ounces of coal, producing an incredible quantity of gravy; and, for close of all, a jelly made of the bones of beef, the best for clearness and good relish, and the most delicious that I have ever seen or tasted." Papin kept up his correspondence with the Royal Society after settling in Germany, submitting to them a proposal to apply a steam engine to the propulsion of ships, and asking for a grant of £15 for his "expense, time and pain" in putting his ideas to the test. Papin is also credited with the invention of the safety valve.

The next successful step in the construction of steam engines was taken by Thomas Newcomen (1663–1729), an ironmonger of Dartmouth, who seems to have entered into correspondence on the subject with Robert Hooke, and, together with Cawley, another tradesman of his native town, produced a machine which in several ways was better than its predecessors. He introduced a cylinder with a piston that could be raised by the pressure of steam, the piston rod being mechanically connected with a pumping arrangement. The steam was condensed in the cylinder itself by a jet of water, and the work was mainly performed in the downward stroke, when the atmospheric pressure of air pressed the piston down into the vacuum formed inside by the condensation of steam. Newcomen's engines came into general use for the pumping of water.

In all the attempts made so far, no consideration is given to the economical use of fuel, a disadvantage which was severely complained of by those who used the engines. A new era began with the work of James Watt (1736–1819

We are all familiar with the story which tells how as a boy he watched the steam escaping from a tea-kettle, and dreamt of the future of steam-power. Such tales about precocious signs of future greatness may have a psychological interest when they are well authenticated, and given in the correct perspective of surrounding circumstances; but even then we should not be able to estimate their true value unless we knew how many boys watched tea-kettles and made acute remarks without growing up to be great men. When we are told, for instance, of another eminent man who as a boy was asked to see what time it was, and returning after looking at the clock, said: "I can't tell you what time it is now, but when I looked at the clock it was ten minutes past three," we are tempted to ask what proportion of the boys who could give such an answer became great mathematicians, and how many merely great prigs. The story of Watt's tea-kettle rests on a memorandum dictated by an old lady, a cousin of his, fifty years after the occurrence, but the most significant part of her account is not generally mentioned. It was not the power of steam that Watt was watching, but the condensation into water when the steam came into contact with a silver spoon. The incident may be accepted as a sign of a scientific and enquiring mind, perhaps as a token of his interest in the properties of steam, but not as a forecast of his future belief in the powers of steam. James Watt came from a family of mathematicians. His grandfather, Thomas Watt, was a teacher of navigation, and his tombstone bears the title: "Professor of Mathematics." His father was a shipwright, supplying vessels with nautical instruments, and a mechanic. In the latter capacity he made and erected, for the use of Virginia tobacco ships, the first crane ever seen at Greenock. Growing up in these surroundings, Watt at an early age became familiar with the use of tools, and set up a small forge for himself for the making and repairing of instruments. He left his Scotch home and became apprenticed to an instrument maker in London, but bad health obliged him to return at the end of the year. When his attempt to set up a shop at Glasgow was objected to by the guilds, because he had not served his full apprenticeship, the difficulty was overcome by some of the professors who had recognized his ability before he went to London, and established him as instrument maker to the University. This gave Watt the opportunity of entering into intimate scientific intercourse with such men as Joseph Black and John Robison, and gaining a knowledge of the scientific principles of heat.

It was only in 1764, when a working model of one of Newcomen's engines was sent to Watt for repair that his mind was directed to the potential value of these machines. Watt at once recognized the cause of the enormous waste of fuel which constituted the chief defect of the engine. When the steam introduced into the cylinder had done its work by raising the piston, it had to be condensed before the piston could return; this was done by a jet of cold water introduced into the cylinder, which, of course, did not only condense the steam but also cooled down the mass of metal which formed the walls of the cylinder. When the steam was reintroduced, the whole had to be raised up again to the temperature of the steam before the piston could be lifted. In order to avoid this waste of heat Watt saw that the cylinder ought to be maintained permanently at the temperature of the steam, and for this purpose it became necessary to condense it, not in the cylinder itself, but in another vessel, into which it had to be driven after it had done its work. The invention of this separate condenser was Watt's first contribution to the steam engine. He settled down in Birmingham with Matthew Boulton, a capitalist, and gained experience in the manufacture of his improved machines, which were still used exclusively for pumping water.

The next great step was made in 1782. Up to that date steam was only admitted to the cylinder on one side of the piston, the return stroke being made by the pressure of the air against the vacuum formed by the condensation of steam. Watt now invented the double-acting engine, in which steam is alternately admitted and acts on both sides of the piston. The third advance, which brings us still nearer to the modern engine, is due mainly to the scientific knowledge which Watt had gained of the properties of steam, investi gating for himself the connexion between its temperature, density, and pressure. Instead of allowing the steam to pass into the cylinder during the whole of the stroke, Watt saw that a considerable economy could be effected by stopping the admission when the stroke had reached a certain point, and allowing the pressure of the steam already in the cylinder to complete it. It is not necessary to enter further into the many improvements of detail which the steam engine owes to Watt, who, realizing the future that was before it, also devised various means by which the up and down stroke of the engine could be converted into rotatory motion.

Savery is said to have been the first to suggest that the measured power of performance of an engine might be in terms of horse-power, but Watt actually investigated the work that a horse could do in a given time, and defined one horse-power as the rate at which work is done when 33,000 lbs. are raised one foot in one minute.

Watt was of a retiring disposition, due, no doubt, to the weakness of health which, in the early part of his life, greatly interfered with his work. He speaks of himself as "indolent" and "not enterprising," and as being "out of my sphere when I have anything to do with mankind." His inventions were not confined to the steam engine. He constructed a press for copying manuscripts, such as is now in common use. It is also claimed on behalf of Watt, and with some justification, that he was the first to discover the true composition of water as a compound of oxygen and hydrogen. The controversy which arose has already been referred to (page 85).

The condenser used by Watt can be easily attached to stationary engines, but is inconvenient when an economy of space is imperative, as when steam is used for road propulsion. The condenser may then be dispensed with, but the pressure of steam has to be increased. Richard Trevithick (1771–1833), whose father was the manager of a Cornish mine, invented a road locomotive with high pressure steam, and conveyed passengers with it on Christmas Eve, 1801. Some sort of steam vehicle had, however, already been built in France by Nicolas Cugnot as early as 1769, and William Murdock (1754–1839) is reported to have constructed a carriage drawn by steam about 1786. Nevertheless, Trevithick was the first to build a locomotive in the modern sense, and to use it on the lines of a horse-tramway in Wales. Finally, the introduction of two cylinders, the steam escaping from one being utilized to increase the work by acting on a piston in the second, may be mentioned as being the prototype of the present compound engines. This innovation is due to Jonathan Carter Hornblower (1753–1815), who, among other things, invented a machine for sweeping chimneys by a blast of air. Patent difficulties stood in the way of putting the idea of the double cylinder into practice, but it was re-invented and used in machinery set up in Cornish mines in 1804 by Arthur Woolf.

The name of Murdock recalls that he was the first to make a practical use of coal gas as an illuminating agent. His father was a Scotch millwright; he entered the employment of Boulton and Watt at the Soho Factory, Birmingham, in 1777, and a few years later was sent to Cornwall to superintend the fitting of water engines in mines. He established himself at Redruth, and is credited with several inventions; there is a tradition that he created a sensation among the inhabitants by carrying, to and from the mine, a lantern lit by gas supplied from a bag concealed under his coat. After his return to Birmingham in 1799, he improved his methods for making and storing the gas so much that the exterior of the Soho Factory, and soon after the whole of the interior, was lighted with the new illuminant.

During the last few years of the eighteenth century, another great step forward in the transmission of power was made when James Bramah (1749–1814) laid the foundation of a new branch of engineering by the invention of his hydraulic press. Bramah was the son of a Yorkshire farmer. Being incapacitated for agricultural labour on account of an accident, he started business as a cabinet-maker in London, and made a number of inventions, such as the lock which is known by his name. He suggested improvements in the steam engine, foresaw the possibility of propelling ships by screws, and advocated the hydraulic transmission of power.

CHAPTER IV

(Physical Science)

THE HERITAGE OF THE NINETEENTH CENTURY

IN a superficial review of the history of science a new idea or a striking experiment is associated with an individual name and a particular date. Hence, we receive a general impression that science proceeds by sudden inspirations; yet, on closer examination, we find that the salient features are connected with each other, and that the great landmarks are generally reached only by a succession of intermediate steps, some of which may be as important as the last which culminates in the final discovery. Time tends to efface the intermediate steps, and so it happens that it is only in dealing with the more recent events that we can obtain a correct view of the continuity of science. To trace this continuity is one of the functions of the historian, but occasionally his efforts will fail, and he will be faced by what appears to be an entirely new departure. Such was Volta's discovery of current electricity, which surprised the scientific world in the first year of the nineteenth century. The electrical shocks which certain fishes can inflict on those who touch them, and an accidental observation by Galvani, an Italian doctor, disclosed a class of phenomena called "animal electricity." But there was much confusion of ideas with regard to the significance of the observed facts until Volta, the great Italian experimenter, succeeded in separating what was physical from what was physiological in Galvani's results, and so laid the foundation of a new science. By discovering the electrical effects that could be obtained at the contact of two dissimilar metals, Volta was led to those wonderful researches which gave us the electric battery. His previous work had earned for him the Fellowship of the Royal Society in 1791, and desirous of showing his appreciation of the honour, he not only contributed an important paper to the Philosophical Transactions in 1793, but announced his latest and greatest discovery in a letter addressed to the President of the Royal Society, Sir Joseph Banks. That letter bears the date March 20th, 1800, and appears to have been sent in two parts, the second of which was delayed in delivery, so that it could not be read before the meeting of the Society, held on June 26th of the same year. In the meantime, the first part of the letter had been privately communicated to Sir Anthony Carlisle, the celebrated surgeon of Westminster Hospital, and Professor of Anatomy to the Royal Academy. Carlisle was mainly interested in the physiological effects of electricity, and consulted William Nicholson, a man of varied interests, who was employed at different times as an official in the East India Company, a traveller for the firm of Wedgwood, a school teacher and a civil engineer. He had embarked on the publication of a scientific periodical—*Nicholson's Journal*—and relates in its fourth volume the important results he obtained by experimenting with the battery constructed according to Volta's directions. When two brass wires connected with the electric poles were immersed in a tube containing water, gas bubbles were seen to rise from one of the wires, while the other became corroded. The gas proved to be hydrogen. On replacing the brass wires by platinum, it was found that oxygen was set free as well as hydrogen; the electrolytic decomposition of water was thus completely effected. This was the first step in the brilliant series of experiments by which English chemists and physicists traced the connexion between chemical and electric action. But we must here interrupt our account, and turn for a moment to another subject.

The time had come when the correlation between the various physical manifestations, such as light, heat and power, forced itself into the foreground. The production of heat by mechanical means was effected on a convincing scale by Benjamin Thompson, better known as Count Rumford, who had entered the service of Bavaria for the purpose of organizing the manufacture of implements of war. His previous experiments had convinced him that in accordance with the views of Robert Hooke and other early physicists, heat consisted in a motion of the ultimate particles of a body, and as he controlled the machinery at Münich for making guns, he had the opportunity of testing the matter. While a cannon was being bored he filled the hollow already formed with water, and found that it became hotter and hotter until it boiled. The conclusion was obvious: heat could actually be generated by mechanical power.

During an adventurous life Rumford rendered active services to several countries. His family had settled in Massachusetts, where he was born in 1753. At an early age he showed mathematical tastes, but occupied himself with abortive attempts to discover perpetual motion, and with experiments on fireworks. After the outbreak of the American war he entered a local regiment of militia on the American side, where his position was rendered untenable by the doubt which was cast on his loyalty to the cause of freedom. He left the army and, when Boston was evacuated in 1776, he came to England, where he was appointed to a clerkship at the Colonial Office, rising rapidly within four years to the position of Under Secretary of State. In the meantime he carried on his scientific pursuits, and was elected a Fellow of the Royal Society in 1779. He returned for a time to America on active service, but resigned again at the conclusion of the war, with the rank of Colonel. He then determined to join the Austrian army, then engaged in war with Turkey. While on the way to Vienna he was introduced to Prince Maximilian, the future King of Bavaria, and was persuaded to enter the government service of that state. With the consent of King George III., who bestowed the honour of knighthood upon him, he remained at Münich, where he held consecutively the offices of Minister of War, Minister of Police, and Grand Chamberlain. In addition to the improvements he effected in the Bavarian army, he developed the industries of the country and did much to mitigate the extreme poverty of a large part of the population. His methods were strongly philanthropic. "To make vicious and abandoned people happy," he said, "it has generally been supposed necessary first to make them virtuous. But why not reverse this order? Why not make them first happy and then virtuous?" He adopted the name Rumford on being created a Count of the Holy Roman Empire in 1791. Some years later he returned to England and founded the Royal Institution, which received its charter in 1800. His later years were spoilt by an unhappy attachment he had formed to the widow of Lavoisier, the great French chemist, who had suffered death on the guillotine during the Revolution. Their marriage took place in 1804, but resulted in an uncomfortable life for several years, until a separation was agreed upon. He died in France in the sixty-second year of his age.

Rumford probably rendered his greatest service to science when, in 1801, he selected Humphry Davy for appointment as first lecturer on Chemistry and Director of the Laboratory at the Royal Institution. Davy (1778–1828) had already shown his intense enthusiasm for research, though his first attempts at original work were remarkable for great power of scientific imagination, rather than for sobriety of judgment. A trial lecture at which Rumford was present, settled, however, the question of his appointment.

> "I consider it fortunate that I was left much to myself when a child, and put upon no particular plan of study, and that I enjoyed much idleness at Mr. Coryton's school. I, perhaps, owe to these circumstances the little talents that I have and their peculiar application."

These words of Davy's, written to his mother at a later date, show that Davy did not establish any reputation for studiousness as a boy; but his literary gifts must have appeared at an early age, for we are told that the love-sick youths of Penzance employed him to write their valentines and letters.[1] Davy's father had died in poor circumstances, and the mother established a milliner's shop in Penzance to provide the means of educating her younger children. Humphry, the eldest of them, had then already spent four years at the Grammar School at Penzance, and one at Truro. At his father's death he realized the necessity of setting to work seriously, and was apprenticed with an apothecary and surgeon practising in Penzance. He then began a course of extensive reading covering nearly all branches of learning. Metaphysics seems to have more especially attracted his attention, and he wrote a number of essays on such subjects as "The Immortality and Immateriality of the Soul," "Governments," and "The Credulity of Mortals." Some of his aphorisms indicate great originality of thought, and one almost hears the voice of Poincaré in the passage in which he declares that: "Science or knowledge is the association of a number of ideas, with some idea or term capable of recalling them to the mind in a certain order." Turning his attention to experimental research, Davy at this period studied Lavoisier's "Elements of Chemistry," and formed original, but not very happy, ideas on the nature of light, which he communicated to a medical man, Dr. Thomas Beddoes, with important results on his future life. Dr. Beddoes had a notion that the study of the physiological effects of different gases might have important therapeutical applications. With this purpose in view, he founded the "Pneumatic Institution" at Bristol, and, impressed by Humphry Davy's work, he put him in charge of the laboratory. The experiments on gases led to results of importance. While examining the properties of nitrou oxide, Davy observed those remarkable physiological properties which give to this gas its familiar name of "laughing gas." Mary Edgeworth, a sister of Mrs. Beddoes, thus describes the discovery:

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[1] The account of Davy's life and work is almost entirely derived from Sir Edward Thorpe's most excellent and interesting little volume, "Humphry Davy—Poet and Philosopher" (Century Science Series).

> "A young man, a Mr. Davy, at Dr. Beddoes', who has applied himself much to chemistry, has made some discoveries of importance, and enthusiastically expects wonders will be performed by the use of certain gases, which inebriate in the most delightful manner, having the oblivious effects of Lethe, and at the same time giving the rapturous sensations of the Nectar of the Gods! Pleasure even to madness is the consequence of this draught. But faith, great faith, is, I believe, necessary to produce any effect upon the drinkers, and

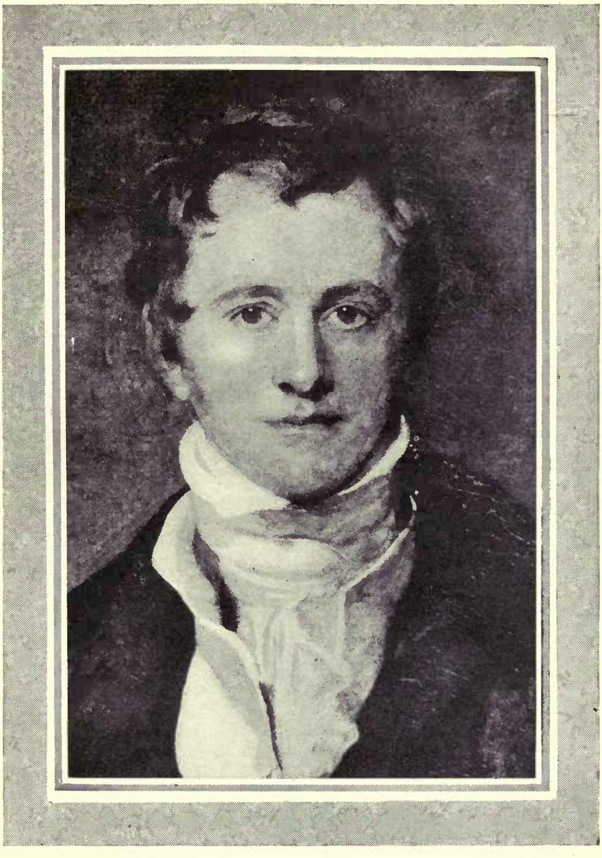
> I have seen some of the adventurous philosophers who sought in vain for satisfaction in the bag of 'Gaseous Oxyd,' and found nothing but a sick stomach and a giddy head."

As a result of further experiments with nitrous oxide, Davy mentions its power of destroying physical pain and suggests its application in surgical operations; but no notice of this suggestion was taken for half a century. Davy's researches on gases were preceded by the unhappy publication already referred to—"On Heat, Light, and the Combinations of Light, with a new Theory of Respiration," in which he tries to demolish Lavoisier's theory that oxygen was a compound of an elementary substance and "heat." The paper is in great part of a speculative nature, and full of hasty and ill-considered opinions. He was, no doubt, right in his contention that heat is not a substance, but he spoils his case by adhering to the belief in the compound nature of oxygen, replacing only Lavoisier's "heat" by the equally imaginary substance "light." He tries to prove by experiments which are not to the point that light is not due to the vibrationary motion of an elastic medium, and even states that oxygen cannot be produced from oxide of lead by heating it in the dark. A statement of this kind renders it doubtful whether he was sufficiently careful in excluding all possible sources of error in another experiment, described in the same paper, in which two pieces of ice were melted in an exhausted receiver by rubbing them together.

The errors of a self-trained, impulsive young man would hardly be worth recording were it not for the chastening effect which the severe criticisms they evoked had on his subsequent work. Davy never forgot his lesson; he remained impulsive, but became much more careful in his experiments, and avoided speculative theories like a child avoids fire when it has burnt its fingers. Within a year he published a letter in *Nicholson's Journal*, in which he says: "I beg to be considered as a sceptic with regard to my particular theory of the combinations of light, and theories of light generally." Before we leave Davy's activities at Bristol, we may quote a passage from one of his letters which illustrates his wonderful powers of intuition in hitting on the essential points of an experiment:

> "Galvanism" (we should now call it "current electricity") "I have found, by numerous experiments, to be a *process purely chemical*, and to depend wholly on the oxidation of metallic surfaces, having different degrees of electric conducting power.
>
> "Zinc is incapable of decomposing *pure* water; and if the zinc plates be kept moist with *pure* water, the galvanic pile does not act; but zinc is capable of oxidating itself when placed in contact with water holding in solution either oxygen, atmospheric air, or nitrous or muriated acid, etc., and under such circumstances the galvanic phenomena are produced, and their intensity is in proportion to the rapidity with which the zinc is oxidated."

Davy took up his position as Assistant Lecturer at the Royal Institution in London, and so brilliantly did he discharge his duties that his audience was taken by storm, and the lecture room was soon filled with enthusiastic listeners. The full title of lecturer was given him at once, and the *Philosophical Magazine* predicted that "from the sparkling intelligence of his eye, his animated manner, and the 'tout ensemble,' we have no doubt of his attaining a distinguished eminence." The control of the subjects to be investigated rested at the time with the governing body, and the Institution having been founded with a view to the practical applications of science, the managers resolved that Davy should give a course of lectures on the Principles of the Art of Tanning; he received leave of absence during three summer months for the purpose of making himself acquainted with the subject. Subsequently he was requested to devote his energies to agriculture, and the various duties which the authorities of the Royal Institution imposed upon him took up much time which would have been better employed in research work. Nevertheless, he found sufficient leisure to return to his favourite study, the chemical action of electric currents, with the result that in 1806 he communicated a paper to the Royal Society which was made the Bakerian lecture of the year. It constitutes a most important contribution to science, and lays the foundation—in



Sir Humphry Davy

From a painting by Sir Thomas Lawrence, in the possession of the Royal Society

some respects more than the foundation—of our present science of electro-chemistry. The sensation which the paper created in England was great; its effect abroad may be judged from the fact that the French Academy recommended Davy as first recipient of the gold medal, promised by Napoleon for "the best experiment that should be made in each year on the galvanic fluid." This recognition had a special value, owing to its being bestowed in the face of a bitter political hostility between France and England, then at war with each other.

Davy continued his researches and in the following year was already able to announce another discovery of fundamental importance which forms the subject of his second Bakerian lecture. The construction of electric batteries had been materially improved by Cruikshank, a surgeon, and Davy had modelled his own apparatus on Cruikshank's pattern. The metals used were copper and zinc, and two of the batteries consisted of 50 and 100 cells respectively, the plates in the first measuring six, and in the second, four square inches. With the two batteries in series, Davy made a determined attempt to decompose the so-called fixed alkalis: soda and potash. When a current is passed through the aqueous solution of these bodies, only hydrogen and oxygen are set free at the poles. Other experimental methods had, therefore, to be tried. As potash at ordinary temperatures does not conduct the current sufficiently well to show any effect, it was raised to a temperature at which it fused, and the current then produced a highly inflammable substance, which burst into flame by contact with air. In order to isolate that substance, Davy saw that it was necessary to conduct the experiment at ordinary temperatures, and succeeded in doing so by utilizing the hygroscopic properties of the substance, which, on exposure to damp air, cause it to become covered with moisture. The current then passed through the highly-concentrated liquid surface layer. With his 150 cells Davy found the electrical effect he looked for, and was able to isolate metallic potassium. He announced his discovery in these words:

> "Under these circumstances a vivid action was soon observed to take place. The potash began to fuse at

> both its points of electrization. There was a violent effervescence at the upper surface; at the lower, or negative surface, there was no liberation of electric fluid; but small globules having a high metallic lustre, and being precisely similar in visible characters to quicksilver, appeared, some of which burnt with explosion and bright flame, as soon as they were formed, and others remained, and were merely tarnished, and finally covered by a white film which formed on their surfaces."

Sodium was similarly obtained from soda.

The interest which the announcement of the discovery of two new elements created throughout the scientific world was accentuated by the peculiar properties which distinguished them from all known metals. They are both lighter than water, and when brought into contact with that liquid burst into flame, owing to their great affinity for oxygen. The investigation of their chemical properties was most difficult, because they oxidize rapidly when exposed to air, and can only be preserved by being immersed in naphtha or some similar liquid. Though a serious illness interrupted Davy's work, he continued to give the Bakerian lecture for six successive years, each time adding something to our knowledge, mainly in connexion with the researches which have already been described. He received the honour of knighthood in 1812, and shortly afterwards informed the managers of the Royal Institution that he could not pledge himself to continue his lectures, but was prepared to retain his position as Professor of Chemistry and Director of the Laboratory without salary. This offer was accepted. In the same year he published his "Elements of Chemical Philosophy," in which he described the "Voltaic Arc," that column of light which is formed between carbon points when a current of sufficient electromotive force is passed between them. Even Davy's vivid imagination could hardly have foreseen the part which this discovery was to play in the future history of illumination. The same paper contains another important result. Partly anticipating the subsequent work of Ohm, the electric resistance of a conductor was shown to be proportional to its length directly, and inversely to its cross-section.

His connexion with the Royal Institution was finally severed in 1813, and during the late autumn of that year he set out—accompanied by his wife and Faraday—on what he called a "journey of scientific enquiry." He was received with great honour in Paris, where he attended the meetings of the Academy of Science, which elected him a corresponding member. On November 29th a paper was read to the Academy on a new and remarkable substance discovered by Courtois, which, when heated, gave out a violet-coloured vapour. This was followed a week later by a communication from Gay Lussac, pointing out its analogies to chlorine and bromine, and proposing the name "iode" for it. It is characteristic of the impetuous manner in which Davy rushed through a research that, having obtained a small quantity of the substance, he at once set to work, and on December 20 a letter, in which he described his experiments, was submitted to the Academy by Cuvier. After a few days he forwarded his complete results to the Royal Society, proposing the name of iodine as the English equivalent for the new substance.[1]

Another example of Davy's activity during this journey remains to be mentioned. At Florence he made use of the great burning-glass belonging to the Accademia del Cimento, by means of which it had already been shown in the reign of Cosimo III. that a diamond is inflammable when the rays of the sun are concentrated upon it. On repeating the experiment Davy found that the products of combustion consisted almost entirely of carbonic acid, and pronounced diamond to be pure carbon. This result had an importance greater than that which attaches to the record of a new experimental fact; for it was the first well-established instance of a chemical element existing in two different—now called allotropic—forms.

Shortly after Davy's return to England in 1815, a Society that had been formed to discover, if possible, some method by which explosions of fire-damp could be prevented, asked his assistance. These explosions claimed many victims, and some remedy had become a pressing need. Davy acceded to the request with enthusiasm, and offered at once to visit some of the mines. The invention of the miner's lamp, which, perhaps, has saved more human lives than any other contrivance, was the result of Davy's efforts. It is not necessary here to describe the principle on which it is constructed, but it may be pointed out that the lamp embodies a technical application of pure science, which no one would have been able to devise without a thorough knowledge of the principles of Physics and Chemistry, together with a considerable experience in laboratory work. The invention was at once appreciated by those whom it was intended to benefit, and one can imagine the pleasure with which Davy received the following letter signed by eighty-three Whitehaven colliers:

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[1] The French Academy began to publish its "Comptes Rendus" only in 1835. For a reprint of the papers connected with the discovery of iodine, the reader is referred to four communications in the Annales de Chimie," vol. 87, pp. 304–329.

> "We, the undersigned, miners at the Whitehaven Collieries, belonging to the Earl of Lonsdale, return our sincere thanks to Sir Humphry Davy for his invaluable discovery of the safe lamps, which are to us life-preservers; and being the only return in our power to make, we most humbly offer this, our tribute of gratitude."

His services were recognized officially by the bestowal of a baronetcy. Davy acted as Secretary of the Royal Society between 1807 and 1812; and was elected President in 1820. His predecessor, Sir Joseph Banks, had before his death expressed his preference for another Fellow, and based his objection to Davy on the ground "that he was rather too lively to fill the chair of the Royal Society." Davy, however, was elected, and filled the chair to the time of his death in 1827.

No account of Sir Humphry Davy's life would be complete without reference to his poetic temperament and literary talents. Coleridge said of him: "If Davy had not been the first chemist, he would have been the first poet of his age." By a vivid and impressive style of lecturing, he attracted large audiences to the Royal Institution, which soon became popular. It was a fortunate day for that Institution when Davy was put in charge of the chemical department, for serious financial difficulties were threatening its existence. The stress was at once relieved by the large addition of new members attracted by the engaging personality of the young lecturer.

A significant light is shed on the small value then attached by the English Universities to experimental science by the fact that none of them ever publicly recognized Davy's work. The only University honour he received was the LL.D. degree from Trinity College, Dublin.

Yet a great revival of scientific activity had already begun at Cambridge, though at the time of Davy's death it was mainly confined to the domain of pure mathematics. It is sad to think how a spirit of loyalty to its greatest ornament should have paralysed that great University for almost a century, by compelling a rigid adherence to the details of Newton's formal procedure, for it was almost purely a question of nomenclature that delayed progress. In using the method of "fluxions," which is identical in its fundamental ideas with what we now call the Differential Calculus, Newton denoted the rate of change of a quantity, say u, depending on another quantity, say t, simply by placing a dot over the u. If u be the length of path travelled over by a point, and t the time, $\dot{u}$ would represent the velocity. Leibnitz, starting from the idea of infinitely small quantities, placed a d before the symbol of the variable quantity; dt would be an indefinitely small time, and du/dt would represent the velocity. From the purely philosophic point of view there is much to be said for Newton's notation, but as an instrument of research, that introduced by Leibnitz had considerable advantages, more especially in the inverse process of integration. When Cambridge began to wake up, Charles Babbage (1792–1871) was among those who helped to introduce the methods which had been so successful in the hands of the great French mathematicians of the eighteenth century. A special society—the Analytical Society—having been formed for the purpose, Babbage neatly expressed the objects of the society as "advocating the principles of pure '*de*-ism' for the '*dot*-age' of the University."

The founder of the new school was Robert Woodhouse (1773–1827), Lucasian Professor of Mathematics between

1820 and 1822, and subsequently Plumian Professor of Astronomy. Already in his earliest work he strongly advocated the continental system of notation, but little progress was made at the time. His views began to prevail mainly through the efforts of Babbage, combined with those of two other Cambridge mathematicians, George Peacock and John Frederick Herschel, the son of Sir William Herschel the great astronomer.

Charles Babbage is widely known in connexion with an ambitious calculating machine which he proposed to construct. His first machine was designed mainly for the preparation of astronomical tables; his second was to perform all kinds of arithmetical operations, but it never emerged from the state of general design, and no detailed drawings were made. His mathematical work, however, was not without importance. He was generally active in the cause of science. It was partly through his efforts that the Royal Astronomical Society was founded, and he strongly supported the British Association in its early days. It is noteworthy that at the second of its meetings he strongly urged that "attention should be paid to the object of bringing theoretical science in contact with the practical knowledge on which the wealth of the nations depends."

Babbage occupied for a time the Lucasian Chair of Mathematics, but spent the last years of his life in London.

George Peacock (1791–1858), another important member of the new group, occupied for a time the Lowndean Chair of Astronomy, which he resigned on his appointment to the Deanery of Ely. He played an important part in the foundation of the Cambridge Philosophical Society, and in the early history of the British Association. For the latter body he wrote an account of the progress of mathematical analysis, the first of the important series of reports in different branches which are published in its annual volumes.

Of John Herschel we shall have to speak in another connexion; his name is introduced here because his earlier work deals with mathematical analysis, and helped to introduce the differential notation.

In their endeavours to reform the teaching of mathematics Peacock and Herschel were assisted by William

Whewell (1794–1866), whose name will chiefly be remembered by his "History of the Inductive Sciences," a book in three volumes published in 1837, and containing a large quantity of useful information. Whewell ultimately became Master of Trinity College, and gained great influence in the University, but his attitude in later life became strongly conservative and antagonistic to all proposed reforms.

A new branch of science—"Physical Optics"—emerged from the work of Fresnel and Young, and when Arago and Brewster had discovered the beautiful colour effects shown by polarized light transmitted through plates cut out of crystals, mathematicians had a good opportunity of applying their talents to test the powers of the wave-theory. When, as in Arago's experiments, the light sent through the plate is confined to a parallel beam, the difficulties are comparatively slight, and were dealt with satisfactorily by the French physicists. But a number of parallel beams sent through the plate in all directions, and properly focussed, show more complicated and very beautiful effects, coloured bands being crossed by light or dark brushes of various shapes. The mathematical analysis then becomes more formidable, especially when the crystals have—as in the case of quartz—the peculiar property of turning the direction of the light vibration. Among those who successfully attacked these problems Airy held a distinguished place.

George Biddell Airy (1801–1892) had a brilliant University career. He entered the University at the age of eighteen, and four years later graduated as Senior Wrangler, and obtained the first Smith's prize. In 1826 he was elected to the Lucasian Professorship, a position which Newton's name has always invested with a certain glamour.

Though keenly interested in many branches of Physics, Airy was more particularly attracted by astronomical problems, and when a vacancy in the Plumian Professorship occurred in 1828, he became a candidate, and after election took charge of the Cambridge Observatory, which had just been established, mainly through the efforts of George Peacock. The wide range of subjects enriched by Airy's investigations may be illustrated by noting the titles of his first six contributions to science. These were: "On the figure of the earth"; "On the use of silvered glass for the mirrors of astronomical telescopes"; "On the figure assumed by a fluid whose particles are acted on by their mutual attraction and small extraneous forces"; "On the principles and construction of the achromatic eye-pieces of telescopes, and on the achromatism of microscopes"; "On a peculiar defect in the eye and a mode of correcting it"; "On the forms of the teeth of wheels." All these papers mark an advance in their subject matter, and they were written before Airy had reached the age of twenty-four.

His investigation on eye-pieces was considered to be of sufficient importance for the Royal Society to vote him the Copley Medal, their highest award, in 1831. The paper which he wrote on a "peculiar defect of the eye" deals with astigmatism. Airy, finding that he could not read with one eye, investigated the cause, and observed that the defective eye could not properly focus a point of light which was drawn out into line. This suggested the method of correcting the defect by employing a cylindrical lens. Airy was not aware that Thomas Young had already previously described the astigmatism of the eye. But Young had only met with slight cases, and thought that an ordinary lens slightly inclined was sufficient to correct the defect.

Airy's principal contribution to Physical Optics is contained in a paper in which the coloured curves observed in crystalline plates are mathematically explained and the results more particularly applied to the beautiful spiral forms seen in quartz under certain conditions. Another paper deals with the rainbow, the general explanation of which was first given by Descartes. Most people will have observed that the violet of the rainbow is frequently followed by a dark red and a succession of colours, sometimes twice repeated. The cause of these so-called supernumerary rainbows was given in a general way by Young, who showed that their appearance depends on the interference of light which manifests itself when the sizes of the raindrops are nearly equal; but Airy gave the first mathematical treatment of the subject.

Terrestrial Magnetism was another subject to which Airy devoted his attention, more especially after he had gone to Greenwich as Astronomer Royal. The connexion of astronomy with the problems of navigation has always been maintained at the Royal Observatory, and the introduction of iron ships presented new problems, because the ship became magnetic under the influence of the earth's forces, and the compass needles were very seriously deflected from the normal direction. An iron ship, *The Rainbow*, having been placed at his disposal, Airy was able to determine the amount of the deviation experimentally, and following up the observations by a mathematical investigation, he showed how the effects could be compensated by placing small permanent magnets near the compass.

In the work of spreading the new ideas on the nature of light, useful help was given by J. Baden Powell (1796–1860), the son of a gentleman who at one time was High Sheriff of Kent. He graduated at Oxford, took holy orders, and devoted himself to mathematical studies while holding a living in Kent. In 1827 he was appointed Savilian Professor of Geometry at Oxford, where he took an active part in advocating University reform. Powell wrote a treatise on experimental and mathematical Optics, investigated the reflexion of light from metallic surfaces, and showed that highly absorbing bodies in the crystalline state resembled metals in some of their optical peculiarities. He also established the commonly used empirical law connecting the refractive indices of rays of light with their wave-length.

Important as these results may be, they only dealt with isolated problems, but did not touch fundamental principles. The work of George Green (1793–1841) stands on a higher level; indeed, had it become more generally known and appreciated, it might rank as one of the landmarks of science. Green, the son of a miller in Nottinghamshire, entered the University of Cambridge when he was forty years old, and had already written a most important mathematical investigation, which was published by private subscription. This paper dealt with electricity and magnetism, and it was only during the last few years of his life that he published his investigations bearing on Optics. This part of his work was introduced by a paper on Sound, in which the subject is treated by powerful methods, now familiar to every student of mathematical physics, but then quite novel; it marked a considerable step in the philosophical treatment of the subject. As one result of this investigation, the complete internal reflexion which occurs when sound passes from one medium to another, possessing different elastic properties, was demonstrated in opposition to Cauchy, who had come to a contrary conclusion.

The subject of light is dealt with in a masterly manner in two papers. The general properties of elastic media are, for the first time, examined mathematically, and light is treated as a special case of waves passing through a perfectly elastic body. Green must be considered to be—after Newton—the founder of the Cambridge school of Mathematical Physics. He did not—like Cauchy and Franz Neumann—discuss the causes which give bodies their elastic properties, and could, therefore, dispense with any hypothesis on the mutual action of molecules, or on the ultimate constitution of the luminiferous æther. All he needed was the assumption that its properties were such as to comply with the principle of the conservation of energy. That principle had not, at that time, been formulated, but appears implicitly in Green's work. The investigation solved, under certain suppositions, the problem of the transmission, reflexion and refraction of waves passing through homogeneous elastic bodies. The only question that remained was, whether the observed laws of light could be made to agree with the mathematical formulæ obtained. The two main experimental tests that could be applied were the intensities of light reflected at the surface of transparent bodies and the laws of double refraction. The French physicist Fresnel had broken the ground, and obtained satisfactory solutions for both problems, but his analysis was not free from serious defects, and the hypothesis he applied in one case was inconsistent with that introduced in the other. The more rigid treatment of Green, together with the subsequent investigations of Stokes, McCullagh and Rayleigh, led to a deadlock, for no consistent hypothesis could be framed to fit all cases. Fortunately Clerk Maxwell's electrodynamic theory of light disposed of these difficulties.

Green's first paper on Electricity and Magnetism is considered to be his most important contribution to science, but being of a highly technical character, it must suffice to point out that the use of a certain mathematical function already introduced by Laplace was now employed to the greatest advantage under the name "potential," a term which has proved of such universal utility in all branches of physics, owing to its nominal as well as real connexion with the conception of "potential energy."

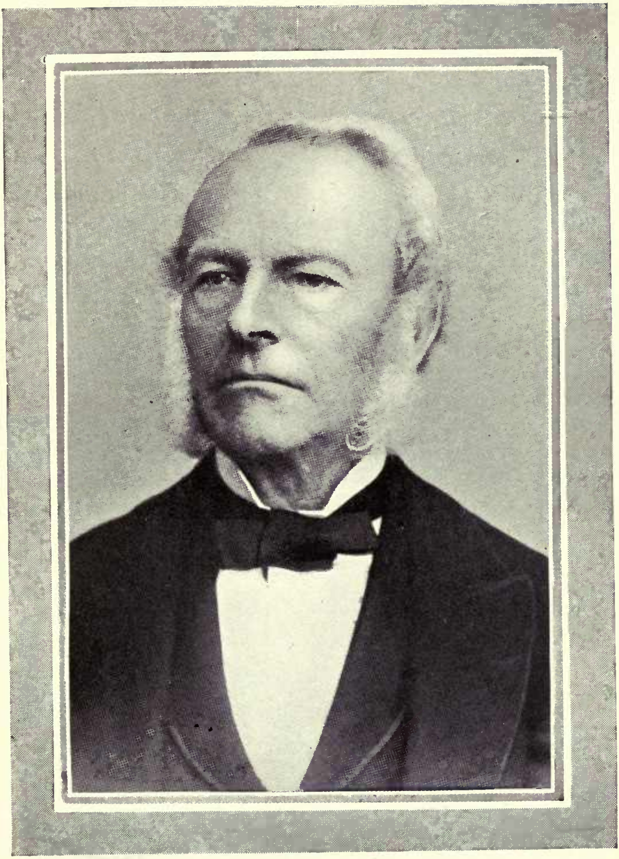
Here begins the golden age of mathematics and physics at Cambridge. Its period is coincident with the scientific activity of George Gabriel Stokes (1819–1903), which began in 1842, and extended, with but slightly diminished vigour, to the end of last century. Stokes' position as an investigator is among the greatest, but his influence cannot be measured merely by the record of his published work. He united two generations of scientific workers by the love and veneration centred in their gratitude for the assistance and encouragement which, with kindly and genuine interest, he showered upon them out of the wealth of his knowledge and experience. Even those who intellectually were his equals owed much to his sound and impartial judgment. Turning away from the grave which was closing over his lifelong friend, Kelvin was heard to say: "Stokes is gone, and I shall never return to Cambridge."

Stokes' first papers dealt with fluid motion, a favourite subject, to which he frequently returned. It is impossible in an account intended to be intelligible to the non-mathematical reader, to indicate even the general import of his fundamental investigations in one of the most difficult subjects of applied mathematics. The interest attaching to the shape and propagation of waves will, however, be readily understood, and the importance of questions of stability, which enter so much into the recent advances of aeronautics, does not need emphasizing at the present time. Both questions rest on that most careful consideration of the fundamental principles of fluid motion, to which Stokes applied his great critical powers.

The subject of light is, perhaps more than any branch of physics, indebted to Stokes. The problems of the aberration of light and the phenomena of double refraction were the first to attract his attention, and he recurs frequently to the question of the constitution of the luminiferous æther.

He wrote from the point of view of the elastic solid theory of light, which now is abandoned, but his papers, and more especially that on the Dynamical Theory of Diffraction, have lost none of their value.

Though a keen mathematician, Stokes was equally interested in realities, and he has given us at least one experimental discovery of primary importance. It was known already to the Jesuit Kircher (1601–1680), and to Robert Boyle, that extracts of certain woods presented a different appearance when examined by transmitted or reflected light; John Herschel and David Brewster added some material facts, and though they tried to theorize on them, they did not make much headway in fitting the facts into the general framework of Optics. Stokes attacked the problem in the true Newtonian manner. Sunlight admitted through a slit in a shutter entered the room, and, after passing through three prisms, was made to form a spectrum on a screen. Solutions of the substances to be examined, such as sulphate of quinine or esculine, were placed in a test tube, and then passed along the screen, so that they were successively illuminated by the different colours of the spectrum. In the red, yellow, green and blue, the substances behaved much like transparent liquids, but when placed in violet they began to shine, emitting a strong blue light, and this was accentuated when the test tube was moved beyond the visible spectrum, into what we now call the ultra-violet. The existence of such rays had already been proved by means of their chemical action, but Stokes widened their range to a quite unexpected degree by using prisms made of quartz, instead of glass; for the glass, as he showed, strongly absorbed those rays. The practical application of these researches, extending optical investigations into the regions of waves which are too short to affect our eyes, became apparent after the introduction of spectrum analysis, and Stokes himself, in a subsequent research, investigated the ultra-violet spectra of metals. But at the time, the novel result emerging from the work was the discovery that the substances experimented upon had the power of changing the wave-length of the light which fell upon them. This was quite contrary to what Newton had taught. Newton was



Sir George Gabriel Stokes

From a photograph by
Fradelle & Young

right, of course, with regard to all phenomena known to him, and the proposition that the refrangibility of a ray of light cannot be altered by reflexion or refraction was a great step in advance at the time. As constantly happens, however, new facts require a revision of old dogmas, and though Brewster could never be persuaded, Stokes showed in an absolutely conclusive manner that certain substances could, and did, alter the refrangibility, or, as we now should say, absorbed the incident light and emitted it again with different periods of oscillation. As fluor spar was one of the substances possessing this peculiar property, Stokes called the whole series of phenomena "fluorescence."

The later years of Stokes' life centred largely in his activity as Secretary of the Royal Society. The range of his knowledge, the width of his sympathies, and his almost infallible judgment, peculiarly fitted him for a position which offered so many opportunities of advising striving men, and guiding their researches into profitable directions. He died an old man, but his scientific outlook always remained young. New ideas pleased him, even when he could not agree with them, and he delighted in any discovery that did not fit into established theories.

Two years after Stokes graduated as senior wrangler and first Smith's prize man, the same honours fell to John Crouch Adams (1819–1892). There could be no sharper contrast between two men of similar intellectual attainments than that which marks the scientific life of the two mathematicians. Stokes freely presented his knowledge and experience to others, while to Adams we may apply with greater truth what Maxwell said of Cavendish, that he cared more for doing the work than for communicating it to others. How much of this reserve was due to the events connected with his first research it is impossible to say, but it is difficult to believe that these left him entirely unaffected. For that research was an arduous one, and should have led to the first discovery of the planet Neptune, if the responsible astronomers at the time had paid more attention to the calculations of the young Cambridge mathematician. A full account of the history of the new planet, from the pen of Simon Newcomb, is published in the "Encyclopædia Britannica," and we may here confine ourselves to its salient features. When the path of Uranus, the planet discovered by William Herschel in 1781, was carefully examined by Alexis Bouvard of Paris, it was found that it showed irregularities which could not be accounted for by the gravitational action of the other planets known at the time. Bouvard himself entertained the idea that the discrepancies might be due to the attraction of an ultra-Uranian planet, and an English amateur astronomer, the Rev. J. T. Hussey, wrote in 1834 to Airy, who was then Astronomer Royal, offering to make a search for this planet, if some idea of the position could be given him. Adams heard of and became interested in these discussions as an undergraduate, and the following memorandum, in his own handwriting, dated 3rd July, 1841, is still preserved : "Formed a design, in the beginning of this week, of investigating, as soon as possible after taking my degree, the irregularities in the motion of Uranus, which are yet unaccounted for; in order to find whether they may be attributed to the action of an undiscovered planet beyond it; and, if possible, thence to determine the elements of its orbit, etc., approximately, which would probably lead to its discovery."

Having graduated in 1843, he at once set to work on the problem. His first solution was communicated to James Challis, the head of the Cambridge Observatory, in September 1845, and about the 1st of November of the same year he sent his calculations to Airy, indicating the position at which the new planet might be looked for. Although, according to the American astronomer Newcomb, two or three evenings devoted to the search could not have failed to make the planet known, Airy was not satisfied, but sent a further enquiry to Adams, which, apparently, was left unanswered. Meanwhile. Leverrier, a young French astronomer, had, at the suggestion of Arago, taken up the same subject, and made an independent calculation, which led to a position of the unknown planet agreeing so closely with Adams', that Airy's interest became seriously engaged, and he suggested to Challis, on the 9th of July, 1846, to make a search for the planet. Three weeks later Challis started work in a leisurely way, but was hampered by the want of a good star map.

The delay was decisive, for, on the 18th of September, Leverrier, who had apparently no telescope of sufficient power at his command, wrote to Galle, an assistant at the Berlin Observatory, and the search was commenced on the 23rd. Star charts were at the time being prepared under the auspices of the Berlin Academy of Sciences, and one of them covered the critical region. The same night a star was discovered which was not registered in the map, and the following night its change of position proved that it was the looked for planet. It was afterwards found that Challis, in his sweeps, had observed the planet on the 4th of August, but not having compared his observations with those made subsequently, had failed to recognize it as a moving object. Had he done so, the first discovery of Neptune would have fallen to the credit of Cambridge. The relative merits of Adams and Leverrier were warmly discussed, but history quickly disposes of all such questions of priority. Whether of two discoverers one is a few weeks ahead of, or behind, the other, seems all important at the time, but very soon the adjudgment of merit turns upon the manner in which the work was carried out rather than on the calendar. Nevertheless, when so much seemed to depend on being the first in the field, the disappointment of a young man standing on the threshold of his career must have been severe, and we cannot absolve either Airy or Challis from blame.

Adams' subsequent work was unostentatious, but always sound and thorough. We may note his investigations on the secular acceleration of the moon's mean motion and on the orbit of the swarm of meteors known as the Leonides.

After 1844 a series of eminent men passed in rapid succession through the Mathematical Tripos. William Thomson (Lord Kelvin) graduated in 1845, and P. G. Tait in 1848, but their period of activity is associated with Glasgow and Edinburgh rather than with Cambridge. Edward John Routh (1831–1907) was born at Quebec and took his degree as senior wrangler in 1854. For many years he held a unique position as a teacher in his University, and it may be said that the Mathematical Tripos in its best days owed much of its success to Routh. Such, at any rate, is the testimony of many distinguished men to whose work this country owes its pre-eminent position in the history of applied mathematics. Routh's "Dynamics of Rigid Bodies" is much more than a text-book, and has become almost a classic; he has also given us valuable contributions to the investigation of the "stability" of motion.

Second to Routh in the Tripos list of 1854 stands Clerk Maxwell, one of the men whose work forms one of the great landmarks of science. But, as in the case of Kelvin, much should be said in addition to what has already appeared in the first chapter. The subject of colour vision attracted Clerk Maxwell's attention at an early period, and his experiments on the subject helped to establish Young's physiological theory which reduced all colour sensations to three primary effects. In dynamics his investigations on Saturn's rings are fundamental. The conclusion arrived at is "that the only system of rings which can exist is one composed of an indefinite number of unconnected particles revolving round the planet with different velocities, according to their respective distances. These particles may be arranged in a series of narrow rings, or they may move through each other irregularly. In the first case the destruction of the system will be very slow, in the second case it will be more rapid, but there may be a tendency towards an arrangement in narrow rings which may retard the process."

In pure mathematics, Cambridge in modern times gave us Sylvester (1814–1897) and Cayley (1821–1895). Both started life by being called to the Bar, but soon returned to their favourite subject. Sylvester was second wrangler in the Tripos of 1837, but, being a Jew, could not take his degree. After four years' teaching at University College, London, as Professor of Natural Philosophy, he accepted the Chair of Mathematics at the University of Virginia in 1841. He returned to England in 1845, and during the next ten years was connected with a firm of accountants. In 1855 he became Professor of Mathematics at the Royal Military Academy, Woolwich, but on the foundation of the Johns Hopkins University in 1877 he returned to the United States. In 1883 he went to Oxford as successor to Henry Smith. Sylvester's work dealt mainly with higher algebra and the theory of numbers. He possessed great originality; his work is described as "impetuous, unfinished, but none the less vigorous and stimulating."[1] His efforts at poetry may be noted, more especially as he possessed the unique power of expressing Heine's songs in English verse. He was also devoted to music, and at one time took singing lessons from Gounod.

Cayley's contributions range over a wide field of modern mathematics, and he ranks with the greatest mathematicians. An idea of the nature of his researches may perhaps be given by quoting the verses of Clerk Maxwell, composed to help the promotion of a fund collected for a portrait to be painted by Lowes Dickinson :—

O wretched race of men, to space confined !
What honour can ye pay to him, whose mind
To that which lies beyond hath penetrated ?
The symbols he hath formed shall sound his praise,
And lead him on through unimagined ways
To conquests new, in worlds not yet created.

First, ye Determinants ! in ordered row
And massive column ranged, before him go,
To form a phalanx for his safe protection.
Ye powers of the n^{th} roots of minus one !
Around his head in ceaseless cycles run,
As unembodied spirits of direction.

And you, ye undevelopable scrolls !
Above the host wave your emblazoned rolls,
Ruled for the record of his bright inventions.
Ye Cubic surfaces ! by threes and nines
Draw round his camp your seven-and-twenty lines—
The seal of Solomon in three dimensions.

March on, symbolic host ! with step sublime,
Up to the flaming bounds of Space and Time !
There pause, until by Dickenson depicted,
In two dimensions, we the form may trace
Of him whose soul, too large for vulgar space,
In "n" dimensions flourished unrestricted.

In another branch of science William Hallowes Miller (1801–1880) was a worthy colleague of the distinguished men who encouraged the study of science at Cambridge. He graduated as fifth wrangler in 1826, and was elected to the Professorship of Mineralogy three years later. The mathematical knowledge he had acquired fitted him peculiarly to deal successfully with that branch of his subject to which he mainly devoted himself. He developed a new system of crystallography, which rapidly gained acceptance owing to its simplicity and mathematical symmetry. Miller also took a great interest in primary standards, and had a large share in the reconstruction of the standards of length and weight, in 1839, after their destruction in the fire which broke out in the Houses of Parliament.

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[1] W. R. R. Ball, "A Short History of Mathematics."

We must postpone considering the achievements of a younger generation of Cambridge men, including John Hopkinson, George Darwin, John Poynting and others, until the earlier work of other seats of learning has been dealt with.

The Scotch Universities claim our first attention. At the beginning of the nineteenth century Thomas Charles Hope (1766–1844) enjoyed an unrivalled reputation as a teacher. It is recorded that in 1823 he lectured to a class of 575 students. At the age of twenty-one he was appointed Professor of Chemistry at Glasgow, but resigned soon after to become Assistant Professor of Medicine. In 1795 he settled down at Edinburgh, as joint Professor of Chemistry with Joseph Black, becoming sole Professor of the subject at the latter's death in 1799. Hope discovered the important fact that within a certain range of temperature just above the freezing point, water does not behave like ordinary substances, expanding when the temperature is raised, but contracts, reaching a point of maximum density near 4° C. This is a matter of considerable importance in the economy of nature, for when in the cold of winter the temperature of a sheet of water sinks below the critical point, the colder water is also the lighter. Hence ice first appears as a thin layer on the surface, while the main body can be in stable equilibrium below at a temperature higher than the freezing point. But before the ice can form at all, the whole mass must have cooled down below 4° C. Hope also had an important share in the discovery of the element strontium. A mineral discovered at Strontian in Argyllshire in 1787 was at first believed to be a carbonate of barium. Dr. Crawford threw doubt on this, and suggested that it contained a new substance, and this was confirmed and definitely proved by Hope.

John Playfair's successor in the Chair of Mathematics at Edinburgh, and subsequently in that of Natural Philosophy, was John Leslie (1766–1832). After passing through the University as a student of Mathematics and then of Divinity, he spent a year as private tutor in Virginia, and subsequently in the family of Josiah Wedgwood, where he devoted his leisure to Natural Science, translating Buffon's "Natural History of Birds." Returning to his native place, Largo, in Fifeshire, Leslie devoted ten years to scientific research, and then settled down at Edinburgh University. He received the honour of knighthood shortly before his death. Leslie's name is generally connected with his researches on radiation, which would have been more fruitful had he been less dogmatic in upholding what he conceived to be Newton's teaching. He refused to recognize the obvious bearing of Herschel's discovery of radiations less refrangible than red light, and formed artificial and erroneous theories to explain the facts. Nevertheless, his experiments on the radiative power of different substances were conducted with great skill and are of permanent value. The differential thermometer, he employed, maintained for a long time its reputation as a delicate and trustworthy instrument. We owe to him also a valuable method of determining the specific heats of bodies by measuring their rate of cooling. He was the first to freeze water by evaporating it rapidly under the action of an air pump, the vacuum being maintained by sulphuric acid, which rapidly absorbed the aqueous vapour formed. He was also the first to give the correct explanation of the rise of liquids in capillary tubes.

David Brewster (1781–1868), a man of forceful character and great ability, enjoyed a considerable reputation among his contemporaries, but the weight of his influence was not always placed in the right scale. Like Leslie, he adhered to a verbal interpretation of Newton's doctrine, and in face of the rapidly growing and decisive evidence in favour of the undulatory theory of light, his attitude exceeded all reasonable limits. Even when Fizeau had made his crucial experiment and shown that the velocity of light in ordinary refracting bodies was smaller than in air and not greater, as it should be according to the corpuscular theory, Brewster refused to admit the validity of the evidence.[1] Nevertheless, Brewster was a great experimenter, though an unkind Nemesis turned his most important investigations into an armoury which supplied effective weapons to his opponents. He studied the laws of polarization by reflexion and refraction both for transparent and metallic media; he discovered the connexion between the refractive index and polarizing angle, and the double refraction due to strain. He also first examined crystalline plates under the polariscope in diverging light. He was a prolific writer, and contributed many articles to the early editions of the "Encyclopædia Britannica." He is said to have given the first impulse to the foundation of the British Association, and was one of its chief supporters during the first years of its existence.[2]

While Brewster was battling in vain against the tenets of modern physics, a young Scotsman, equally distinguished as an experimenter, but superior in judgment and scientific insight rapidly rose to eminence. James David Forbes (1809–1868) was the fourth son of Sir William Forbes, seventh baronet of Pitsligo. He entered the University of Edinburgh at the age of sixteen, and soon afterwards contributed anonymously to the *Edinburgh Philosophical Journal*. At the age of twenty-three, which even then must have been a quite exceptionally early age, he was elected a Fellow of the Royal Society. In 1833 he was appointed Professor of Natural Philosophy at Edinburgh University in succession to Sir John Leslie, Sir David Brewster being the competing candidate, and in 1859 he succeeded Brewster in the

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[1] The authority for this statement is an oral communication by Stokes.

[2] In the "Encyclopædia Britannica," eleventh edition, it is stated: "In an article in the 'Quarterly Review,' he threw out a suggestion for 'an association of our nobility, clergy, gentry and philosophers' which was taken up by others, and found speedy realisation in the 'British Association for the Advancement of Science.'" No such article can be found in the "Quarterly Review."

Principalship of the United College of St. Andrews. His demonstration of the polarization of heat by all the various means by which ordinary light acquires that property, was an experimental achievement of the highest rank, and was a powerful link in the chain which connects the phenomena of radiation. In another series of researches, Forbes appears as one of the pioneers in the important but often neglected field of Geo-physics. He was the first to conduct systematic observations on the temperature of the earth, by inserting thermometers reaching down to different depths beneath the soil, in such a manner that they could be read off without disturbing them. Such experiments allow us to measure the thermal conductivity of the soil, and the loss of heat of the earth through radiation. Later on he determined the thermal conductivity of metals, and discovered that this conductivity diminished as the temperature increased. During a number of visits to Switzerland he investigated the flow of glaciers, and showed that the movement of the ice of glaciers followed the laws of viscous bodies. The tremors of the earth caused by earthquakes also occupied his attention, and he constructed an instrument which was not sufficiently sensitive, but must be considered as the forerunner of the modern seismographs.

Passing on to more recent times, the name of Peter Guthrie Tait (1831–1900) has already been mentioned as belonging to the Cambridge school of mathematics. The work of his life was devoted to the Edinburgh University, where his teaching of Natural Philosophy exerted a wholesome, though perhaps restraining, influence on the many students who passed through his hands. While he will be remembered chiefly as a vigorous apostle of the doctrine of energy and a forceful propagator of sound dynamical ideas, he made substantial contributions to science, and the " Elements of Natural Philosophy," written jointly by Thomson and Tait, though never completed, is a monument " more permanent than bronze." Associated with Tait as a prominent University teacher, the name of Crum Brown, Professor of Chemistry between 1869 and 1908, will be remembered by many students who passed through his hands.

George Chrystal (1851–1911), another Cambridge man whom death has too soon removed, occupied the Chair of Mathematics at Edinburgh from 1879 to the end of his life. He was a brilliant teacher, possessing one of those clear and critical minds which care more for the quality than the quantity of their work. Everything that flowed from his pen was of the highest standard. He had the distinction of being the first to carry out original investigations in the Cavendish Laboratory at Cambridge, where he tested the truth of Ohm's law to a degree of accuracy far surpassing all previous work. He published a "Treatise on Algebra" and several papers of a mathematical character. During the last years of his life he was occupied with an interesting investigation on the oscillations of level ("seiches") in the Scotch lakes, initiated by Forel's observations at the Lake of Geneva.

Glasgow University was naturally dominated during a great part of last century by Lord Kelvin's prodigious activity. His work on heat has already been described; his contributions to the practical applications of science will be referred to later, and as regards his researches on hydrodynamics and other parts of Mathematical Physics, the reader must be referred to special treatises.

During a period of forty years, Philip Kelland (1808-1879) taught mathematics at the same University, but his published work deals mainly with the undulatory theory of light, and is concentrated into a few years following his degree course at Cambridge

The University of Glasgow rendered one of the most important services that have ever been conferred both on science or on industry when, in 1840, it founded, under the auspices of Queen Victoria, the first Professorship of Civil Engineering in the United Kingdom. The second holder of the Chair, W. J. Maquorn Rankine (1820–1872), stands out as a man of striking originality and a great teacher. Most of his early instruction was received at home. Before he entered the University of Edinburgh, at the age of sixteen, he had already studied Newton's "Principia." He then became engaged in various engineering enterprises, until he was appointed Professor of Engineering at Glasgow in 1855. Rankine was one of the imaginative men who are not satisfied with the summary of facts contained in a mathematical formula, but require a definite picture of atoms and molecules, whose dynamical interactions he tried to trace in their details. He invented theories on the causes of elasticity, the constitution of gases, and the motion which constitutes heat. But while most of these theories had to be abandoned, the use which he made of them, and the consequences he drew from them, remained, because they were founded on true dynamical principles, and the results proved in many cases to be independent of the particular hypothesis from which they happened to be derived. Inspired by Joule and Kelvin, the dynamical theory of heat occupied much of his attention, and he was an early convert to the doctrine of the conservation of energy. We owe to him the introduction of the term "potential energy," one of the happy inspirations which, furnishing an appropriate nomenclature, allowed the fundamental principle of the conservation of energy to be expressed in a crisp and impressive form. Among his more technical papers, the most important ones deal with stream lines, the efficacy of propellers, and the construction of masonry dams. Rankine was an accomplished musician, and occasionally indulged in poetry. Some of the songs composed and set to music by himself were published in a separate volume.

Rankine's successor at Glasgow University, James Thomson, was a man of almost equal distinction. Like his brother, Lord Kelvin, he never went to school. The two brothers passed through the University together, and James took his M.A. degree at the age of seventeen. He was for a time apprenticed to Messrs. Fairbairn at Manchester, but bad health obliged him to return home, where he occupied himself with the invention of appliances for the better utilisation of water power. At various periods of his life he returned to the subject, and we owe to him several forms of water-wheels, a centrifugal pump, and improvements in turbines. At a meeting of the British Association in 1874 he described a pump for drawing up water by the power of a jet, which led to the construction of such pumps on a large scale. Among his purely scientific contributions, that on the lowering of the freezing point of water by pressure is the most important.

From purely theoretical considerations, James Thomson was able to predict that the freezing point of water must be lowered by pressure. His starting point was that water increases in volume on being converted into ice, and the reasoning depends on an application of the second law of thermodynamics. The fact itself was verified soon afterwards by Lord Kelvin, and though the change in the freezing point only amounts to three quarters of a degree Centigrade for 100 atmospheres, it yet plays an important part in the behaviour of glaciers, for it explains the plasticity of ice discovered by Forbes. The binding together of snow by the pressure of the hand is also a consequence of the partial melting by pressure, and solidification when the pressure is removed.

Scotland claims also Sir William Rowan Hamilton (1805–1868) as one of its great men, though his life was spent in Dublin, where his father—a solicitor—had settled as a young man. The genius of men possessing exceptional mathematical powers frequently shows itself at a very early age, and Hamilton was no exception to this rule. But even before he had an opportunity of discovering his own powers in that direction, he showed a wonderful facility of acquiring foreign languages. At the age of thirteen he is reported to have learned Persian, Arabic, Sanskrit, and Malay, besides the classical and modern European languages. At the age of sixteen he had mastered Newton's "Principia" and the "Differential Calculus," and soon after began a systematic study of Laplace's "Mécanique Céleste." When he was eighteen years old Dr. John Brinkley, the Astronomer Royal for Ireland, is said to have remarked: "This young man, I do not say *will* be, but *is* the first mathematician of his age." He entered Trinity College, Dublin, but before he had taken his degree, his career as a student was cut short by his appointment to the Professorship of Astronomy at the Dublin University, and he established himself at the Dunsink Observatory. To all students of Mathematics and Physics, "Hamilton's Principle" is known as one of the fundamental instruments of dynamics, which may be applied to nearly all natural phenomena.

Hamilton's first investigation on "Systems of Rays" led to an optical discovery that created considerable interest at the time because it drew attention to a curious phenomenon of refraction in biaxal crystals which had not previously been noticed. According to Fresnel's theory, there are in such crystals two directions such that a ray passing along them will emerge as a conical pencil. It follows that, under certain experimental conditions, the two spots of light produced by double refraction are spread out and joined so as to form a ring. Hamilton's prediction was immediately verified by Humphrey Lloyd, and was received as a striking confirmation of Fresnel's theory.

The later years of Hamilton's life were spent in developing the new calculus of "Quaternions," to which he attached great importance; but, though it has yielded methods of great elegance, it has not quite fulfilled its early promise, and has few adherents at the present time. Some of its conceptions, however, permanently survive in the modern vector analysis.

No single teaching institution has a higher record of scientific output during the last century than Trinity College, Dublin. Humphrey Lloyd, James McCullagh, John Hewitt Jellett, George Salmon, Samuel Haughton, George Francis Fitzgerald, Charles Jasper Joly are names that any University would have reason to be proud of. Lloyd (1800–1881) has already been mentioned in connexion with the verification of conical refraction. In later years he devoted much time to the study of terrestrial magnetism, and took an active part in the magnetic survey of Ireland. James McCullagh was an eminent mathematician whose contributions to the undulatory theory of light take a conspicuous place in the history of that subject. Jellett (1817–1888), like McCullagh, was a mathematician, primarily attracted more by physical and even chemical problems than by pure theory. He is, perhaps, best known for his improvement of the experimental methods for studying the rotation of the plane of polarization, observed in certain bodies like sugar. George Salmon (1819–1904), for many years Provost of Trinity College, confined himself to problems of Pure Mathematics, notably in the domain of Geometry. Samuel Haughton (1821–1897) was primarily a geologist, but his versatile mind made frequent excursions into other subjects, partly suggested to him by his interest in the structure of the earth, but partly disconnected entirely from his main work, such as his investigations on some problems of sound and light and on the velocity of rifle bullets. He claimed amongst other achievements to have been the originator of the "long drop" in capital punishment.

Of G. F. Fitzgerald (1851–1901) we cannot speak without lamenting the loss inflicted on science by his early death. He was one of the select few whose genius extends beyond the limits of their own productive work, stimulating the thoughts and penetrating the efforts of their contemporaries. One of the earliest students of Maxwell's electromagnetic theory, he realized probably more than anyone else its wonderful future. Of the practical applications of wireless telegraphy he had no thought—his interests lay in other directions—but he felt that the final proof of the theory must be sought in the experimental confirmation of the transmission of electro-dynamic waves through space, and saw that the difficulty to be overcome was the power necessary to convey the energy from the metallic conductors to the medium. His thoughts even ran ahead of Maxwell's theory, and he escaped the common error of apostles of a new doctrine, who adopt the unavoidable limitations of a first presentment as an immovable dogma, mistaking the passing faults of a child for essential features of its character. It was a necessary step in the evolution of the Faraday-Maxwell conception of electrical action that an electric current should be looked upon as the flow of a coherent substance satisfying everywhere the condition of incompressibility. But when the relation between electrical actions and molecular phenomena were considered, the laws of electrolysis suggested that, like matter, electricity might have an atomic constitution. Most of the professed adherents of Maxwell's doctrine would have none of this idea. It seemed to them to violate the dogma of incompressibility. But Fitzgerald recognized that there was no real contradiction, and he became one of the great advocates of the electron theory. In this, as in other matters, his mind was receptive and appreciative of the efforts of others, and his generous disposition made him a willing helper of all who were seeking advice. Though his influence on contemporary thought was all the greater in consequence, the output of his own work was interfered with.

Scientific education in Ireland owes much to George Johnstone Stoney (1826–1911), the uncle of Fitzgerald, and for many years, up to the time of its dissolution in 1882, the Secretary of Queen's University. During twenty years he acted in the same capacity to the Royal Dublin Society, an institution founded in 1731 for promoting the arts and industries of Ireland. As an original investigator Stoney was distinguished by a philosophical and balanced mind, but his work was suggestive rather than conclusive. He showed remarkable foresight when he interpreted the true significance of Faraday's laws of electrolysis as indicating the atomic nature of the centres of electric action, and he gave the name of "electron" to the ultimate constituent of electricity.

When the Queen's Universities were founded in 1845, the appointment of first Vice-President at Belfast fell to Thomas Andrews (1813–1885), a man of remarkable gifts and quite exceptional experimental powers. After a course of study of chemistry at Glasgow University and—for a short time—under Dumas at Paris, he took the degree of Doctor of Medicine at Edinburgh, and then returned to practise medicine at Belfast. But the call of science was too strong, and he accepted the appointment at Queen's College, which was combined with the Professorship of Chemistry. Andrews' first paper, published in 1836, dealt with a question which has since acquired considerable importance: "On the conducting power of certain flames and of heated air for electricity." He next devoted himself to the study of the heat developed in chemical combinations. His work gained in importance as he proceeded, and together with Tait he was the first to demonstrate the true nature of ozone, proving it was only an allotropic form of oxygen. The research for which he is most renowned is that dealing with the liquefaction of gases. When Faraday had succeeded in liquefying carbonic acid, chlorine, and other vapours by pressure, the question naturally arose whether all gases could be converted into liquids. Pressure alone seemed ineffective with gases like oxygen, nitrogen, and hydrogen, but that might have been due to our inability to apply sufficient power. Andrews, investigating the conditions under which carbonic acid could be liquefied, and taking exact measurements of the pressure required at different temperatures, discovered that there was a critical temperature, such that, if the gas be heated above it, no pressure, however great, could convert it into a liquid. Previous experiments by Cagniard de la Tour and others had foreshadowed such a result, and Faraday came very near to the true solution of the problem, but this does not detract from the value of the classical research by which Andrews finally established his results. We have seen in our own time how, in the hands of Sir James Dewar and of the Dutch physicist, Kammerlingh Onnes, the subject has developed into a new branch of science, enabling us to investigate the properties of bodies at temperatures so low that molecular motion is almost annihilated.

The reputation of Oxford University as a centre of research did not, during the last century, rest on its activity in scientific pursuits; but it had among its teachers and pupils at any rate one man whom any seat of learning would have been proud to claim as its own. Henry John Stephen Smith (1826–1889) was both a brilliant mathematician and a great man. He was born in Ireland, but after his father's death his mother removed to the Isle of Wight, and it was there that Henry Smith received his first education. After a short time spent under a private tutor, he went to Rugby, where he became head boy under Dr. Tait. In spite of ill-health, which for some time interrupted his studies, he obtained a Balliol scholarship in 1844, the Ireland scholarship in 1848, and a first-class both in the classical and mathematical schools in 1849. In the meantime he had spent a winter in Paris, where in 1847 he attended the lectures of Arago and Milne Edwards. In 1861 he was elected to the Savilian Professorship of Mathematics as successor to Baden Powell. His researches on the theory of numbers and the elliptic function placed him in the front rank of mathematicians; and he showed the same perfect mastery over every subject he touched. The reader is referred to the excellent obituary notice from the pen of Dr. J. W. L. Glaisher for an account of the extent and value of his researches.[1] With regard to his teaching capacity, those who remember him will agree with Dr. Glaisher that: "As an expounder of mathematics before an audience he was unsurpassed for clearness, and his singular charm of manner gave him a remarkable power for fixing the attention of those present."

His sound judgment was often called upon by others; he was a member of the Royal Commission on Scientific Instruction (1870), and of the Oxford University Commission (1877). During the last sixteen years of his life he acted as Chairman of the Meteorological Council and devoted much time to the work. Quoting again from Glaisher's obituary notice: "It is difficult to give an idea of the position Professor Smith held in Oxford and in society generally, so brilliant were his attainments and so great and varied his personal and social gifts."

Though Henry Smith was the greatest of the scientific men who taught at Oxford, mention should be made of Odling, the Professor of Chemistry, and Vernon Harcourt, inventor of the pentane lamp as a standard of light. The optical work of Baden Powell has already been referred to, and it will be remembered that Sylvester for a time taught at the same University, succeeding to the Professorship vacated by the death of Henry Smith. The revival of astronomical research at Oxford owes much to the efforts of Charles Pritchard (1808–1893), who, on his appointment to the Savilian Professorship, succeeded in persuading the authorities to erect a new observatory, and to provide an adequate equipment. Pritchard, after graduating as fourth wrangler at Cambridge, had spent nearly thirty years as Headmaster of Clapham Grammar School. After his retirement in 1862, he undertook some clerical duties, began to take an active interest in astronomy, and filled the office of Hon. Secretary, and subsequently of President, of the Royal Astronomical Society. When he was appointed to the Chair of Astronomy at Oxford he was already sixty-three years old, but nevertheless energetically organized the new Observatory. Pritchard was one of the early advocates of the use of photography in astronomical research, and showed how it could be applied to obtain accurate measurements, and in photometric determinations.

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[1] "Monthly Notices," Roy. Ast. Soc., Vol. XLIV., 1884.

CHAPTER V

(Physical Science)

THE HERITAGE OF THE NINETEENTH CENTURY—*continued*

THE foundation of the University of London, followed by that of the newer Universities, plays so important a part in the history of our subject that a few words must be said on the origin of the movement. It arose not so much out of a feeling that the number of Universities in the country was too small, but in consequence of the religious exclusiveness of Oxford and Cambridge, which only admitted adherents of the Church of England to University honours. In October 1828, therefore, a number of Nonconformists of various religious denominations combined, and University College was opened as the "University of London," with power to grant degrees. Unfortunately, some influential persons, though favourably inclined to the scheme on educational grounds, objected to its entire dissociation from the national church, and successfully pressed their objections. At the present time the difficulty—such as it is—would be met by the establishment of a religious Hall of Residence, but no one thought of that expedient, and King's College was founded for the purpose of combining secular teaching with instruction in "the doctrines and duties of Christianity, as the same are inculcated by the Church of England and Ireland."

The University of London then became a mere examining body, granting degrees, without control of the teaching, while University College received a new charter, without the power of conferring degrees. Among its first Professors was Augustus de Morgan (1806–1871), who was elected to the post a year after he had graduated at Cambridge as fourth wrangler. De Morgan, the son of a Colonel in the Indian Army, was born at Madras, but brought to England as a child. He combined exceptional mathematical talents, inherited from his mother, with great powers of exposition, and his lectures attracted many men of distinction. Original in his views and his methods, and possessing great strength of character, he followed the dictates of his conscience without regard to consequences. Shortly after his appointment at University College, he sent in his resignation because a colleague, the Professor of Anatomy, had been dismissed without assigned cause. He subsequently consented to be re-appointed when the regulations had been altered so as to prevent a repetition of similar incidents. Ultimately he severed his connexion with University College because the governing body took too narrow a view of the religious neutrality of the college, and refused to appoint Dr. Martineau to one of its Chairs on the ground that he was pledged to Unitarianism. But we are here concerned with his scientific productions. His work on the Differential Calculus is one of those rare books which never seem to become antiquated. Its introductory chapter gives us what is probably the best exposition of the fundamental principles of the Calculus that has yet been given. De Morgan's "Budget of Paradoxes," reprinted after his death from articles that had appeared in the *Athenæum*, contains, besides an historical account of the vagaries of circle-squaring and the trisection of angles, the views of the author on many subjects. Like many mathematicians, De Morgan was devoted to music; he was a good player on the flute, and had also a talent for drawing caricatures.

Thomas Graham (1805–1869), the first of the series of great chemists who have adorned the laboratories at Gower Street, commenced his studies at Glasgow, and after completing them under Hope and Leslie at Edinburgh, returned to the former city, where for a short time he held the Chair of Chemistry. When in 1837 he was called to University College, London, as Professor of Chemistry, he had already established his reputation as an original investigator. His chief interest was centred in the study of those physical and chemical properties which may be expressed in terms of molecular motion. The connexion between the density of gases and the velocity of their diffusion was first investigated by him in 1828, but established with greater precision ten years later. The conclusion arrived at, that the velocity of the diffusion is inversely as the square of the density, proves, in the light of subsequent investigation, that the molecules of different gases have—at the same temperature—the same energy of motion. Graham's investigation covered the whole field, including the inter-diffusion of different gases, their transpiration through capillary tubes, and their effusion into a vacuum, the peculiarities being carefully examined in each case. A further series of papers dealt with molecular motion in liquids, and established the distinction between the inert "colloid" and the more rapidly diffusing "crystalline" substances. These have had important consequences, and we now know that in the colloidal state we are dealing with molecular aggregates of comparatively large dimensions, the greater individual masses accounting for the slowness of the movements. Graham's experiments on the passage of liquids through certain membranes opened out a fruitful field of research on the phenomenon called osmosis, which has recently gained great importance. In the domain of pure chemistry, a paper "On water as a constituent of salts" led to results of interest, more especially through the discovery of the polybasic nature of phosphoric acid.

W. H. Wollaston (1766–1825), a medical man who gave up his practice in order to devote himself to the study of chemistry, had, in the course of his researches on platinum, discovered two new elements, palladium and rhodium. Investigating the peculiar power which palladium has to absorb hydrogen, Graham came to the conclusion that hydrogen, like a metal, could form alloys, and connecting this with the chemical behaviour of this element in other respects, he formed the idea that it was the vapour of a highly volatile metal, to which he gave the name of "hydrogenium." The expectation then raised was that hydrogen when condensed into the liquid or solid form would present the characteristic appearance of a metal, but this was not confirmed when Sir James Dewar actually accomplished the condensation.

University College during Graham's time had two Professorships of Chemistry, that of "Practical Chemistry" being held by George Fownes (1815–1849), who, on his death four years after the appointment, was succeeded by Alexander M. Williamson (1824–1904). Like Graham, he was of Scotch descent, but his education was cosmopolitan. After attending schools in London, Paris, and Dijon, and studying chemistry during five years in Germany, he stayed three years in Paris and then returned to England. His most important contribution to science is that which elucidated the chemical process by which ether is formed when alcohol is brought into contact with hot sulphuric acid. Apart from the intrinsic importance of the subject, the research illuminated a number of problems in chemical dynamics, and led to a better understanding of "catalytic" actions, by which the presence of a body induces chemical transformations without itself being apparently involved in the change. Organic chemistry owes to Williamson many other fruitful ideas. In inorganic chemistry his views on the constitution of salt solutions, though essentially different from our present ideas of "ionization," yet come sufficiently near to them to have prepared the way for the readier acceptance of the theory subsequently developed by Arrhenius. They held the field for a time, and made the process of electrolysis more intelligible.

Williamson played an important part in the scientific life of London; his was a well-known figure at the meetings of the Chemical Society, and he started the publication, in its Journal, of the monthly reports of all papers of a chemical nature published elsewhere. He acted as Foreign Secretary to the Royal Society during sixteen years, and also assisted the efforts made at various times to convert the University of London into a teaching body. In 1855, when Graham resigned the Chair of Chemistry in University College on becoming Master of the Mint, the two Professorships were united, and Williamson continued to hold the combined Chairs until 1886.

One of Williamson's colleagues at University College, whose brilliant career was cut short by premature death, may here be referred to. William Kingdon Clifford (1845–1878), second wrangler in 1867, held the Chair of Applied Mathematics during eight years, but was stricken with tuberculosis, and died in Madeira. He has left many important contributions both to applied and pure mathematics.

Among the Professors at King's College appointed at or shortly after its foundation were two men of world-wide reputation, John Frederick Daniell (1790–1845) and Charles Wheatstone (1802–1875). Daniell constructed the first electric cell which was free from the irregularities caused by polarization, so that constant currents could be obtained. He was mainly interested in meteorology, and rendered valuable services in insisting on accurate and systematic observations of the various phenomena on which the physics of the atmosphere depends. His most successful instrument was that by means of which the humidity of the air is determined from the temperature at which dew begins to deposit.

Wheatstone began his career as a maker of musical instruments, and during the ten years 1823 to 1833 published a number of papers on sound. In 1831 he was appointed to the Chair of Natural Philosophy at King's College, and three years later conducted some experiments which were devised to measure the velocity with which electrical effects are transmitted along a wire, and the duration of an electric spark. In these experiments a rotating mirror was first used to measure small intervals of time. He was also one of the first to recognize the importance of Ohm's law, and to insist on accurate standards and good methods of measuring electromotive force, resistance and current. The Bakerian Lecture for 1843 contains a description of the methods employed by him, including the arrangement of wires now familiar to every student of science under the name of the "Wheatstone bridge." As he points out himself, the arrangement was first used by Samuel Hunter Christy (1784–1865), Professor of Mathematics at the Military Academy, Woolwich.

Wheatstone was the first to show how a number of clocks can simultaneously be regulated by the electric current.

In Optics he invented the stereoscope and conducted valuable experiments on the physiology of vision. At the British Association in 1871 he exhibited an instrument by means of which the solar time could be determined by utilizing the polarization of the blue light of the sky. This method, as he explained, has several advantages over the ordinary sundial. Wheatstone's spectroscopic observations and his contributions to telegraphy will be referred to in another place (*see* pp. 154, 188).

The first sight that meets the eye of a visitor entering the Town Hall of Manchester is the statue of Dalton on his left, and that of Joule on his right. These two great men found a congenial home in the town which numbered amongst its citizens others who, long before it became the seat of a University, upheld the dignity and usefulness of its Literary and Philosophical Society. Such were Thomas Henry (1734–1816), the author of valuable investigations in Chemistry; his son, William Henry (1774–1836), who studied the laws of absorption of gases by liquids, and William Sturgeon (1783–1850), the inventor of the electro-magnet, who started life as a shoemaker, entered the army as artillerist, became teacher of physics at the military academy of the East India Company, and spent the last twelve years of his life in scientific investigations at Manchester. The ambition of that town to become the seat of a University dates back to the seventeenth century, and though renewed at various times long remained unsatisfied. By the will of John Owens, who died in 1850, a college was founded, which after a period of difficulty rapidly rose to eminence. It numbered among its first professors Edward Frankland (1825–1899), whose researches were fundamental in the development of modern chemistry, and who, next to Davy and Dalton, must probably be considered to be the greatest chemist this country has ever produced. Having discovered a number of organic substances containing metallic atoms as essential constituents, he investigated the general laws of the formation of chemical compounds, and originated the conception that the atom of an elementary substance can only combine with a certain limited number of atoms of other elements. This led to the discovery of "valency" as the groundwork of chemical structure. Frankland only stayed six years in Manchester; on returning to London, he became lecturer in Chemistry at St. Bartholomew's Hospital, and subsequently Professor of Chemistry at the Royal Institution and the School of Mines. The latter years of his life were spent in work connected with the examination and purification of the water supply. He was made a K.C.B. in 1897, two years before his death.

When Frankland, in 1857, resigned his position at Manchester, the choice of a successor lay between Robert Angus Smith (1817–1884) and Henry Enfield Roscoe (1833–1915). The former was personally known in Manchester, where he resided, and had already done some meritorious work on the impurities found in the air and water of towns, a subject to which he devoted the greater part of his life. Roscoe was only twenty-four years old, but the promise of future success was already foreshadowed in his academic career, and fortunately for Owens College, whose fortunes were then at a low ebb, he was elected to the Professorship. At the age of fifteen, Roscoe had entered University College, London, where he came under the influence of Thomas Graham and Alexander Williamson. After taking his B.A. degree at the University of London, he spent four years at Heidelberg under Bunsen. His activity in Manchester is marked by the foundation of a school of chemistry through which many men of high distinction have passed, and by the happy relations which he established between the industrial community and the academic life which was centred in the college. The prosperity of that institution was soon secured by his strong and genial personality, and when other men eminent both in science and literature had joined its staff, its rise to the dignity of an University became only a question of time. Roscoe was one of the first to point out the need of technical education in this country, but he did not interpret that term in a narrow sense. With him it meant a sound scientific instruction directed towards industrial ends, but not excluding a wider culture. He served on the Royal Commission on Technical Education appointed in 1881, and at the conclusion of its labours received the honour of knighthood. His earnest desire to spread the knowledge and appreciation of science led him to organize a series of popular penny lectures which attracted large audiences, who had the privilege of listening to such men as Huxley, Huggins, Stanley Jevons, Clifford, and others scarcely less eminent.

Roscoe's first scientific investigations dealt with the chemical action of light. The subject was suggested by Bunsen, and partly carried out in conjunction with him. Apart from the purely scientific interest attaching to the effect of light in inducing hydrogen and chlorine to combine, the research was conducted with the practical object of obtaining a means of measuring the actinic value of daylight under different atmospheric conditions. His principal contribution to pure chemistry consists in his investigation of the element vanadium, which established its true position as a trivalent element of the phosphorus group, and showed that the substance Berzelius had considered to be the metal was really its nitride.

Among Roscoe's colleagues at Manchester who have helped to establish the reputation of Owens College as an important centre of scientific research, two men stand out prominently: Balfour Stewart (1828–1887) and Osborne Reynolds (1842–1912). It was probably fortunate that a mind of such striking originality as that of Reynolds was never submitted to the discipline of school, though it is difficult to believe that even the severest group-education could have shaped it into a common mould. His father was a clergyman who had passed through the Mathematical Tripos as thirteenth wrangler. The son was brought up at home, and entered the workshop of an engineer at the age of nineteen. He soon found that a knowledge of mathematics was essential to work out the problems that presented themselves to him, and he decided to go to Cambridge, where he graduated as seventh wrangler in 1867. He then returned to the office of a civil engineer in London, but within a year offered himself as a candidate for the newly-founded Professorship of Engineering at Owens College. He remained connected with that institution from 1868 to 1905, when he retired owing to failing health. In his methods of instruction Reynolds was a follower of Rankine; his lectures were sometimes difficult to follow, but capable and earnest students always derived great benefit from them, and he brought up a number of distinguished men who look back with gratitude and affection to the inspiration they received from his instruction.

His researches nearly all possessed fundamental importance. To quote Horace Lamb[1] :—

> "His work on turbine pumps is now recognized as having laid the foundation of the great modern development in those appliances, whilst his early investigations on the laws governing the condensation of steam on metal surfaces, and on the communication of heat between a metal surface and a fluid in contact with it, stand in a similar relation to recent improvements in boiler and condenser designs."

He laid the scientific foundation of the theory of lubrication, and his papers on hydrodynamics have become classical both on account of their theoretical importance and practical applications. Like Rankine, his mind was not satisfied with finding useful applications of his scientific knowledge, but he took an active interest in all questions which touched the foundation of elemental forces and atomic structure. He was the first to give the correct explanation of Crookes' radiometer, and in his later years he tried to formulate a structure of matter and æther which should account for gravitation as well as for electrical and other forces. Whatever may be the ultimate fate of these speculations, they were worked out in a systematic and original manner, and incidentally contain results of permanent value.

Three years after Roscoe's appointment in Manchester, Robert Bellamy Clifton was elected to the Chair of Natural Philosophy, but resigned in 1865 to take the Chair of Experimental Physics at Oxford. His successor, William Jack, subsequently Professor of Mathematics at Glasgow, was interested mainly in the theoretical side of the subject, and resigned in 1870. It fell to his successor, Balfour Stewart, to organize the department as an effective home of research, and to take the first step in that direction by fitting up a laboratory, and encouraging students to submit themselves to a training in accurate scientific measurements.

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[1] Obituary Notice of Osborne Reynolds, "Proc. Roy. Soc.," Vol. LXXXVIII., p. xvi (1913).

Balfour Stewart was brought up for a commercial career, and went out to Australia as a man of business. But his scientific ambitions, inspired as a student at Edinburgh University, soon made him return to that University, where he became assistant to David Forbes. Between 1859 and 1870 Stewart acted as Director of the Kew Observatory, and devoted his energies mainly to investigations on Terrestrial Magnetism. Chiefly interested in the connexion between Terrestrial Magnetism and cosmical phenomena such as the periodicity of sunspots, he did not, in the opinion of some influential members of the Gassiot Committee of the Royal Society, which controlled the work of the Observatory, pay sufficient attention to the routine of observations. Some friction resulted, and the vacancy in the Professorship at Manchester gave him the welcome opportunity of changing over to a more congenial position. Unfortunately, a few weeks after he had delivered his first lecture, he met with a serious injury in one of the most terrible railway accidents that have taken place in this country. After an interval of a year, he recovered sufficiently to take up his work again, and though at the age of forty-three his accident had left him with the appearance of an old man, his mind remained fresh and young. During the time in which Balfour Stewart presided over the Physical Department at Manchester, he counted among his pupils several men who subsequently rose to eminence—among them John Poynting and Sir Joseph Thomson. His own work at that time was chiefly statistical, dealing with the periodicities of meteorological and cosmical phenomena.

Balfour Stewart's first and most important work on the radiation of heat is much interwoven with the early history of Spectrum Analysis, and affords the opportunity of giving a brief account of that subject, especially as both in what may be called the period of incubation and in its later developments this country took a most important share.

As early as 1752, one Thomas Melville, about whose history nothing seems to be known, experimented with coloured flames, and noted the yellow colour imparted to a flame by soda. His observations were published in a book bearing the title "Physical and Literary Essays." Exactly fifty years later, William Hyde Wollaston, who has already been mentioned as the discoverer of palladium and rhodium, examined the blue light at the base of a candle flame through a prism, and described the bright bands which appear in its spectrum. Young repeated the experiments, and committed what is perhaps the one great error of his scientific work, when he ascribed the colours seen to effects of diffraction. In these and most of the subsequent observations, the light to be examined is passed through a slit, and traversing a prism is separated into its components. The eye focussing on the slit, with or without lenses, sees it illuminated by the various elementary vibrations which the original light may emit. These vibrations show themselves, therefore, as luminous lines, which are images of the slit. The whole appearance is called a spectrum, of which it is customary to speak as consisting of "lines," a misleading term, because it implies that the "line" is a characteristic of the substance, while it is only an incident of the instrument by which the spectrum is examined. The expression, having been universally adopted, may be retained with the understanding that it is the position of the line which indicates the nature of the light vibration, and therefore characterizes the luminous body. Sir John Herschel investigated coloured flames in 1823, and made two significant observations: "The colours thus communicated by the different gases to flame afford, in many cases, a ready and neat way of detecting extremely minute quantities of them," and "no doubt these tints arise from the molecules of the colouring matter reduced to vapour, and held in a state of violent motion." Fox Talbot in 1826 looked at the red lights occasionally used to illuminate the stage in theatres. He correctly ascribed a red line to nitre, but believed the yellow sodium line to be due to sulphur or water. Eight years later Talbot returned to the subject, and clearly pointed out that "optical analysis can distinguish the minutest portions of these substances (lithium and strontium) from each other with as much certainty, if not more, than any other known method." He also offered the remark that "heat throws the molecules of lime into such a state of such rapid vibration that they become capable of influencing the surrounding ætherial medium and producing in it the undulations of light."

In 1845 William Allen Miller (1817–1870), Professor of Chemistry at King's College, London, published some observations on flame spectra, which were not very accurate, and his plates left it doubtful whether the bright bands or the dark intervals between them ought to be looked upon as the essential feature. This seems to have been one of the stumbling-blocks of early investigators when comparing the continuous spectra of ordinary flames with the discontinuous spectra of incandescent substances.

An important contribution to the subject was made by William Swan (1818–1894), who, between 1859 and 1880, held the Professorship of Natural Philosophy at St. Andrew's. Swan was the first to introduce (1847) the collimator into spectroscopic observations, and in 1857 he examined and accurately mapped the spectrum of hydrocarbon flames. He discussed the origin of the ubiquitous yellow line and came to the correct conclusion that it is due to the presence of minute quantities of sodium.

The spectra of the electric sparks passing between poles of different metals were first examined by Sir Charles Wheatstone, and described in a communication to the British Association in 1835. Unfortunately an abstract only was published, but even the short account given ought to have drawn attention to the extreme importance of the matter. The spectrum of mercury was observed and accurately described, and proved to be identical, whether the spark be taken in air, oxygen gas, the vacuum obtained by an air pump, or the Torricellian vacuum. From these observations the correct inference was drawn that the spectrum is the result of the volatilization and ignition (not combustion) of the ponderable matter contained in the spark. The spectra of zinc, cadmium, bismuth and lead were also obtained by taking the sparks from poles of the melted metals. The paper was published in full in the *Chemical News* in 1861, and was then found to contain this significant passage: "the number, position, and colour of these lines differ in each of the metals employed. These differences are so obvious that any one metal may be instantly distinguished from the others by the appearance of its spark, and we have here a mode of discriminating metallic bodies more ready even than chemical examination, and which may be hereafter employed for useful purposes." Wheatstone himself fully realized the importance of the subject, as is shown by his remark that "the peculiar effects produced by electrical action on different metals depend, no doubt, on molecular structure, and contain hence a new optical means of examining the internal mechanism of matter."

So much for what was known of the emission spectra of luminous bodies before the date of Kirchhoff and Bunsen's work; let us now turn to the phenomena of absorption. Wollaston was the first who mentioned the dark lines which traverse the spectrum of solar light, but he seems to have looked upon them mainly as lines separating the different colours, though he points out two of them that were not. During the researches which Fraunhofer, the famous optical instrument maker of Munich, conducted with a view to improving the methods of determining the refractive indices of different kinds of glass, sunlight was examined, and found to contain many fine dark lines in its spectrum; these are now called "Fraunhofer lines." A large number of them were carefully mapped, and the most prominent served him as standards for his measurements; but he examined also the light of a luminous flame and that of some of the stars and planets. The first experiments date back to 1814; nine years later he returned to the subject and measured the wave-lengths of the principal lines by means of his gratings. He pointed out that by using a blowpipe he could obtain a flame which emits a close doublet of yellow light coincident with the solar lines D. Fraunhofer examined the spectrum of the "electric light," and noticed bright lines; he used the spark of an electric machine as source of illumination and apparently took what we now know to be the spectrum of air as characteristic of the electric source of illumination. Of greater importance are his observations on the spectra of the stars and planets, which allowed him to recognize that the planets, like the moon, have a spectrum identical with that of the sun, but that some of the stars, like Sirius, show only a few very strong lines. Sir David Brewster in 1834 compared the solar spectrum observed by him with Fraunhofer's drawings, and noticing additional lines which change with the position of the sun, ascribed them correctly to effects produced in our own atmosphere. He had already in 1832 referred with approval to Herschel's suggestion that the dark Fraunhofer lines were produced by absorption in the atmosphere of the celestial bodies. An interesting observation which ought to have attracted attention at the time, but, like many others, was only saved from oblivion when the method of spectrum analysis had been permanently established, was made in France by Foucault. In the spectrum of the voltaic arc, he noticed the presence of what we now know to be the sodium lines, and identified them with Fraunhofer's line D. He found further that on passing the sunlight through the arc, these lines became darker, and further discovered that the lines under certain conditions may be reversed in the arc itself.

In all these observations many important facts were recorded, but the ideas on radiation were vague at the time and no effort was made to connect it with absorption. Stokes; in his own mind, seems to have been clear on the matter, and in private conversation with Lord Kelvin "explained the connexion of the dark and bright line (of sodium) by the analogy of a set of piano strings tuned to the same note, which if struck would give out that note, and also would be ready to sound it, to take it up, in fact, if it were sounded in air. This would imply absorption of the aerial vibrations, as otherwise there would be creation of energy."[1] At this stage historically, but in ignorance of much of what has been described, Balfour Stewart undertook a comprehensive investigation of the subject of radiation and absorption. Adopting Preevost's views that equilibrium of temperature means a balance between absorption and radiation, he applied for the first time the ideas of the principle of conservation of energy to the subject, by considering an enclosure impermeable to heat radiations and at a uniform temperature. This led him to the conclusion that the internal radiation must everywhere be the same and only depend on temperature. The rest follows easily: absorption and radiation must bear a constant relation to each other in such an enclosure. He illustrated the results by many striking experiments.

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[1] The quotation is from a letter addressed by Stokes to Sir J. Lubbock (afterwards Lord Avebury); see G. G. Stokes, "Memoir and Correspondence," by Sir J. Larmor, Vol. II., p. 75.

Much has been written about the relative merits of several observers who anticipated, in various directions, the great work of Kirchhoff and Bunsen. But the history of science should not aim at assigning marks of merit to different investigators. What interests us is how a great generalization gradually matures, how it begins frequently with the observation of isolated facts, generally overlooked at first because their importance is not recognized. It may be that some link between the disconnected observations is wanting; it may be that experiment has gone ahead of theory or theory may be waiting to be confirmed by experiment. When the time is ripe, someone with a better appreciation of the significance of the facts or a deeper insight into their mutual connexion touches the matter with a master hand, and presents it in a form which carries conviction. Though he may have worked in ignorance of what has been done before, he has worked in an atmosphere in which previous ideas and tendencies of thought have been absorbed, and in general he owes something to the pioneers who have gone before him. In some cases the succession of events which lead to a discovery may be compared to what would happen if a delicate balance carried on one side the arguments in favour of a new idea, and on the other hand the objections which are brought against it. At first the side that bears the objections is much the heaviest; as time goes on the difference becomes less marked, sometimes by the removal of objections, but more frequently by increased evidence in favour of the new idea. Ultimately when sufficient weight is put on that side, a point is reached when the balance tips over. This is the psychological moment when the discovery is accepted, and he who adds the last grain is technically the discoverer. Those who started loading the scale are then forgotten, unless someone with a taste for historical continuity happens to come across the record of their work. Especially when some national feeling is involved, discussions on priority may then be raised, and continued interminably, because there will always be a conflict between those who attach importance to the intrinsic merit of an investigation and those who look only on the actual influence it has had on scientific thought. In the strict administration of historical justice, oral expressions of opinion like that of Stokes are not admitted as evidence; he himself disclaimed any share in the discovery of spectrum analysis. But as a testimony that the analogy of sound can be applied to the radiations of light and heat, it was a distinct step, and a well ascertained and clear pronouncement such as that which passed between Stokes and Kelvin deserves to be placed on record, without detracting from the merit of others.

In order to appreciate correctly Balfour Stewart's work the following consideration is important. If the foundation of spectrum analysis be made to depend on such laws of radiation as can be derived from the consideration of what happens inside an enclosure of uniform temperature, his priority is well established. He undoubtedly was the first to realize the significance of studying the equilibrium of heat inside such enclosures, and led the way in a direction of research which has proved to be of capital importance in the theory of radiation. But as regards their practical bearing on spectrum analysis, too much weight has been given to theoretical considerations founded on thermal equilibrium. In all spectroscopic observations, the loss or gain of heat is the essential factor. The step which takes us from the uniform enclosure to the radiation and absorption when there is no equilibrium is not so simple as has generally been assumed, and it is safer to accept spectrum analysis as being mainly founded on experiment together with such plausible theoretical analogies between sound and light as were pointed out by Stokes. In this respect, the work of Herschel, Talbot, Wheatstone, and Swan is of greater importance in the history of spectrum analysis than the theoretical work of Balfour Stewart, who, however, also illustrated his views by striking experiments on the relation between radiation and absorption. Incidentally, he corrected a wrong idea based on erroneous experiments by a Dr. Bache in the United States, who claimed to have shown that, while the surface colour greatly affected the absorption, it had no effect on the radiation of a body.

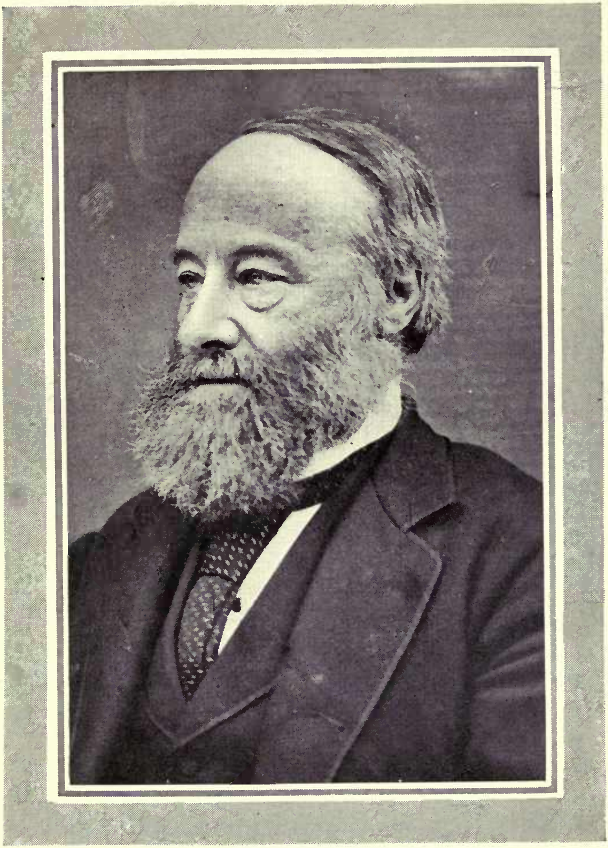
Bearing in mind what has been said, it is not surprising that, notwithstanding all that had been done before their time, Kirchhoff's and Bunsen's work created a deep impression. The combination of a physicist and chemist was almost necessary to bring out the full significance of the observations; and the accumulated experimental evidence furnished by them was complete in itself, and left no doubt as to the value of the new method of investigation, which formed not only a most delicate test of the chemical nature of substances which we handle in the laboratory, but would also be applied to the analysis of any light-emitting body however great its distance might be. It is well known how the spectroscope at once revealed a number of new metals, among them being thallium, which was first identified by Sir William Crookes.

The further development of the subject disclosed a far greater potentiality of the spectroscopic attack than was dreamed of by its originators. At first it was considered that the spectrum was an atomic property; in other words, that each atom preserved its spectrum when combined with other elements, so long at any rate as the substance remained in the gaseous state. There was not much opposition to the next step, by which compounds were shown to have independent spectra, but when it appeared that even one and the same element could give a number of different spectra under different conditions, fresh fields of investigation were opened out. In the further elucidation of the subject, this country has helped as much as, and perhaps more than, any other. It will be sufficient to mention the work of Lockyer, Liveing and Dewar, and the investigations of Lord Rayleigh on the Optics of the Spectroscope, which, by pointing out the limits of their power for given optical appliances, have shown the direction in which an extension of these limits is possible. In the investigation of the absorption spectra of organic compounds a prominent place must be given to Sir William Abney and Walter Noel Hartley (1846–1913).

The success of Manchester in establishing great research schools encouraged other cities to introduce university teaching into great manufacturing centres. But Manchester had a start of over twenty years, and its record is necessarily greater for that reason alone. Nevertheless, some of the younger universities soon attracted men of eminence, and of these, two stand out prominently, Arthur Rücker (1848–1915) and John Poynting (1852–1914), the first Professors of Physics at Leeds and Birmingham respectively.

Although Rücker was only connected with Leeds University during eleven years, much of his scientific work originated during that time; and notably his researches on thin films, carried on jointly with Professor Reinold. From the colours of soap bubbles or of similar films their thickness may be calculated, but as they thin out, the colour effects disappear, and the film is black by reflected light. This means that its thickness is less than the wave-length of light and can not be measured by the simple optical method. In order to investigate the molecular phenomena which ultimately lead to the breaking of the film, Reinold and Rücker undertook the extremely difficult task of measuring the thicknesses of films when they are too thin for the colour test to be applied. Their first method consisted in determining the electric resistance of the films, the second in increasing the number of films, until their aggregate thickness became as great as the wave-length of light. Both methods led to the same results, and some delicate points in the subject of Molecular Physics were cleared up by the investigation.

It is not possible here to enter more fully into other important researches of Rücker, which included the two great magnetic surveys of the United Kingdom, carried out in association with his friend, Sir Edward Thorpe. Rücker was an organizer and administrator of the highest ability, and left the mark of his activity on all the institutions with which he was connected. In 1886 he was appointed Professor of Physics at the Normal College of Science in London, and in 1896 elected Secretary of the Royal Society; both



James Prescott Joule

positions he gave up when he accepted the Principalship of London University in 1901.

John Poynting was the first Professor of Physics at Mason College (now the University), Birmingham. He was brought up in Manchester, and obtained his first instruction in Physics from Balfour Stewart. In due course he went to Cambridge, graduated as third wrangler, and was elected to a Fellowship at Trinity College in 1878. For a time he worked in the Cavendish Laboratory, and in 1880 went to Birmingham, where he remained until his death. Poynting belonged to the rare type of men who are more critical of their own work than of that produced by others. The number of his papers is therefore comparatively small, but each of them marks some definite and generally important step. He broke new ground when he investigated the path along which energy may be considered to be propagated in an electromagnetic field, and the vector, by means of which he represented the magnitude and direction of the transmitted energy, has proved to be a fruitful conception. His investigations on the "pressure of light" have also led to many interesting consequences, which are likely to gain considerable importance in questions connected with the constitution of the sun and stars. In another series of experiments he attacked the difficult problem of gravitational attraction and showed how an apparently unpromising method may be skilfully applied so as to give valuable results.

Turning to the share of non-academic workers in the recent progress of science, it is not surprising that it tends to become less prominent, various reasons combining to render it more and more difficult for the so-called amateurs to hold their own. It is now generally only in those subjects which, in consequence of great specialization, have become almost entirely self-contained, that a man who is unable to devote his whole time to study can hope to produce original work of high quality. The most effectual of the contributing causes has, however, probably been the growth of the universities and their emancipation from the narrow ideas of the Middle Ages. There is a university within the reach of nearly everyone and men are drawn into the academic profession who previously would have had to pursue their science in solitude. But when all is said, much valuable work is still being done, and was to an even greater extent being done last century, by men who can only spare their leisure to the pursuit of science. The work of the most prominent of them may be briefly summarized.

Francis Baily (1774–1844), the third son of a banker at Newbury, may serve as an example of a man who, without exceptional abilities, exerted a great and beneficial influence on the science of his time by perseverance, organizing power, and an unselfish devotion to its interests. After a long and adventurous journey to America, on which he spent three years of his early life, he engaged in commercial pursuits. While he was earning a considerable fortune, he found time to write an important work on the "Doctrine of Interest and Annuities analytically investigated and expounded," and a similar book on the "Doctrine of Life Annuities and Assurances." Through an acquaintance with the chemist Priestley, he had developed a taste for experimental enquiry, and later he became interested in astronomy, to which subject he devoted himself entirely after his retirement from business in 1825. He was one of the founders of the Royal Astronomical Society, and acted as its secretary during the first three years of its existence. He did not himself observe, but his critical and historical work proved to be of great value. The publication of serviceable star catalogues, first for the Astronomical Society and then for the British Association, is mainly due to his zeal. His experimental work included the investigation of the effects of air resistance on the time of swing of a pendulum, and a repetition of the Michell-Cavendish experiment on gravitational attraction.

John Peter Gassiot (1797–1877), originally a wine merchant, was the first who systematically studied the luminosity observed when an electric discharge passes through gases at low pressure. The glass tubes with metal electrodes which he had constructed for the purpose soon came into common use under the name of Geissler tubes. Gassiot was not only a successful experimenter, but also a benefactor who used his wealth in encouraging and promoting science. His gift of £10,000 to the Royal Society, to be devoted to the carrying out of magnetical and meteorological observations with self-recording instruments, has proved to be of special value.

Lord Justice Grove (1811–1896), while actively engaged in practice at the Bar, found time to invent the electric battery which goes by his name, and was, before the days of electrodynamos, the most convenient appliance for the production of large currents. Many of his electrical and chemical experiments were of value, and his book on the correlation of physical forces gives proof of a wide outlook in science.

William Spottiswoode (1825–1883), the head of the well-known printing firm, was at the same time an eminent mathematician, and his scientific attainments were sufficiently distinguished to justify his election to the Presidency of the Royal Society, an office which he held at the time of his death.

Edward Schunck was the typical man of independent means who unselfishly devotes his whole time and wealth to the pursuit of knowledge. He was born in Manchester in 1820, his father having founded an important business in that city. He studied chemistry in Germany, and shortly after his return to England, settled down to research work mainly connected with the colouring matter derived from plants. Alizarin, the colouring substance of madder, attracted his first attention, and his investigations prepared the way for its subsequent artificial production.

He also made important additions to our knowledge of the chemical composition of indigo and chlorophyll. His laboratory, containing a finely ornamented room used as a library, was beautifully fitted out for purposes of research. Its contents were left to Owens College by his will, and ultimately the laboratory was taken down and re-erected as an annexe to the Chemical Laboratories of the Manchester University, where it is now entirely devoted to research work.

Henry Clifton Sorby (1826–1909) was another of the busy men of so-called leisure who devote their lives to the pursuit of science. His instrument was the microscope, and he began investigating the minute structures of minerals with a view to elucidating problems of geology. By studying sections of rocks he laid the foundation of modern petrography and, devising methods for the examination of metal surfaces, he originated a new era in the science of metallurgy. He became interested in metals because he wanted to examine the structure of meteorites. Not being able to cut sections sufficiently thin to be transparent, he applied acid to the polished surfaces, which then showed patterns indicating the manner in which the crystallized parts of the body hang together. The same method applied to ordinary metals, and more especially to steel, has led to results of far-reaching importance in practical engineering.

It is difficult to assign a correct position in the history of science to a man whose work is entirely neglected and buried, to be brought to light only when its novelty has disappeared. Such a man has had no influence in shaping scientific thought, yet his merits are as great as if his discoveries had been acknowledged at the time. John Waterston (1811–1884) probably furnishes the most conspicuous example of a long-continued neglect of work which would have marked a great advance in knowledge, had it been recognized at the time of its maturity. A paper which contains results of the highest value in the theory of gases was presented to the Royal Society, but only a short and insufficient abstract was printed. In the words of Lord Rayleigh : " the omission to publish it at the time was a misfortune which probably retarded the development of the subject by fifteen years." In the complete investigation discovered in the archives of the Royal Society by Lord Rayleigh and published in the Philosophical Transactions fifty years after it had been communicated, it is shown how the kinetic theory can explain in a simple manner the physical behaviour of perfect gases. It is proved that the kinetic energy of a molecule is a measure of its temperature, whatever the nature of the gas, and it contains the discovery—though imperfectly demonstrated—that " in mixed media the mean square molecular velocity is inversely proportional to the specific weight of the molecules." The ratio of the specific heats of constant pressure and volume is calculated for molecules exhibiting internal motions, only a slip of calculation preventing the correct result being obtained.

Of Waterston's life very little is known. He was born in Edinburgh in 1811, and showed great aptitude for mathematics while at the High School of that town. He then became Naval Instructor in the service of the East India Company. After his retirement he lived in various towns of Scotland, and finally at Edinburgh. One evening in the spring of 1884, he left his lodgings for his evening walk, and was never seen again. It is supposed that he went to Leith to look at a new breakwater which was being constructed there, and that he accidentally fell into the water and was swept away by the tide; but this rests on surmise only.

Among professional British astronomers during the last century four men stand out prominently: Sir George Airy, Sir John Herschel, John Crouch Adams, and Sir David Gill. When Airy was called to take charge, first of the Observatory of Cambridge and later of the Royal Observatory at Greenwich, he had already made his name famous by his mathematical and optical investigations, which have been mentioned in connexion with his career at Cambridge. In astronomy he proved himself to be equally eminent as an administrator and investigator. He introduced revolutionary reforms in the practice of observatories by insisting on a rapid reduction and publication of all observations. After his appointment as Astronomer Royal, he set to work at once to reduce the series of observations of planets which had accumulated during eighty years without any use having been made of them. This was followed up by a similar reduction of 8,000 lunar observations. He was equally energetic in adding to the instrumental equipment. When Greenwich was first founded, the longitude determination at sea depended to a great extent on measuring the distance between stars and the moon. Hence accurate tables of the position of the moon were essential, and the preparation of these tables has always been considered to be the chief care of Greenwich. The observations were made with a transit telescope which could only be used when the moon was passing the meridian, until Airy in 1843 persuaded the Board of Visitors to take steps for constructing a new instrument which would enable him to observe the moon in any position. In 1847 this instrument was at work, and other important additions to the equipment were made as occasion arose. Airy also originated the automatic system by which the Greenwich time signals are transmitted each day throughout the country. Among his theoretical investigations in pure astronomy, one of the most important resulted in the discovery of a new inequality in the motions of Venus and the earth due to their mutual attraction, and this led to an improvement in the solar tables.

Sir John Herschel (1792–1871) was the only son of the great astronomer whose work was considered in a previous chapter. After graduating as senior wrangler in 1813, he joined a number of friends in their efforts to reform the teaching of mathematics at Cambridge. The astronomical problems which had occupied the later years of Sir William's life then attracted the son, who, after his father's death, completed the work on double stars, and published an important memoir on their orbits.

In 1833 he embarked for the Cape, in order to extend to the southern hemisphere the general survey of the heavens which his father had carried out in the northern sky. It was to a great extent a spirit of loyalty to his father which kept him to the subject of astronomy, for his own bent of mind drew him more towards physics and chemistry. He discovered the solvent power of hyposulphite of soda on otherwise insoluble salts of silver, a property which later proved so useful in photography. As a writer he was clear and effective. His article on "Light" in the Encyclopædia Metropolitana forms an excellent record of what was known at the time, and his "Outlines of Astronomy" may still serve as a useful book of reference.

The work of Adams has already been described in a previous chapter (p. 125).

David Gill (1843–1914), after a period of study at the University of Aberdeen, entered his father's business, which consisted in the making of clocks. But his interest in science, stimulated by the influence of Clerk Maxwell, who for a time held a Professorship at Marischall College, soon asserted itself, and he established a physical and chemical laboratory in his father's house. Turning his attention to astronomy, he became acquainted with, and ultimately engaged as private assistant by, Lord Lindsay, an enthusiastic amateur astronomer, then about to erect a private observatory at Dunecht. He accompanied Lord Lindsay in his expedition to Mauritius, undertaken for the purpose of observing the transit of Venus in 1874. This rare event, as previously explained in connexion with its first observation by J. Horrocks, serves to determine the distance between the earth and the sun, but alternative methods promising more accurate results had already been suggested. The relative distances of the different planets from the sun being known by their times of revolution, we may substitute the measurement of the distance of any one planet which is in a suitable position for the direct determination of the solar distance. Certain planets occasionally approach the earth sufficiently near to apply this method. As the earth turns round its axis, the observer's point of view is sufficiently altered between a morning and evening observation to show a measurable shift in the position of a planet as compared with that of the surrounding stars. While at Mauritius Gill found that one of the minor planets, Juno, happened to be suitably placed to test the method, and he obtained most encouraging results. A good opportunity of pursuing the investigation presented itself in 1877, when the situation of the planet Mars was exceptionally favourable for the purpose. Gill left the service of Lord Lindsay and established himself on the island of Ascension. Though the results obtained were good, Gill confirmed his conclusion that the minor planets were better suited for accurate measurements. He returned to the subject ten years later, and a combination of observations of three minor planets, made partly by Gill at the Cape and partly by other astronomers whom he had interested in the work, has given us the best determination of the solar parallax we possess.

In 1879 Gill was appointed Astronomer Royal at the Cape, and he directed the work of the observatory with distinguished success until 1906. Unbounded perseverance, unrivalled skill in observing, and an exceptional mechanical knowledge which served him in the design of instruments were combined in his person to a rare degree. A favourite instrument of his, the potentialities of which for accurate measurements he was the first to recognize, was the heliometer, the essential part of which consists of an object-glass divided into two halves, which could be made to slide along the dividing line. If the image of a star formed by one half be brought into coincidence with the image of a neighbouring star formed by the other half, the angular distance between the stars is indicated by a suitable measuring arrangement. With a telescope of this construction Gill instituted a series of observations for the determination of stellar parallaxes, which raised the subject up to a higher plane. Another important research carried out by Gill with the assistance of others was the determination of the mass of Jupiter by observations of his satellites.

Gill was not only an eminent investigator; large ideas originated in his mind, and were pushed forward with unlimited energy. He originated the great international enterprise for cataloguing and charting the whole sky by photography. He also successfully advocated an accurate trigonometrical survey of the whole of South Africa, and formed a scheme for the measurement of an arc of meridian which should run along the thirtieth meridian east of Greenwich through the whole length of Africa to the mouth of the Nile, and connect by triangulation through the Levant with the Roumanian and Russian arcs. He secured the assistance of Mr. Cecil Rhodes, and the work, though frequently interrupted, partly through the political troubles in Africa and partly through want of money, was proceeding slowly when stopped by the outbreak of the present war.

Gill's scientific activity was continued after his return to England, and during the last years of his life he endeavoured to stimulate the manufacture of optical glass in this country. His efforts deserved a better response than they received and though they were primarily directed towards securing the large blocks required for telescopes, the whole question of glass manufacture, which has since become of such pressing importance, was involved. By his death British science lost an intensive driving force.

While professional astronomers carried on their excellent researches the great improvements in the construction of reflecting telescopes during the nineteenth century was entirely the work of amateurs. William Parsons, third Earl of Rosse (1800–1867), took the first step in 1827. As William Herschel had never published his methods, there was no established procedure to shape concave mirrors. Lord Rosse had to start from the beginning, and to invent the machine for grinding and polishing the speculum metal to the required shape. After a number of attempts he was eminently successful, and in 1845 completed a mirror six feet in diameter with a focal length of nearly sixty feet. The structure necessary to hold and move such a gigantic telescope presented considerable engineering difficulties, but these were overcome, with the result that Lord Rosse was soon able to announce a number of important discoveries. Many luminosities that had been classed as nebulæ were found to consist of closely packed star clusters. Others remained unresolved, and among them the interesting family of spiral nebulæ was recorded. Further improvements in the methods of shaping and polishing mirrors are due to William Lassell (1799–1880) and James Nasmyth (1808–1890). The former, a Lancashire brewer, had already, in 1820, constructed a small telescope with his own hands, being too poor to purchase one. Later he improved on Lord Rosse's methods, and with a larger instrument discovered two new satellites of Uranus, a satellite of Neptune, and an eighth satellite of Saturn. James Nasmyth, chiefly known as the inventor of the steam hammer, was also much interested in astronomy. The sharpness of his vision and quality of his instrument is shown by his observations of the granular structure of the solar surface which no one had noticed before him.

Warren de la Rue (1815–1889), a member of the well-known printing firm, was a generous supporter of many scientific enterprises. In early life he had made further improvements in the process of shaping concave mirrors, and successfully constructed a reflecting telescope. He was the first to appreciate the opportunities offered to astronomers by the invention of photography, and in 1860 fitted out an expedition to observe a total eclipse in Spain. The slow acting plates of the time were not sufficiently sensitive to show the solar corona which appears during an eclipse, but the red flames shooting out from the edge of the sun were clearly shown in his photographs. This was an important achievement, as there had been some doubt whether these so-called protuberances were real phenomena belonging to the sun. De la Rue also introduced the daily photographic record of the sun, originally carried out at Kew, and now at Greenwich and other places in the British Empire.

So far all concave mirrors used in reflecting telescopes had been made of speculum metal, an alloy of tin and copper, which tarnishes in the course of time. A process of polishing almost as troublesome as the original shaping of the surface had then to be undertaken. It was, therefore, a substantial step in advance when Andrew Ainslie Common (1841–1903), an engineer by profession, introduced mirrors made of glass silvered at the surface, for the silvering could be renewed without interfering with the shape of the surface. Common acquired great skill in grinding the surfaces of glass; one of his mirrors, three feet in diameter, is now at work at the Lick Observatory, and a five-foot mirror forms part of the equipment of Harvard. The photograph which Common obtained of the nebulæ in Orion first showed the complicated structure of that wonderful object, and was described by Sir William Abney as "epoch-making in astronomical photography."

With the introduction of dry plates a new era began for Astronomy, and one of the most persevering and successful workers in the field was Isaac Roberts (1829–1904), whose beautiful collection of photographs of celestial objects, and notably of nebulæ, form a permanent record which will in the future prove of the greatest value. Roberts was a builder by profession. In 1890, the year after his retirement from business, he moved from Liverpool to Crowborough, in Sussex, where the clear air allowed him to produce his finest work.

Until the middle of last century the astronomer was confined in his observations to the use of the telescope; he could determine the position of stars,investigate their displacements in the sky, and examine the structure of star clusters and nebulæ. Beyond this he was unable to go, until the invention of the spectroscope gave him the power to extend his range in an unexpected direction. The history of science can furnish no more striking instance of an almost unlimited field of research suddenly opened out by a simple application of a few laboratory experiments. The most successful of the workers who utilized the great opportunities provided by the new method of Spectrum Analysis were Sir Norman Lockyer and Sir William Huggins. Lockyer's first great achievement was the observation in broad daylight of the prominences which up to that time could only be seen during total solar eclipses. He proved that they mainly consisted of glowing hydrogen. The merit of the discovery is in no way diminished by its having almost simultaneously been made by the French astronomer Janssen. Continuing his researches, Lockyer established that the upper layer of the sun's atmosphere, which reveals itself at the edge of the solar disc in the form of a bright line spectrum, consisted mainly of the lighter metals such as calcium and barium with hydrogen. A bright yellow line was also universally present which could not be identified as belonging to any known element. Lockyer conjectured that it was due to an unknown gas which he called helium; this gas, as will appear, was subsequently discovered on the earth, and is found to play a most important part in modern physics. The identification of terrestrial elements in the atmosphere of the sun or stars ultimately proved not such a simple matter as was at first supposed, because the relative intensities of the lines emitted by a luminous body, and sometimes the whole spectrum, changed when the conditions were altered. Lockyer turned this complication to good account by trying to gauge not only the substance itself, but its temperature and physical condition in the celestial bodies. He was thus led to his meteoric hypothesis of the formation and subsequent evolution of the solar systems, into which it is not possible to enter here.

The most memorable discovery with which the name of Huggins is connected is the measurement of the velocity of stellar bodies in the line of sight. A body moving directly towards, or away from, us keeps the same apparent position in the sky, but just as the whistle of a locomotive alters its pitch when, after approaching us, it passes and then moves away, so is the wave of light received by us affected according as a star is receding or approaching. Huggins showed how this principle can be applied to stellar motion, and thus laid the foundation of a branch of astronomy which is continuously growing in importance. Previously Huggins had, in conjunction with W. A. Miller, carefully mapped some star spectra; he also had investigated the spectra of nebulæ, and found that some of them consisted of glowing gases. In subsequent researches he found the luminosity of comets' tails to be mainly due to carbon compounds. By patient and painstaking work Huggins further developed the methods of obtaining photographic records of stellar spectra, and the important results obtained formed the starting point for the many distinguished astronomers who have since taken up the work.

Before leaving the subject of Astronomy reference must be made to a notable advance in the construction of refracting telescopes. During the middle of last century, the largest lens made had a diameter of sixteen inches. At the exhibition of 1862, Messrs. Chance, of Birmingham, exhibited glass discs of crown and flint twenty-six inches in diameter, and Mr. Robert Stirling Newall (1812–1889), of Gateshead, induced Messrs. Cook, of York, to construct from these discs an achromatic lens of twenty-five inches. This was successfully accomplished, and the telescope is now doing excellent work in the Astrophysical Observatory of Cambridge. Larger instruments have been made since, but the step from sixteen to twenty-five inches is one which deserves a permanent record in the history of the subject.

Modern astronomy, like other branches of science, depends so much on photography that a brief account of the history of this interesting and fascinating art may be here introduced.

The darkening action of light on silver chloride was first discovered and investigated by the Swedish chemist Scheele. W. H. Wollaston had observed that the colour of the yellow gum guaiacum was altered by the action of light, and Sir Humphry Davy had noted a similar effect in the case of moist oxide of lead. The first actual photographic print was obtained in 1802 by Thomas Wedgwood (1771–1805), who threw shadows on paper moistened with a solution of silver nitrate, and obtained prints giving the outlines of the shadows, but his picture was evanescent, as he was unable to fix it. Rudimentary as this procedure was, it contained the germ of the future contact printing. Next came the work of Daguerre and Niepce in France, resulting in the well-known daguerreotype. In 1840 Sir John Herschel introduced hyposulphite of soda as a fixing agent, and in 1841 Fox Talbot greatly improved Wedgwood's original process, using silver iodide on paper sensitized by "gallo-nitrate of silver." The introduction of collodion as a convenient vehicle holding the silver salts was first suggested by G. le Gray, and put to practical use by Frederick Scott Archer and P. W. Fry. In the subsequent development of the dry plate important progress was due to R. Manners Gordon, W. B. Bolton, and B. J. Sayce. The gelatine emulsion process was used by R. L. Maddox in 1871 and by J. King in 1873, but first introduced in a workable form by R. Kennett in 1874. The merit of giving rapidity of action to dry plates belongs to C. Bennett (1878). Further progress was made by Colonel Stuart Wortley and by W. B. Bolton in 1879.[1]

The modern theory of photography almost entirely depends on the investigations of Sir William Abney. He introduced scientific methods in the measurement of the sensitiveness of plates, investigated the effects of temperature, and showed the important influence which the size of the sensitive particles had on their behaviour in different parts of the spectrum. He was thus able to obtain a silver bromide sensitive to the red light, and was the first to photograph the infra-red rays of the solar spectrum.

A few words should be said about the history of colour photography. Lord Rayleigh pointed out in 1887 how particles of silver might be deposited in layers half a wave-length apart. A film containing such layers would have the power of reflecting copiously that special kind of light which had served to form it. This process was actually employed to reproduce natural colour effects by M. Lippmann, of Paris; but it suffers from the disadvantage that the correct colours are given only when the light falls on the film at the particular angle under which it was originally produced. The process of Joly, introduced in 1897, is free from this defect; the principle on which it is based is the same as that subsequently employed with great success by "A. Lumière et Fils," of Lyons, whose method of working, however, differs materially from that of Joly.

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[1] For a fuller account of the history of photographic processes, see the article on "Photography," by Sir Wm. Abney, in the "Encyclopædia Britannica," XIth ed.

Photography is looked upon by some as a pleasant pastime, by others as an art. The chemical and physical properties of matter which allow the rays of light to form a latent picture, to be subsequently developed, fixed and printed, are in themselves a fascinating study, and there is no limit to the utility of photography as an aid in scientific investigations. Here, as elsewhere, science exerts its greatest charm when it forms a connecting link between the ordinary interests of our daily life and the abstract questions which engage the attention of academic philosophers. Thus, nearly all problems of geophysics have both an intensely practical and a deeply theoretical side. The commonplace necessity of defining the boundaries of land leads to the demand for accurate maps, and this, again, opens out investigations on the figure and size of the earth. One question suggests another, until abstruse mathematical problems acquire a special interest owing to their connexion with the history of the world's formation. Similarly, forecasts of weather that shall be helpful to the farmer demand a study of aero-dynamics, involving mathematical treatment, combined with experimental work of high precision, and the ordinary phenomenon of the tides takes us inevitably to problems demanding the genius of such men as Kelvin and George Darwin.

The ordinary making of maps is a task belonging to the Government services, and it is to officers in the Army and the officials in charge of the various surveys at home, or in the colonies, that we are mainly indebted for our knowledge of geodesy. Such work, important as it is, often receives insufficient acknowledgment because, being co-operative, the share of each man cannot always be clearly defined. But a few examples may be given.

Captain Henry Kater (1777–1835), the son of a sugar baker, entered the army and joined his regiment in Madras. He had a taste for mathematics, and became assistant to William Lambton, who was conducting a survey of the Malabar and Coromandel coast. After his return to England he took part in the British survey, and turned his attention to the improvement of accurate geodetic and astronomical measurements. Kater's pendulum is an ingenious arrangement for eliminating the errors due to an irregular distribution of mass in the ordinary pendulum when it is used for gravity measurements. The determination of the difference in longitude between Paris and Greenwich gave him further opportunities for exercising his ingenuity in devising new methods of observation. In 1827 Kater was elected Treasurer of the Royal Society, and held that position during three years.

General Sir Edward Sabine (1788–1883) organized worldwide observations on gravity, and the elements of terrestrial magnetism. The importance of his work calls for a short account of his life. He was educated at the Woolwich Military Academy, and received a commission in the Royal Artillery at the age of fifteen. After seeing much active service, he returned to England in 1816. Shortly afterwards he was appointed astronomer to the Arctic Expedition which sailed under Ross in search of the North-West Passage, and after his return home took part in a second Arctic Expedition under Edward Parry. In 1823 he undertook an extensive journey to measure the value of the gravitational force at different points of the earth's surface. In 1830 he was recalled to active service, the condition of Ireland necessitating an increased military establishment. He stayed in Ireland until 1837, using part of his time to organize the first magnetic survey of the British Isles. During his subsequent life, which was entirely devoted to science, he was indefatigable in getting magnetic observatories established in many countries, and promoting further pendulum observations, more especially in India, where ever since they have formed an important part of the Government Survey's work. Sabine was Treasurer of the Royal Society from 1850 to 1861, and during the following ten years he filled the position of President.

Most distinguished among the Directors of the British Survey was Alexander Ross Clarke (1828–1914), who has given us the most accurate determination so far obtained of the size and figure of the earth. He was concerned in several of the principal measurements of meridional arcs, and in 1860 was entrusted with the comparison of the national standards of different countries, a most delicate piece of work, which required the building of a separate room at the Ordnance Survey Office.

Our account of the progress of Meteorology must be short and incomplete, but we may recall William Charles Wells (1757–1817), the London doctor who first gave the correct explanation of the formation of dew, Luke Howard (1772–1864), who classified the clouds, and John Apjohn (1796–1880), who showed how to calculate the humidity of the air from observations with the wet and dry bulb thermometer. We must also remember the wonderful balloon ascents of James Glaisher (1809–1903), who, reaching a height of over 30,000 feet, obtained the first observation of the upper air. A kite was used in meteorological work as early as 1749 by Alexander Wilson, of Glasgow, and its modern application dates from the experiments made in England in 1882 by E. D. Archibald. One of the most enthusiastic workers in Meteorology, Alexander Buchan (1829–1907), studied at Edinburgh and was engaged for some time as a school teacher, but in 1860 he was appointed secretary of the Scottish Meteorological Society, and was henceforward able to devote himself entirely to his favourite study. His work on atmospheric circulation possesses considerable importance, and he was also one of the chief promoters of the observatory which, during a number of years, stood on the summit of Ben Nevis.

A discovery of great value to meteorology was made by John Aitken, of Falkirk, who in 1883 observed that water vapour always requires some nucleus to condense upon. The most common nuclei are the dust particles which are always present in the atmosphere, and every drop of rain or particle of fog contains some solid contamination at its centre. The best protection against fog is, therefore, the purification of the atmosphere. The condensation of water on solid matter has been utilized by Aitken in constructing a little instrument which allows us to count the number of particles of solid matter contained in the air. He found that even the cleanest air will contain about 20 particles per cubic centimetre, while in London or Paris the number generally rises to well over 100,000.

The work of Sir George Howard Darwin (1845–1912) may serve to illustrate how a geophysical problem which in its main features is easily understood, is found to involve the whole history of the Universe as soon as we pass from the general explanation to the more detailed study required to give accurate numerical results. That the tides of the ocean are due to the gravitational attraction of the sun and moon was known already to Newton, and it can be shown without difficulty that the explanation agrees in a general way with observations. But, if we wish to formulate a mathematical theory, we must begin by simplifying the problem, and assume the earth to be a rigid solid sphere covered entirely by a layer of water having the same depth everywhere. The statement of this problem is simple enough, but its solution becomes already complicated when the combined attractions of the sun and moon are considered. Yet we are not anywhere near the real tides on the real earth. The ocean does not cover the whole globe, it is not of uniform depth, and the solid core of the earth is not absolutely rigid, but appreciably yields to the disturbing forces. When we try to take account of these complications, even in the roughest manner, we see that there must be a frictional effect tending to retard the rotation of the earth; this involves a re-acting force on the moon, and it can be shown that this must slowly drive it further away. Hence we conclude that there must have been a time when the moon was nearer, and the earth rotated more rapidly, and, looking still further back, this brings us to the time when the moon may have formed part of the earth and ultimately separated from it. Can we form an approximate estimate of that time? Such are the questions which occupied George Darwin during a considerable part of his life. The whole problem does not, of course, affect the earth only, but concerns every celestial body. It opens out the whole question of the stability of fluid gravitating and rotating bodies. George Darwin's own contributions to the subject have materially helped to establish a scientific basis for the treatment of a subject, fundamental in cosmogony, which has fascinated the most powerful mathematical brains in recent times. For his other important researches the reader must be referred to his collected works, but some reference may be made to the time which he ungrudgingly devoted to assist all efforts which aimed at an organized co-ordination of scientific work, and co-operation between different scientific bodies. During thirty years he was a member of the Meteorological Council, and of the Treasury Committee which superseded it. He actively supported international scientific undertakings, and more especially the International Geodetic Association, on which he represented England for many years; in 1909 he was elected its President.

Several instances have already been given of the reciprocal relation between utilitarian objects and abstract scientific truth, and a further example is furnished by the work of John Milne (1850–1913). After studying Geology and Mineralogy at King's College and the Royal College of Mines, he gained some practical experience in the mines of Cornwall and Lancashire, extending his knowledge by a course of study at Freiberg, and a visit to the mining districts of Germany. In 1875 he was appointed Professor of Geology and Mining at the Imperial College in Tokio, where he was at once confronted with important practical problems arising out of the frequent occurrence of earthquakes in Japan. In order to construct buildings and bridges so that they should resist the movements of the foundations on which they are built, it is necessary to study, in the first instance the nature of these movements. Milne was attracted by both the practical and theoretical side of the investigation, but as no suitable instruments were available for the purpose, he supplied the want, and for a number of years his seismographs became the standard instruments. Important questions immediately suggested themselves, and Milne became the founder of a new science. After his return to England, he organized, with the assistance of the British Association, in different parts of the Empire and other countries, a large number of suitable stations at which earth tremors were accurately observed. The records of the observations, interpreted partly by Milne himself and partly by other seismologists, proved to be of the highest interest. The waves propagated through the earth from the centre of a large disturbance are found to be noticeable with delicate instruments all over the world. We now know that the general movement spreads out from the centre of a disturbance in three distinct waves, each propagated with its own peculiar velocity. The first is a longitudinal wave, which passes through the earth like a sound wave does through air. The second is a transverse wave, arriving somewhat later; both these waves reach us by transmission across the body of the earth. A third set of waves, which in the records appears as an oscillation of larger amplitude and longer period than the rest, spreads over the surface of the earth with a velocity of about 3·5 kilometres per second. The interval between the arrival of these three types of waves serves to indicate the distance of the centre of the disturbance, and Prince Galitzin has shown how the direction of the first impulse gives us the direction in which that centre lies. Hence it is now possible to locate a distant earthquake by means of observations taken at any one place where it is still able to affect the delicate instruments which, by a self-registering arrangement, are always ready to record the waves.

The scientific interest of the subject lies in the information it is likely to yield on the internal constitution of the earth; for some of the waves that reach us, if the centre of disturbance be far away, have passed through deep regions, approaching in some cases the actual centre of the earth. The manner in which their path bends round owing to changes in the elastic properties of the earth at different depths is indicated by the direction and magnitude of the oscillation which the wave impresses on our instruments. It is difficult to interpret completely the observed effect, but the investigation has already advanced sufficiently to show that important results may still be expected from that study of earth tremors which Milne initiated.

The survey of the history of British physical science has now been brought to the period when men of the present time were called upon to receive the heritage, and do their best to hand it on to their successors. The problems of to-day may not be seen in their right perspective; yet the last thirty years have been so exceptionally fertile in new discoveries that we may anticipate with confidence the judgment of posterity on those great advances which have revealed an entirely new class of phenomena, and enabled us to form views on the structure of matter which, at any rate, may be considered to be an advance on our previous knowledge. A very brief summary, however, must suffice.

In the seventies of last century it was generally thought that our power to discover new experimental facts was practically exhausted. Students were led to believe that the main facts were all known, that the chance of any new discovery being made by experiment was infinitely small, and that, therefore, the work of the experimentalist was confined to devising some means of deciding between rival theories, or by improved methods of measurement finding some small residual effect, which might add a more or less important detail to an accepted theory. Though it was acknowledged that some future Newton might discover some relation between gravitation and electrical or other physical phenomena, there was a general consensus of opinion that none but a mathematician of the highest order could hope to attain any success in that direction. Some open-minded men like Maxwell, Stokes, and Balfour Stewart, would, no doubt, have expressed themselves more cautiously, but there is no doubt that ambitious students all over the world were warned off untrodden fields of research, as if they contained nothing but forbidden, though perhaps, tempting, fruit. When Crookes, in the year 1874, constructed his radiometer, it looked for a short time as if he had definitely disposed of such timid and discouraging opinions; but, on the contrary, he seemed only to have confirmed them. For the apparent repulsion of light observed in the radiometer was found to be due to the residual gas in his exhausted vessels, and could be explained by the then accepted kinetic theory. He had, no doubt, by greatly improved methods, discovered a new effect, but this had only led to perfecting an established theory in an important detail.

The new era begins with Lord Rayleigh's discovery of argon. The research which led to it was originally undertaken with a view to testing the hypothesis of William Prout (1786–1850), a London doctor, according to whom the atomic weights of all chemical elements are exact multiples of that of hydrogen. In the course of an accurate determination of the density of nitrogen it was found that, when the gas is prepared from air by removing all other known constituents, it has a density half per cent. greater than when it is obtained directly from ammonia. Rayleigh then drew the conclusion that the discrepancy was due to some unknown body, probably a new gas in the atmosphere heavier than nitrogen. While the research was advancing successfully, William Ramsay joined the investigation, and the final results were published by Rayleigh in conjunction with him.

Sir William Ramsay (1852–1916) then entered into that period of his activity in which discoveries rapidly succeeded each other. Sir Henry Miers drew his attention to a certain mineral which was known to give out an inert gas when dissolved in an acid. This gas was supposed to be nitrogen, but Miers thought it might turn out to be argon. Ramsay extracted the gas, examined it with a spectroscope, and to his surprise found the bright yellow line which appears so brilliantly in the light emitted all round the edge of the sun and in its protuberances. The gas proved, therefore, to be identical with the one spectroscopically discovered many years previously by Sir Norman Lockyer, and named by him "helium." Subsequently, by applying the process called "fractional distillation" to liquid air, Ramsay could isolate three additional elements: krypton, xenon, and neon.

In the meantime, experiments on the discharge of electricity through gases had made rapid progress. His experiments with the radiometer had led Crookes to introduce great improvements in the construction of the mercury pumps used to obtain high vacua in glass vessels. By sending electric currents of high potentials through such vessels, Crookes investigated the vivid phosphorescent luminosity which appears near the negative electrode. Important results were obtained in these researches. Investigations by other observers which cannot here be described, led to the conclusion that gases, which ordinarily are insulators, could in various ways be made to conduct electricity, and the phenomena suggested that the conductivity was due to the formation of carriers analogous to the ions which normally exist in liquids. Gases, in fact, could be ionized. The stage was now reached where experiments definitely pointed to the conclusion that electricity, like water, had an atomic constitution. To furnish the proof, it was necessary to show that the atomic charge was the same in all cases. The experiments with liquids gave no direct measure of this charge, but they allowed us to determine its ratio to the mass of the carrier. That carrier in liquids is the chemical atom, and it was natural at first to suppose that the same would be the case in gases; if so, the matter could be tested, as we know the relative masses of different chemical atoms. The first experiments made in that direction led to no decisive results, though they supplied a method which proved useful. The question was finally solved by Sir Joseph Thomson, who proved that the carrier of negative electricity had a mass much smaller than that of a chemical atom; ultimately it was found that, near the kathode of an electric discharge through gases, it is actually the atom of negative electricity which is set free, and acts as carrier.

Thomson further determined the charge of the electron, the name given to the atom of electricity by Johnstone Stoney (*see* p. 139), and found it to agree with that which may indirectly be derived from the electrolysis of liquids.

There can be no doubt that Sir Joseph Thomson's experiments will be looked upon in future as a landmark in the advance of science as great as those that have been described in our first chapter.

Thomson's discovery was announced at the British Association meeting of 1899. Since then our ideas have advanced rapidly, and we now consider corpuscles of positive and negative electricity to be the elemental atoms from which all matter is built up. In the origination and development of this theory Sir Joseph Larmor has taken an active part.

During the last few weeks of the year 1896 some remarkable experiments of W. C. Roentgen revealed to us a new and quite unexpected class of phenomena. The electric discharges in a highly-exhausted vessel were found to be capable of generating a radiation—now known to be due to very short waves—which could penetrate many bodies opaque to ordinary light. This was the X-radiation which has proved to be of such enormous value in surgery. Their investigation indirectly led to our knowledge of a still more remarkable class of phenomena. The French physicist, Becquerel, while trying to find whether the sun emitted X-rays, observed a most surprising effect, which could only be accounted for by assuming the existence of a new form of radiation, essentially different from that of the X-rays. Separating the substance that was mainly responsible for it, M. and Mme. Curie discovered the new metal radium. This is the typical radio-active element, but two other known chemical elements—uranium and thorium—proved to resemble radium in its peculiar properties. A new science then opened out.

The effects of radio-activity show themselves by their power of ionizing air and affecting photographic plates, but the first results were extremely puzzling, and experimenters were being led away on a wrong track when Sir Ernest Rutherford took up the work. He first discovered that thorium and radium gave up gases—the so-called emanations—which themselves were radio-active. It was the disturbing effect of these gases which, diffusing through the air of the laboratory, had affected the instruments, and led Becquerel and Curie astray; it had to be separated from that of the parent substance before the different phenomena could be disentangled. By a series of remarkable experiments, Rutherford soon cleared up the essential features of radio-activity. In conjunction with Frederick Soddy he then developed his theory, which now stands on a firm basis. Radio-activity was shown to be the result of the ejection of corpuscles from the parent body, which thereby became transformed into another substance which was generally itself subject to further decomposition through the emission of other corpuscles. The decomposition proceeds at a perfectly definite rate, and the life of any radio-active substance can, therefore, be foretold. The ejected particles consist either of one or more negative electrons (β particles), or positively charged corpuscles (α particles); frequently both are emitted. The α particle carries twice the charge of an electron, and weighs about twice as much as an atom of hydrogen: that is to say, as much as a helium atom. Rutherford formed the idea that the two might be identical and this was experimentally confirmed by Sir William Ramsay. The emanation of radium which emits an α particle in its decay was introduced into, and kept in an exhausted tube for several days, when it was found that the spectrum line of helium could be clearly seen, though no helium had originally been present. This experiment, which gave the proof of Rutherford's surmise, was an historical event, as it supplied the first definite example of the decomposition of a so-called chemical element. For the emanation possesses all the characteristics of such an element and was shown to decompose spontaneously, helium being one of the products. The subsequent development of radio-active experiments and theories confirmed the original ideas, and many new and interesting facts were brought to light.[1] These must be passed over, and we might here close our account, were it not for the brilliant researches of a young man, who promised to become one of the great investigators of his time.

Henry Moseley (1887–1915) was the grandson of Canon Moseley, a distinguished mathematical physicist, and the son of Professor H. N. Moseley, at one time Linacre Professor of Zoology at Oxford. He took his degree at Oxford, but received his scientific training mainly from Rutherford at Manchester. After Laue, at Munich, had proved the existence of a diffraction effect of crystals on X-rays, and Professor William Henry Bragg had developed and improved the methods of observation, Moseley set himself the task of determining the fundamental vibrations of the atoms which give rise to the X-rays. The research required exceptional experimental skill, and great powers of devising new methods of investigation, and the result proved of the highest value. The wave-lengths to be measured are less than the thousandth part of that of visible rays, and in that region the arrangement of the lines was found to be the same for all elements; but proceeding from lower to higher atomic weights, the spectrum was bodily displaced by a definite amount towards the shorter wave-lengths. To see the full bearing of this investigation, we must refer to the theory which Rutherford had formed on the constitution of atoms, based mainly on his experiments on the scattering of α particles by molecules of matter. According to that theory, each atom possesses a positively charged nucleus of exceedingly small dimensions. The nucleus is made up of definite numbers of unit charges, and if we arrange the elements in order of their atomic weights, it is natural to suppose that the total charge increases by one unit as we pass from one element to the next. We may take the atomic number (meaning the number of charges) as the characteristic of each element, and deal, therefore, with figures which are successive integers, rather than with the irregularly increasing numbers representing the atomic weights. Moseley's experiments prove that the high frequency spectrum of the elements which he examined is completely defined by the atomic number. It may be anticipated that this will prove to be the foundation of a new and more precise chemistry, as other properties will be certain to be intimately connected with the forces which regulate the spectra. In confirmation of this, it may be stated that Moseley in fixing the atomic number had to invert the order in the case of potassium and argon, and that of cobalt and nickel, and in both instances it is found that the chemical properties agree with the spectroscopic evidence, and not with that of the order of atomic weights.

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[1] For a detailed account of these investigations *see* Rutherford, "Radio-activity."

Moseley's results, while showing that all elements can be placed in a certain definite order almost identical with that of the atomic weights, allow us also to discover the gaps which we may confidently expect to see filled up by hitherto undiscovered elements. Eighty-three are known at present and Moseley's table of results shows nine gaps between argon and the heaviest of the metals, uranium. The total number of elements reached, when the gaps are filled, will be ninety-three; but some authorities believe in the existence of two further elements lighter than helium.

Moseley's magnificent researches came to a sudden and tragic end. On the threshold of a career of singular promise, looking towards a future pregnant with discoveries that could not fail to fall to his genius and enthusiasm, he answered the call to arms at the outbreak of the war; and a Turkish bullet cut short a life precious to the peaceful glory of his country, but gladly surrendered in its hour of need. That also is a heritage which will go down to posterity.

CHAPTER VI

(Physical Science)

SOME INDUSTRIAL APPLICATIONS

IT is not intended here to catalogue, much less to discuss, the multitude of practical applications of science which have originated in this country during the last century. To mention merely the manufacture of steel, the building of bridges, and the evolution of the modern steam-engine is sufficient to illustrate the all-pervading influence of science on our industries.

The scientific production of steel originated with Benjamin Huntsman (1704–1776), a clockmaker of Doncaster, who discovered the process of making cast steel by melting in crucibles. Starting works in Sheffield, he was the first to introduce a material of uniform temper and composition which could in the modern sense be termed steel. Much might be said on the more recent developments of the steel industry by Henry Bessemer (1813–1898), and on other inventions, such as Sir Charles Parsons' steam-turbine, one of the greatest triumphs that engineering skill has ever achieved. But we must content ourselves with a few selected examples illustrating the effects of pure scientific research on that complex organization of the community which usually goes by the name of civilization.

So much in our modern life depends on the facilities for rapid mutual intercourse that it is curious to note how new devices have often supplied the means before there was a demand. The capacity of inventing outpaced the power of the imagination to understand the use of the invention: the supply had to create the demand. Thus, when Sir Francis Ronalds (1788–1873) submitted to the Government in 1816 the design of an electric telegraph which he had actually tried and found to work with a length of eight miles of wire, the reply of the Secretary of the Admiralty was that " telegraphs of any kind are now totally unnecessary and that no other than the one now in use will be adopted." The word " now " seems to have referred to the conclusion of the French war, and the telegraph mentioned as being in use was the semaphore.

Ronalds was the son of a London merchant; his method of transmitting signals consisted in charging and discharging an electroscope through a long wire. In his experiments he used a length of eight miles of wire, properly insulated and embedded in the soil of a garden in Hammersmith. The distinguishing feature of his apparatus consisted in an arrangement founded on the same principle as the one so successfully employed in the type-printing arrangement invented at a much later date by Hughes. Two discs bearing the letters of the alphabet near their circumferences were made to rotate with the same speed at the two ends of the line. The electroscope placed at the receiving end was discharged from the sending end. The sender watched the moment when the required letter passed a certain position, and the same letter passing the corresponding position at the receiving end at the moment of discharge could therefore be read off. The two discs were adjusted by means of a signal before the message was sent, and it only remained to ensure that the discs rotated synchronously during the time it took to send the message. Bits of the original wire with its insulating covering were dug out later, and are now preserved in the Science Museum at South Kensington.

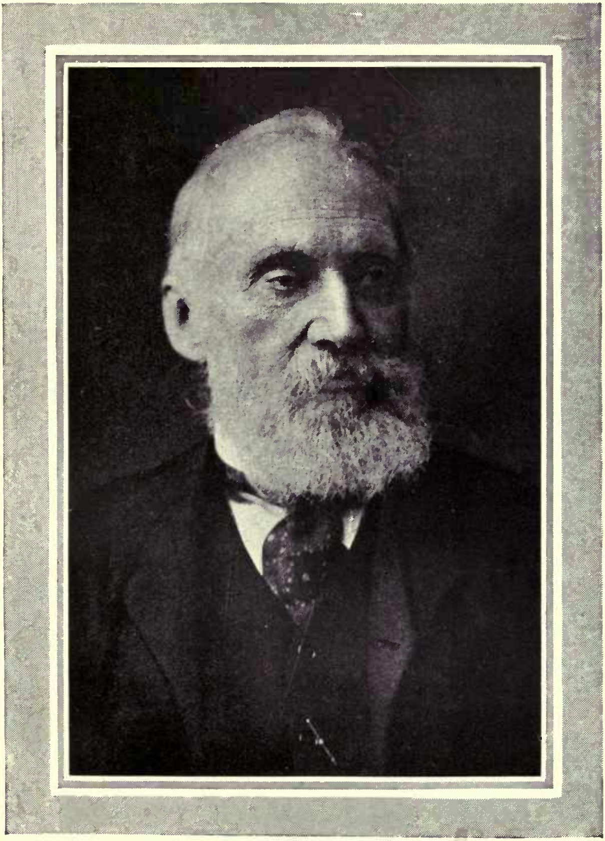
When the electromagnetic effects of currents had been discovered, experiments by Gauss and Weber, Schilling and Steinheil showed how they could be utilized in transmitting signals. These experiments became known in England through William Fothergill Cooke (1806–1879), knighted in 1869) who, in conjunction with Wheatstone, set to work to devise a system of telegraphy that could be commercially successful. The main difficulty was to reduce the number of wires, which were at first thought to be necessary for indicating the twenty-five letters; in this respect Ronalds had been ahead of his successors. The difficulty was overcome by an alphabet of signs introduced by the American inventor Morse, but an alternative one-wire system of Cooke and Wheatstone in which the letters are directly indicated on a dial, though much slower in its working, continued to be employed in the British Telegraph Service at stations where it was difficult to obtain operators sufficiently practised in the Morse code. Subsequent improvements in telegraphy over land lines are mainly of technical interest.

An entirely new set of problems arose when submarine cables had to be laid across the oceans. As water is not an insulator like air, the conductor which serves for the transmission of the message has to be surrounded by a non-conducting material like guttapercha. The copper wire inside and the water outside separated by an insulating substance then act like a condenser which must be charged up before a steady electric current can flow through the wire. This retards the transmission, and otherwise complicates the effects, so that the ordinary telegraphic apparatus become useless. Lord Kelvin's inventive genius soon supplied a suitable instrument, but there were other dangers ahead, such as the enormous mechanical stresses to which the cables are exposed, and the destructive effects of submarine boring animals. The credit of overcoming these difficulties is largely due to Robert Newall, whose name has already been referred to in connexion with Astronomy. As a practical engineer, Newall had improved the manufacture of wire rope to such an extent that quite a new industry may be said to have originated through his efforts. He used the experience gained by introducing wires to strengthen the cables and inventing suitable appliances for paying them out. The first commercially successful cable was laid across the Straits of Dover in 1857, and the possibility of telegraphic communication between Europe and America was then opened out. In July, 1857, a cable was ready, and the shore end was fixed at Valentia; but the cable snapped when 380 miles had been laid. In the following year, after a further failure, a cable was finally stretched across the Atlantic; but, unfortunately, Kelvin's instructions were ignored and high potential currents were used to transmit the messages, with the result that the insulation was completely ruined.

The next attempt, made after an interval of eight years, was again unsuccessful; but in 1866 the *Great Eastern* laid its cable without mishap, and was even able to pick up the lost end of the one that had broken in the previous year. Since then submarine cables, mostly manufactured in England, have rapidly increased, and their total length now at work would, if joined end to end, be able to pass ten times round the equator.

The success of cables depends so much on the durability of the insulating material that this seems to be the place for attention to the services of Thomas Hancock (1786–1865), the founder of the india-rubber trade in England. His work is well described in the "Dictionary of National Biography," from which the following account is—with a few omissions—transcribed. Observing that two freshly cut surfaces of india-rubber readily adhered by simple pressure, Hancock was led to the invention of the "masticator," as it was afterwards called, by the aid of which pieces of india-rubber were worked up into a plastic and homogeneous mass. With the invention of this process, which was perfected about 1821, the india-rubber trade commenced. Eventually, Hancock became a partner in the firm of Charles Macintosh and Company, though he still carried on his business in London. In 1842 specimens of "cured" india-rubber, prepared in America by Charles Goodyear according to a secret process, were exhibited in this country. Hancock investigated the matter, and discovered that when india-rubber was exposed to the action of sulphur at a certain temperature a change took place; he thus obtained "vulcanized" india-rubber. This was patented in 1843. Although Hancock was not the inventor of vulcanizing in the strictest sense of the word, he first showed that sulphur alone is sufficient to effect the change, whereas Goodyear employed other substances in addition. Hancock also discovered that, if the vulcanizing process be continued and a higher temperature employed, a horny substance, now called vulcanite or ebonite, is produced.

David Edward Hughes (1831–1900), whose name has already been mentioned above, was born in London, but his parents emigrated to the United States when he was



William Thomson, Lord Kelvin

seven years old. He was connected for a time with a college in Kentucky, first as Professor of Music and then as a teacher of Natural Philosophy, but gave up the academic career, at the age of twenty-three, to supervise the manufacture of the type-printing machine which he had invented. Everyone is now familiar with that perfect little instrument which distributes typed messages simultaneously all over a city. The income which the inventor derived from it gave him the desired leisure for further scientific investigations. His most important discovery is that of the microphone, in which two pieces of carbon are in loose contact, making an electric connexion that is exceedingly sensitive to the slightest disturbance caused by a wave of sound or an electric impulse. The carbon contact was soon introduced into telephone transmitters, and helped much to make telephones serviceable for ordinary use. In observing the effect of electric impulses in carbon contacts Hughes anticipated the invention of the "coherer," which made the transmission of wireless electric messages to great distances possible. It is, indeed, related that, so far back as 1879, Hughes could detect by the microphone "electric impulses" at a distance of 500 yards.[1] The researches on the microphone and on another useful instrument, the "induction balance," were carried out in England, where Hughes spent the later part of his life.

All industrial applications of electricity are based on Faraday's discoveries, and Sturgeon's invention of the electromagnet. After it had been shown experimentally by the former that an electric current is produced when a wire is moved in a magnetic field, it was pretty obvious that appliances could be constructed for generating currents by mechanical means. There is no indication that at first anyone was aiming at currents of great intensity; machines were constructed partly on account of their scientific interest and partly to be used for purposes of telegraphy. Sturgeon was the first to attack the inverse problem of using a current to do mechanical work, and it has been described in our first chapter how Joule started his work by trying to improve the efficiency of electromagnetic engines. Between 1850 and 1860 many attempts were made to increase the intensity of electric currents obtained by electrodynamic induction, but the turning point came when, in the spring of 1867, Henry Wilde, of Manchester, showed some remarkable experiments in the rooms of the Royal Society. In the previous year he had already described the main principle on which he relied to increase the intensity of currents that could be obtained by electromagnetic induction. A machine constructed according to a model made by Werner Siemens, in which an armature rotated in a magnetic field produced by a permanent magnet, generated an electric current which fed a second and larger machine in which the permanent magnets were replaced by electromagnets. These were excited by the first current and a much stronger magnetic field was produced: a more powerful current was consequently obtained. This was led in a third machine round still larger masses of iron, which were thus magnetized, and finally a current emerged showing effects of surprising intensity. A piece of iron half-an-inch thick melted and burned when the current was made to pass through it, and a rod of platinum two feet long and a quarter of an inch in diameter was also seen to melt. A steam engine of 15 h.p. was required to drive the shafts of the machines. Eye-witnesses testify to the great impression created by these experiments, and there can be little doubt that the public then first began to recognize the potentialities of the electric current. Rapid advances were quickly made, and the modern "dynamo-machine" was soon evolved; Wilde himself had already called his machines by that name.

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[1] "Encyclopædia Britannica."

As soon as commercial interests are involved in scientific appliances, new problems of an economic nature arise. The weight of metal to be put into the different parts of the machinery has to be adjusted so as to obtain the best results at the least cost, and other matters have to be considered. Apart from some contributions by Lord Kelvin, it may be said that the economics of the dynamo-machine depend almost entirely on the researches of John Hopkinson, who, perhaps, more than any other British man of science, combined the commercial faculty with the highest scientific attainments.

John Hopkinson (1849–1898) was born in Manchester, and after studying two years at Owens College entered Trinity College, Cambridge. He graduated in 1871 as senior wrangler, and in the following year was engaged by Messrs. Chance Brothers, glass manufacturers, at Birmingham, as engineering manager. In this position he devoted himself to the improvement of lighthouse illumination, and introduced the system of group flashing lights which is now extensively used. In 1878 he settled in London as consulting engineer, and during the next few years conducted his classical researches on the efficiency of dynamo-machines. These were completed later, in conjunction with his brother Edward, by laying down the general principles by which the performance of any machine may be predicted from its design. Another important contribution to electric lighting was his invention of the three-wire system of electrical distribution.

The efficient working of most of our electrical machinery depends on the magnetic properties of iron, and mention must, therefore, here be made of the valuable investigations of Professor J. A. Ewing, who first clearly pointed out the inevitable dissipation of energy which occurs when a piece of iron is subject to rapidly alternating magnetic forces, as it is, for instance, in a transformer. Owing to a property of iron which he called hysteresis, and which is a kind of internal viscosity brought into action by the rapidly changing orientation of magnetic molecules, some of the energy will always be converted into heat, and is lost as useful work. In other respects also, Ewing has added much to our knowledge of magnetism.

Our electrical industry owes much to William Edward Ayrton (1847–1908), who was the first to introduce sound methods of instruction in applied electricity. He was the most successful and, for a time, the only teacher of the subject. He organized the laboratories at Finsbury College, and at the Central College, Kensington. Men came from all parts of the world to be trained by him, and he knew how to infuse his students with the spirit of research. In the early days of the industry, the measuring instruments, though suitable for a physical laboratory, could not easily be moved, or protected against the disturbing effects to be expected in a large workshop. Ayrton recognized the want, and in conjunction with Professor John Perry designed a number of reliable and practical instruments that could be used in a factory. Some of these inventions have proved of permanent value.

The applications of chemistry to the necessities of the nation are predominant in times of war, and hardly less universal in times of peace. Two great industries stand out on account of their importance, enhanced as it is by the interest attached to, and the instructive contrast presented by, their historical development. While the alkali manufacture which has been prosecuted so successfully in this country is based to a great extent on chemical processes originated or perfected by foreign chemists, Leblanc, Solvay, and Castner, the coal-tar colour industry, founded on pioneer work done in England, was unable to hold its own against foreign competition. There is this possibly to be said in explanation of the difference. The chemistry of the alkali manufacture is extremely simple, and the difficulties which had to be overcome, though serious enough, were mostly on the engineering side; the colour industry, on the contrary, depends, not only in its initial stages but throughout, on persistent and organized scientific research, requiring the encouragement and support of the manufacturers. The institution which is associated with its birth—the Royal College of Chemistry—was an exotic growth disconnected from any university, and without permanent influence on university teaching. Its director, Hofmann, was, at that period, concerned with training scientific men rather than manufacturing chemists, and no efforts were made to bridge the gap between the laboratory and the factory.

The alkali industry presents a more pleasing history, Joshua Ward, of Twickenham (1685–1761), first commercially produced oil of vitriol in glass globes of forty to fifty gallons capacity, and a very important advance was made by Dr. John Roebuck, of Birmingham (1718–1794), who, in 1746, erected the first lead chambers. A name more directly connected with the manufacture of alkali is that of Joseph Christopher Gamble (1776–1884), who was trained up for the Church, and while passing through his studies at Glasgow, attended a course of chemistry under Dr. Cleghorn. He became sufficiently interested to carry on privately chemical experiments in his leisure time. After taking up his duties as Presbyterian minister at Enniskillen, he saw hand-loom weavers in his parish working the flax grown by farmers in the neighbourhood, and prepared solutions of chlorine to assist them in bleaching their linen. Finding that he could utilize the residue left over from the production of chlorine in producing Glauber salts, he decided to resign his ministry and establish chemical works in Dublin. Here he manufactured bleaching powder, using the process patented by Charles Tennant (1768–1838), the owner of the St. Rollox Chemical Works, now merged in the United Alkali Company. He further set up a plant to manufacture the necessary sulphuric acid. Salt or brine, another indispensable ingredient, had, however, to be obtained from a distance, and this led him ultimately to leave Ireland, and build works at St. Helens. There he was associated during ten years with James Muspratt, and afterwards with the brothers Crossfield, soap-boilers, of Warrington. The trouble arising from the damage done to the surrounding country by the noxious gases set free in the process of manufacture hampered the work considerably, and Gamble was slow to adopt the proper remedies. The enmity of his neighbours and ill-health ultimately made him abandon his work altogether.

To appreciate the work done by the chemical manufacturer in Gamble's time, it must be remembered that they had generally to manufacture all the appliances they required. Earthenware pots of sufficient size had to be produced, and Gamble, blowpipe in hand, made his own thermometers and hydrometers.

"Alkali" is an Arabic word originally applied to the ashes of plants, and subsequently to the products derived from these ashes, consisting of carbonate of soda and carbonate of potash. The properties of these substances are so similar that at first they were not distinguished as separate bodies. As chemistry advanced, their metallic bases, sodium and potassium, were grouped together under the term "alkali metals," but technically, when the alkali industry is referred to, it includes only the sodium compounds, and of these, strictly speaking, only the hydrate and the carbonate; but the manufacture of sodium sulphate and of hydrochloric acid is inseparably connected with the same industry. The first successful process of obtaining carbonate of sodium is due to Leblanc, a French chemist, and one of the victims of the French Revolution. Leblanc was born in 1753, near Orleans. He was first trained in an apothecary's shop, but proceeded to the study of medicine, and was appointed surgeon to the Duke of Orleans. In 1775 the French Academy of Sciences offered a prize for the best practical process of producing soda from common salt. There were several competitors, but none of them were judged worthy of receiving the prize. Nevertheless, Leblanc patented his process, and the Duke of Orleans supplied the capital for establishing works on a manufacturing scale. But his connexion with that nobleman proved to be his undoing. The Duke was executed, and the works were confiscated. Leblanc struggled on in dire poverty for thirteen years, when his property was returned to him by the Emperor Napoleon. But it was too late; he had no capital to start afresh, took refuge in a workhouse, and died by his own hand.

James Muspratt (1793–1886), who introduced the Leblanc process into England, was born in Dublin, and as a boy was apprenticed to a wholesale druggist; he quarrelled with his master, and went to Spain to take part in the Peninsular War. His great ambition was to obtain a commission in the cavalry; in this he was unsuccessful, and, refusing to accept the position in the infantry which was offered him, he followed the army in the wake of the troops. He fell ill, made his way to Lisbon, but could not find a steamer to take him home. Ultimately he secured an appointment as midshipman in the Navy, and though promoted to the rank of second officer, could not adapt himself to the strict discipline of the Navy. He deserted while the vessel lay in the Mumbles roadstead, and returned to Dublin. With the knowledge gained during his apprenticeship and a small inheritance, Muspratt then began his career as a manufacturing chemist. He started by making hydrochloric acid and prussiate of potash. This did not satisfy his ambitions, and when, in the year 1823, the prohibitive salt tax was greatly reduced, he determined to work the Leblanc process, and crossed over to Liverpool in search of a suitable locality to erect his works. Not being provided with sufficient capital he continued during a few years the manufacture of prussiate of potash, until in 1828 he joined partnership with Christopher Gamble and together they erected the St. Helens works. Separating again two years later, Muspratt took a new site at Newton-le-Willows. The same trouble arose which, as has already been mentioned, discouraged Gamble. Newton was in the heart of an agricultural district, and the farmers very naturally resented having their crops spoiled by the fumes of hydrochloric acid. Muspratt's business was so seriously interfered with by continuous litigation that he abandoned his works in 1850; and yet, ever since 1835, he might have got over his difficulties had he given a trial to the coke tower condenser of William Gossage (1799–1877), which had been brought to his notice by the inventor. In these condensing towers, the hydrochloric acid, instead of being allowed to escape, is collected, and forms a by-product of considerable commercial value. Gossage's process enabled the alkali industry to develop with great rapidity, so that in the twenty years between 1852 and 1872, the annual production of alkali rose from 26,000 to 94,000 tons. Moreover, the invention allowed the Alkali Acts to be passed and strictly enforced, to the great advantage of the country in which the works were situated.

In the Leblanc process, sulphate of soda (salt cake) is formed by the direct action of sulphuric acid on salt; the sulphate is converted into the carbonate by bringing it into intimate contact with limestone and coal, and heating the mixture. In another method, which has to a great extent replaced that of Leblanc, the salt is acted on by ammonium bicarbonate, with the result that sodium bicarbonate and chloride of ammonium are formed. The ammonium bicarbonate, which forms the basis of the reaction, is generated by saturating a salt solution with the ammonia obtained in the recovery of the plant, and forcing carbonic acid gas into the liquid. The process was first invented by G. Dyer and

J. Hemming in 1838, and worked on a small scale in Whitechapel. Muspratt also had given it a trial at Newton, but abandoned it again. After protracted investigations, the Belgian chemist, Ernest Solvay, overcame the main manufacturing difficulties, and took out a patent in 1872. In the meantime, Ludwig Mond (1839–1909) had settled in England at the age of 23, and had gained practical experience with the Leblanc process while occupied in some chemical works at Widnes. Recognizing the possibilities of the ammonia-soda process, he obtained a licence from Solvay, and in partnership with Sir John Brunner, founded in 1873 the great chemical works near Northwich. Further difficulties were experienced, but these were gradually overcome, mainly by improved devices for recovering the ammonia, on which the commercial success of the process largely depends.

A third method of making alkalies became possible when the introduction of dynamo-machines provided an easy means of obtaining strong electric currents. Various electrolytic processes were then devised and patented. In the Castner-Kellner method, used extensively in this country, the kathode of the electrolytic trough is formed by mercury, and the sodium is transferred by the current from the solution to the mercury with which it amalgamates; by a self-acting arrangement the amalgam is removed before it becomes strong enough to act on the water. That action is ultimately allowed to take place in another vessel, where a solution of caustic soda is formed.

Among the chemical engineers of the alkali trade, Henry Deacon (1822–1876) and Walter Weldon (1832–1885) also hold distinguished places. They both successfully invented independent and quite different processes for the manufacture of chlorine, which are still in use, though partly superseded by electrolytic methods. An important improvement in the manufacture of sulphuric acid was made by J. Glover, who, in 1866, introduced the important de-nitrating tower.

In the early forties of last century a determined effort to promote chemical research was made in London. With the support of Faraday and Brande, it was at first intended to attach the necessary laboratories to the Royal Institution, but on closer consideration the available space was found to be insufficient, and it was decided to establish a separate institution, under the name of the Royal College of Chemistry. The proposal matured largely through the influence of the Prince Consort and the Queen's physician, Sir James Clark. Temporary accommodation was found in George Street, Hanover Square, until a larger building in Oxford Street could be adapted. Justus Liebig, whose authority in questions of chemistry was paramount at the time, was asked to recommend a suitable director for the new institution, and ultimately August Wilhelm Hofmann, a young assistant at the University of Bonn, accepted the appointment. The school was opened in 1845, and Hofmann threw himself so heartily into the work that it soon attracted a large number of promising pupils. It is, indeed, remarkable to find among the early students of the Royal College so many men who subsequently rose to eminence; we note among them Sir William Crookes, Sir Frederick Abel, Herbert Macleod, and Sir William Perkin. The College continued until 1864, when it was absorbed into the School of Mines. Perkin (1838–1907) was fifteen years old when he came under the influence of Hofmann. After passing through the ordinary training, he was appointed honorary assistant to his teacher, and henceforward devoted himself to research work. Hofmann's own investigations at the time dealt with the organic compounds derived from coal-tar; it was a purely scientific research, undertaken without reference to any industrial applications. Perkin was set to work on anthracite, and, though interesting results were obtained, the chief value of his early work was the acquisition of the experience which he was to turn to such good account later.

The artificial production, or synthesis, as it is technically called, of natural organic compounds was then in its infancy, and it was generally supposed that if, by abstracting or adding oxygen or water, a compound could be formed having the same number of oxygen, carbon, and hydrogen atoms as the desired substance, the synthesis was likely to be successful. Hofmann had suggested the artificial production of quinine as a useful subject for research. The problem attracted Perkin, and as he was at the time busy with other work for his Professor, he decided to pursue the investigation in the private laboratory he had established at home. Following the deceptive guidance of the accepted doctrine, he tried to synthesize quinine by treating one of the coal-tar products with bichromate of potassium, but only obtained a dirty reddish-brown precipitate. Maxwell once said that he never stopped a man from carrying out an unpromising research, because, though he would almost certainly not find what he expected, he might find something else. Perkin had found something else, and showed the proper researching instinct by accepting the hint. Replacing the more complicated compound which he had used by another coal-tar product, "aniline," he obtained an almost black precipitate, which, on further examination, proved to have dyeing properties. This led to the discovery of aniline purple, later called "mauve," the first of the artificial colours. Perkin saw the possibility of a useful application before him, and sent a sample of the dye to Messrs. Puller, of Perth, who, recognizing its value, replied: "If your discovery does not make the process too expensive, it is decidedly one of the most valuable that has come out for a long time."

Perkin resigned his position at the Royal College, and with the assistance of his father built a factory at Greenford Green, near Sudbury. To supply the dye cheaply, an economical method of preparing aniline had to be worked out. This was first accomplished by the French chemist Béchamp, whose share in the work was always fully recognized by Perkin. The new dye-stuff was brought into the market towards the end of 1857, and the demand for it increased rapidly.

The aniline dyes are products which do not occur in nature. A fresh departure was made in 1868, when Graebe and Liebermann succeeded in the artificial formation of alizarin, the dyeing principle of the madder plant. The method used was, however, too costly to hold out any hope of competing successfully with the product derived directly from the plant, which was grown extensively in the south of France. Within a year Perkin invented another process that promised and attained commercial success. In the meantime, Graebe and Liebermann had independently been led to the same method. The Greenford factory, however, was ready to start work at once, and until 1873 there was practically no competition with the coal-tar dyes produced in this country.

In his report on the exhibition of 1862, Hofmann wrote :—

> "England will, beyond question, at no distant date become, herself, the greatest colour-producing country in the world; nay, by the strangest of revolutions, she may, ere long, send her coal-derived blues to indigo-growing India; her tar-distilled crimson to cochineal-producing Mexico, and her fossil substitutes of quercitron and safflower to China, Japan and other countries, whence these articles are now derived."

This is not the place to discuss the causes which have falsified Hofmann's prophecy. The "near future" of his prediction is passed, but another future lies ahead of us.

Perkin also carried on investigations of a great value in pure science, even during the busy time of his industrial enterprises. He sold his factory in 1874, devoting himself to the time of his death to a life of scientific research.

Among the pupils working in the laboratories at George Street we find Edward Chambers Nicholson (1827–1890), of whom Hofmann, at a later period, wrote: "He united the genius of the manufacturer with the habits of a scientific investigator." In his first research he determined the constitution of strychnine. After leaving the Royal College, he became associated with Messrs. Maule and Simpson in the preparation of various chemical products, turning his attention ultimately to colouring matters. His name is chiefly connected with the manufacture of "regina purple" and "Nicholson's blue."

A worthy successor of Perkin and Nicholson might, with proper opportunities, have been found in Raphael Meldola (1849–1915), who, between 1879 and 1885, made important discoveries of new dye-stuffs. But though he was during eight years connected with a firm manufacturing colours, he received little encouragement from his employers, and his work bore no immediate fruit. Meldola always held the opinion that the decline of the colour industry in England was not due, as is commonly asserted, to the defects of our patent laws, or other restrictions imposed by the legislature of the country, but to the neglect of continued scientific research within the factory.

Sir Frederick Abel (1827–1902) has been mentioned as one of the students of the Royal College of Chemistry. His subsequent work, carried on while he occupied the position of Professor of Chemistry at the Royal Military Academy and Chemical Advisor to the War Department, dealt mainly with the manufacture of explosives. Through his efforts guncotton could be made and handled without danger, and cordite is the joint invention of himself and Sir James Dewar. He also designed the apparatus, legalized in 1879, for the determination of the flash point of petroleum.

The name of Lyon Playfair (1819–1898) deserves to be remembered as one who actively encouraged research throughout his life, and exercised a considerable amount of influence in promoting scientific enterprises. He was born in India, educated at St. Andrews, and subsequently studied medicine at Glasgow. Attracted towards chemistry by the teaching of Thomas Graham, he went to study the subject under Liebig at Giessen. For two years he managed the chemical department of some print works in Clitheroe. Though he subsequently held for a time the Professorship of Chemistry at the Royal Institution in Manchester, at the School of Mines in London and at the University of Edinburgh, it is neither as a teacher nor investigator, but rather as a consistent upholder of scientific principles, that he has left his mark. He had a considerable share in the organization of the Great Exhibition of 1851, and in the foundation of the Department of Science and Art. In 1844 he sat on the Royal Commission for the examination of the sanitary conditions of large towns and public districts, and maintained throughout his life a great interest in that subject. He served on many other Royal Commissions. In 1868, Playfair was returned as the first representative in Parliament of the Universities of St. Andrews, and in 1885 was elected member for the southern division of Leeds. He held office as Postmaster-General, and later as Vice-President of the Council of Education. The honour of a peerage was conferred upon him in 1892.

CHAPTER VII

Scientific Institutions

GREAT ideas spring from individual brains, but a combination of brains working through scientific organizations may perform important functions in stimulating research, accumulating material or carrying out experiments which are beyond the means of one man. An organization is generally called into existence for a particular purpose, but to be permanently successful its constitution must be sufficiently elastic to allow a change of methods or even of aims when the original need has ceased to be urgent or fresh requirements have appeared. This elasticity has, indeed, been a distinguishing feature of our own scientific institutions, which have generally been able to adapt themselves to the changing circumstances of the time.

The origin of the Royal Society of London may be traced to weekly meetings of men engaged in philosophical enquiries, who came together to discuss questions of scientific interest. These meetings began about 1645. A few years later some of the members moved to Oxford, and independently met in that University. The London meetings were interrupted in 1658, owing to political troubles; but, after the return of Charles II., it was decided to establish a more formal organization. A society was then formed which met at Gresham College; the King became interested in its work, with the result that it obtained a charter in 1662, with the title of "The Royal Society." Further privileges were given in a second charter,[1] which was granted and signed on May 13th, 1663, and the regular activity of the

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[1] The second charter confers the present title: "The Royal Society of London," and adds its purpose: "for promoting Natural Knowledge (pro scientia naturali promovenda)."

Society begins with that date. Twenty-one members were named in the charter to constitute the first Council. Ninety-four additional Fellows were selected by that body shortly afterwards, of whom comparatively few are known by their scientific work. Men of general culture sympathetic to the revival of learning, statesmen, and even poets, were freely included. It was not only science that benefited by this liberal interpretation of the functions of the Society, for, quoting Professor Oliver Elton,[1] "The activities of the newly founded Royal Society told directly upon literature, and counted powerfully in the organization of a clear uniform prose—the close, naked, natural way of speaking, which the historian of the Society, Sprat, cites as part of its programme." The meetings of the Royal Society, at first, served mainly to promote friendly intercourse between its Fellows; experiments were shown by a specially appointed "curator," subjects were proposed for investigation, and sometimes Fellows were asked to undertake particular researches. The publication of results did not originally form any prominent part of the work, and only gradually gained importance.

The preceding pages have been full of examples illustrating the discoveries made by Fellows of the Society; we are here concerned with the influence which the Society exerted in its corporate capacity. From the beginning it acted as adviser to the Government in scientific matters, and interested itself in the general welfare of the country. During the first year of its existence, the King expressed the wish that "no patent should be passed for any physical or mechanical invention, until examined by the Society." In the same year a report was presented and approved by the Society "to plant potatoes, and to persuade their friends to do the same, in order to alleviate the distress that would accompany a scarcity of food." In 1732 it took measures to promote the practice of inoculation. In 1750, its assistance was invoked for the purpose of improving the distressing state of ventilation of prisons, which was the cause of the high death rate due to "jail fever." Sir John Pringle and

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[1] "Encyclopædia Britannica," Article on English Literature.

Dr. Hales on behalf of the Society recommended the use of ventilators, and these being introduced, the number of deaths in Newgate was reduced from seven or eight a week to about two in a month.

In March 1769, the Dean and Chapter of St. Paul's requested the Society's advice as to the most effectual method of fixing electrical conductors on the cathedral to protect it against the dangers of lightning. A committee was appointed, including John Canton and Benjamin Franklin, and reported on the subject; among the recommendations adopted by the authorities was that of using the waterpipes to serve as conductors between the roof and the ground. Three years later a similar request was received from the Government to protect powder magazines, and in 1820 the Society advised the Admiralty on a system of lightning conductors for use on ships which had been proposed by Sir Snow Harris. In May 1824 the Council of the Society appointed a Committee "for the improvement of glass for optical purposes." Valuable results were obtained with glasses prepared under the direction of Faraday, and examined by John Dollond and Sir John Herschel. Unfortunately, owing to the important electrical experiments which then engaged the attention of Faraday, the Committee did not proceed with the further proposal to organize the manufacture of optical glass for general sale.

The indefatigable first curator of the Society had, a few years after its foundation, formed the nucleus of a collection of "natural rarities," and this gradually grew into an important collection or "repository," enriched by contributions from distant countries. Ultimately, the greater part of it was handed to the British Museum, but the following letter, addressed by three Fellows of the Society to the Hudson Bay Company in 1777, shows that the specimens presented were examined with a view to their general utility:—

> "Having endeavoured to find out whether some of the natural productions which you have been so obliging as to present to the Royal Society may not furnish materials for our manufactures, we take the liberty of stating to you the result of our enquiry. We have put some

parts of one of the buffalo's hides into the hands of a tanner, and are informed, both by a very experienced leather-dresser and bookbinder, that it seems to be as good a material as the skin of the Russian buffalo for bookbinding. If these skins, therefore, can be procured in any quantity, the importation may answer well to the Company, and no further preparations of the hides will be necessary in Hudson's Bay, than to dry them properly with the hair on, and to take care that the sea water does not injure them on the passage. It is supposed that each skin brought in this way to England may be worth about four shillings. We also beg leave to present to the Company, in the name of the Society, a pair of stockings made here from the hair of one of the buffalo's hides, which hung near the neck, as also a hat; but it may be proper to inform you, that the greatest part of the materials used in the latter is rabbit's hair, as that of the buffalo cannot be worked into a proper consistence for this purpose, without a mixture of some other hair. As you have presented to the Society likewise a specimen of a wild swan, we have put the skin into the hands of an importer, and we shall, perhaps, surprise you when we inform you, that if it had been in a state to be properly dressed, it would have been worth at least a guinea and a half; so scarce is this commodity at present, and so great is the demand for powder-puffs, the best sort of which can only be made from swansdown. We have stated, however, that the skin sent from Hudson's Bay was absolutely spoilt by not being properly prepared, though we are informed that nothing further is necessary than the following simple process. All the feathers must be pulled off as soon as the swan is killed, leaving only the down on; after this the skin must be cut off along the back, and stripped off the body, then take all the fat away, and turning the skin inside out, let it dry. As swan-skins, therefore, are so valuable an article of commerce at present, and there is a probability of procuring many of them from Hudson's Bay, it may be worth while for the Company to purchase one of them, for the more fully instructing their servants in what state they should be sent over."

Many scientific expeditions were promoted and organized by the Royal Society. Through its efforts the Government was induced to send out well-equipped expeditions to observe the transits of Venus in 1761 and 1769, prominence being given in their representation not only to the importance of the occurrence, but to the circumstance that the first and so far only observation of this rare event was made by the Lancashire curate Horrocks.

In 1773 representations were made to the Earl of Sandwich, first Lord of the Admiralty, strongly urging the desirability of organizing an Arctic Expedition, partly on the ground that this might result in the discovery of a passage to the East Indies by or near the North Pole. The wishes of the Society were complied with ; two ships, the *Racehorse* and the *Carcass*, were fitted out, and an astronomer accompanied the expedition, with instructions drawn up by a Committee of the Royal Society. The ships returned without having achieved much ; but in two later expeditions, leaving England early in 1818 and in 1819, most valuable scientific results were obtained by Colonel (afterwards General) Sabine.

In 1784 the Council of the Royal Society petitioned George III. to place funds at the disposal of the Society to commence a geodetical survey, with a view to establishing a trigonometrical connexion between the observatories of Paris and Greenwich. The King gave his consent, and Major General Roy was appointed to carry out the undertaking. This was the origin of the British Survey Office. Its work was hampered, at the outset, by the unsatisfactory nature of the standards of length. Already, in 1742, the Royal Society and the French Academy had instituted comparisons between the standards of measures and weights of the two countries which led to some improvement, and in 1758 a committee of the House of Commons enquired into the subject; but no legislative action was taken until 1824. The question presented considerable difficulties, because the two original standards, one dating back to King Henry VII., kept at the Tower, and the other made during the reign of Queen Elizabeth, kept at the Exchequer, were of the rudest description, and did not agree with each other.

Francis Baily in 1836, referring to the latter, writes: "A common kitchen poker, filed at the ends by the most bungling workman, would make as good a standard. It has been broken asunder and the two pieces have been dovetailed together, but so badly that the joint is nearly as loose as that of a pair of tongs." In 1816 the Royal Society had received from the Secretary of State a request for assistance in ascertaining the length of a pendulum vibrating seconds of time at different stations of the Trigonometrical Survey. This brought the question of standards into prominence, and led to much valuable work being done; but in the final construction of the present standards the Royal Astronomical Society took the lead, under the energetic superintendence of Francis Baily.

Greenwich Observatory, established by Charles II., was, from its foundation, closely connected with the Royal Society. In 1710 Queen Anne appointed its President and such other Fellows as he might nominate to be visitors of the Observatory. For some time the Society exercised a real control over the work, receiving regular reports, making recommendations, and collecting the results for publication. At present the Royal Astronomical Society is associated with the Royal Society in nominating the members of the Board of Visitors. The important work carried out at Greenwich has been frequently referred to in these pages; it is recognized as the leading observatory of the world, and fixes the time used in all civilized countries.

The study of Meteorology owes much to the Royal Society, which in 1725 provided at its own expense a number of baro meters and thermometers to be used by its correspondents in different parts of the world. In 1773 the Council organized, under the superintendence of Henry Cavendish, regular meteorological observations in its own building, including the measurement of temperature, pressure, moisture, and wind velocity. These observations were conducted, and published annually in the Philosophical Transactions, for nearly sixty years. They were discontinued because the situation of the building was not considered suitable, and regular observations had been established at the Royal Observatory. A meteorological department of the Board of Trade was superseded in 1867 by a Meteorological Committee of the Royal Society, which was entrusted with the whole of the meteorological work of the country. This was followed, in 1877, by the Meteorological Council, consisting of the President and four members nominated by the Royal Society, together with the Hydrographer of the Navy. Since 1905 a special Committee of H.M. Treasury, containing two representatives of the Royal Society, is entrusted with the meteorological organization of the country.

In 1842 regular magnetical as well as meteorological observations were instituted at Kew Observatory, built in 1769 by King George III. for the purpose of observing the transit of Venus which occurred in that year. It came for a time under the direction of the British Association, but was handed over to the Royal Society in 1881; it passed to the National Physical Laboratory in 1905, and is now under the control of the Meteorological Committee. The Royal Society continues, however, to administer a Trust Fund of £10,000 conveyed to it by John Peter Gassiot, for the purpose of providing for magnetical and meteorological observations, which are being taken at Kew and Eskdalemuir. The directors of Kew Observatory included many distinguished men; among them Francis Ronalds, inventor of the first electric system of telegraphy, who designed and introduced the self-registering meteorological instruments, and Balfour Stewart, whose work has been mentioned in Chapter V.

It was chiefly through the influence of General Sabine that the Royal Society was, during many years, the chief promoter of the study of Terrestrial Magnetism. Observatories all over the world were, directly and indirectly, organized by that powerful and energetic personality. The East India Company gave valuable help, and when the Royal Society in the year 1840 approached the Russian Government, a speedy reply was received through the Foreign Office that, in consequence of the representations made by the Society, Russia had established ten magnetical observatories in her Empire, and was willing to provide the funds for a further one to be erected at Pekin.

The National Physical Laboratory was established in

1899, and placed under the control of the Royal Society. Its primary object is to provide proper standards of measurement for all branches of science, to test materials, to verify the indications of instruments and to determine physical constants. To serve these purposes, it has to be provided with means for carrying out researches on a large scale, more especially on problems connected with the industrial applications of science. The Laboratory is administered by an Executive Committee, on which six of the more important technical societies are represented. From small beginnings the Laboratory has grown, under the directorship of Sir Richard Glazebrook, with quite remarkable rapidity, and at present its total annual income amounts to £50,000, of which nearly two-thirds is received for work done for private firms or Government departments.

With foreign academies the Royal Society has always maintained most friendly relationships; intercourse between scientific men of different countries was, indeed, one of its primary objects. In May 1661, before the incorporation of the Society by Royal Charter, one of its members gave an account of the proceedings at a meeting of French scientists who formed the nucleus of the future French Academy of Science, and in July of the same year a letter was addressed to them requesting the interchange of scientific information. In a communication sent to the Council of the Royal Society by Christian Huygens during the same month, after referring to his observations on Saturn, the author writes that the members of the French body were "excited to emulation of the Society of London, and proposed applying themselves to philosophical experiments;" and adds that this is "a good effect produced by your example." The "Académie des Sciences" began to meet regularly in 1666, but was constituted finally only in the year 1699. The intimate relationship between the two scientific societies was illustrated in a striking manner when Sir Humphry Davy visited Paris while France and England were at war with each other. He was received with the highest honours, awarded a gold medal (p. 115), and elected a foreign member.

In the early days of the Society, Mr. Henry Howard (afterwards Duke of Norfolk) interested himself in securing correspondents in different parts of Europe, with a view to adding specimens of interest to its collection, and obtaining information of value to the industries of the country. "Methinks," he writes, "it were worth our knowledge whether there are not now some persons in Italy that know the old Roman way of plaistering, and the art of tempering tools to cut porphyry, the hardest of marbles"; and, again: "I am lately informed that there is a mineral salt plentifully to be found in the mines of Calabria, which has this particularity, that, being cast into the fire, cracks not, nor breaks in pieces. A specimen of that also would be acceptable."[1]

The first communication from the then recently established Academy of Sciences at Petrograd was received at the last meeting over which Sir Isaac Newton presided. After quoting the desire of the Czar to follow the English example in encouraging and cultivating science, the letter concludes with the assurance that the Russian Academicians "are the more inclined to make their addresses to, and desire most to have the approbation of, the Royal Society, as being the first of its kind, and that which gave rise to all the rest."

The Royal Society has always encouraged the formation of scientific bodies of similar aims in other parts of the United Kingdom. In 1684 such a society was established at Dublin, with full encouragement of the authorities of the Royal Society, offered also to a similar effort made at Edinburgh in 1705. In 1731 a separate society for the improvement of medical knowledge was instituted in the latter city, but was re-modelled so as to include other subjects in 1739. It was this body which, under the name of "Royal Society of Edinburgh," received its charter in 1783. The great work carried out by the scientific men of Scotland and Ireland, described in the preceding pages, is a sufficient indication of the influence exerted by the Royal Societies of Edinburgh and Dublin, which—as also the Irish Academy of Sciences (founded in 1782)—have always co-operated with the London Society in their common aims. The Royal Society of Arts was founded in 1753, for the promotion of Arts, Manufactures, and

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[1] Weld's "History of the Royal Society," Vol. I., p. 189.

Commerce, and the success with which it has worked to attain its objects needs no comment.

When science became more specialized, the need for separate societies dealing with the more technical portions of each subject began to grow. These societies now take an important share in the promotion of scientific researches. The Linnæan Society was founded in 1788, the Geological Society in 1807, the Royal Astronomical Society in 1820, and the Chemical Society in 1841.

What strikes the foreign visitor most when he enquires into the working of British scientific institutions is that the Royal Society receives no subvention from the Government. While in all foreign academies, the members receive an annual sum from the State, in England they pay both an entrance fee and regular subscriptions. The great French naturalist, Cuvier, has some interesting remarks on the subject.[1] The Royal Society, the oldest of the scientific academies, is, he says, "sans contredit l'une des premières par les découvertes de ses membres," and he attributes this to the fact that, as it depends for its subsistence on the contributions of its own members, the number of Fellows must necessarily be large. The more numerous a body, he argues, the smaller is the number of those who control its administration; hence the Council of the Royal Society, in whom the administration is vested, is a small body with great powers, and can exert a stronger influence on the progress of science than continental academies can do.

So far from the Royal Society having ever received subventions by the Government for general purposes, its Council resolved unanimously in 1798 to pay into the Bank of England a sum of £500 as a voluntary contribution towards the defence of the country. Up to that time, the whole expenditure of the Society was paid out of the entrance fees and subscriptions of the Fellows, the only legacy which had been received being a sum of £500 from Lord Stanhope, paid over in 1786. During the last century the financial resources of the Society have, however, been increased by a number of valuable endowments.

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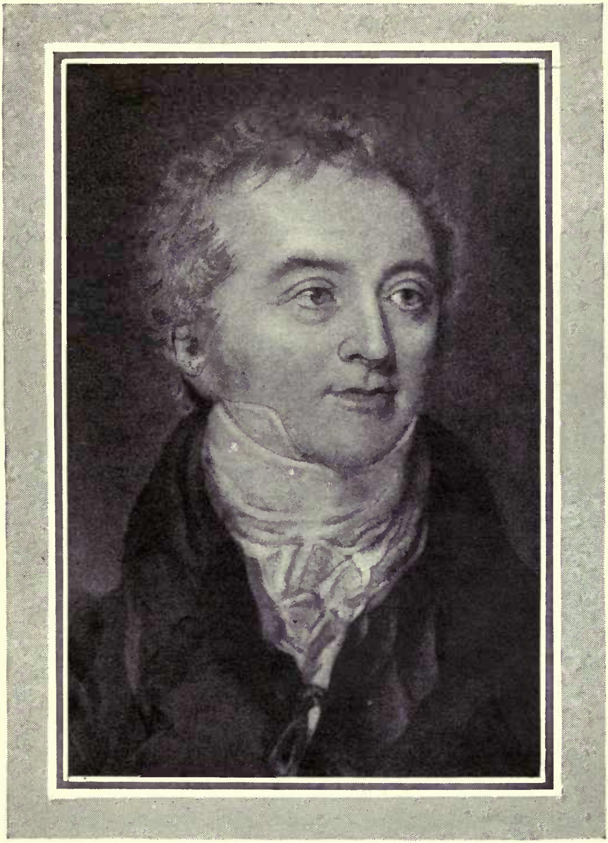
[1] "Mémoires de l'Institut," 1826, p. 219.



Thomas Young

The Society is now entrusted with the administration of certain funds devoted by the Government to definite purposes, such as grants towards scientific researches, and the publication of scientific literature. It has been given free use of its apartments, first in Gresham College, later in Somerset House, and now in Burlington House.

There is no building in the world associated with so many classical and revolutionizing researches as that in which the Royal Institution is housed. The idea which led to its foundation is generally ascribed to Count Rumford; the earliest document referring to the matter is an account of a meeting held at the house of Sir Joseph Banks, the President of the Royal Society, at which Count Rumford and other Fellows of the Royal Society were present. The title and purposes of the institution were then defined to be "for diffusing the knowledge, and facilitating the general introduction, of useful mechanical inventions and improvements; and for teaching, by courses of philosophical lectures and experiments, the applications of science to the common purposes of life."

The idea of research grew up in the time of Young and Davy, though Count Rumford must have had it in mind when through his influence the latter was appointed as first Professor of Chemistry. Much has already been said about the work of these two great philosophers, as well as that of Faraday, who succeeded Davy. Their successors worthily upheld the traditions of the Chairs. John Tyndall (1820–1893) was appointed Professor of Natural Philosophy in 1854, and succeeded Faraday as superintendent of the laboratories in 1866. He spent a useful life in scientific research, but will be remembered mainly as an advocate of scientific principles and popularizer of science. His books have inspired many young men to the pursuit of science, and the one on "Heat as a Mode of Motion" still deserves to be read as a clear exposition of the fundamental principles of heat.

Sir James Dewar, who now occupies the Chair held by Davy and Faraday, has made his name famous through his researches on the liquefaction of gases. He was the first to liquefy air on a large scale, and subsequently following up some earlier work of Worblewsky, he succeeded in not only liquefying, but also solidifying, hydrogen. By using liquid hydrogen, he was finally able to condense helium. He made extensive investigations on the properties of bodies at low temperatures, and his determination of the specific heats of elements as they approach the absolute zero of temperature has thrown quite a new light on the laws which up till then were believed to connect specific heat and atomic weight. Referring to his discovery of the absorptive properties of charcoal, we may quote the words of the President of the Royal Society in awarding him the Copley Medal in 1916: "Many of the most interesting and important investigations made in Physics in recent years would have been impossible but for his invention of the method of obtaining very high vacua by the use of charcoal immersed in liquid air or hydrogen."

A few words may be said in conclusion on the activities of the British Association, which held its first meeting at York in 1831. Its object was mainly the same as that which in the seventeenth century originated the meetings which ultimately led to the foundation of the Royal Society. British science in the nineteenth century could no longer be confined to the metropolis, and the provision of a more intimate and personal scientific intercourse between men residing in different parts of the country became desirable. To the outside world the meetings of the British Association appear to be confined to annual discussions on a variety of subjects; but the main work of the Association is carried on throughout the year, and it can claim to have originated scientific enterprises of the highest value and importance. The introduction of scientific electrical units is the result of work initiated by the British Association, and in great part carried out by one of its Committees. Under the protection and with the financial support of the same body, John Milne was enabled to establish his international organization for the observation of earth tremors, and the need for the establishment of a National Physical Laboratory was first advocated by Sir Oliver Lodge at one of the meetings of the British Association.

The history of the British Association forms a good example of the advantages of a liberal and flexible constitution, which allows it to adjust its procedure and conditions to the ever-changing and increasing requirements of science.

In concluding that part of Britain's heritage which deals with Physical Science, we may express the hope that the country will deserve, with increasing justification, the praise bestowed upon it by Biot[1]: "Souhaiter une chose utile aux sciences c'était avoir d'avance l'assentiment des savants d'Angleterre et l'approbation du gouvernement de ce pays éclairé."

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[1] "Mémoires de l'Institut de France," 1818.

CHAPTER VIII

BIOLOGICAL SCIENCE IN THE MIDDLE AGES

THROUGHOUT the Middle Ages natural science was a study of the written word of ancient writers, whose authority went unquestioned. Processes of observation or experiment were barely known. To this mediæval tradition the age of the Tudors, in its attitude to scientific study, was to a large extent loyal. Authority was still final and definite. What Galen and Hippocrates, Aristotle and Pliny had written was subject-matter for dispute, for discussion, for argument, but not for direct investigation. In the same way the new light derived from the Arabs, which spread through the learned world at the latter end of the twelfth and at the beginning of the thirteenth centuries, was treated as a matter for dialectics by those who set the written word before actual observation or experiment in Nature.

Let us consider the books in English at the disposal of an average man in the latter half of the sixteenth century. Through mediæval times had drifted a certain "corpus" of moralized natural history known as the "Physiologus," which was in essence a *Bestiarium*. It took various forms, and was read throughout Europe and the Near East. This "Physiologus" was primarily religious in its aim, but dealt not only with the animals mentioned in the Bible but with other and often mythical monsters. Scientifically the zoology of the "Physiologus" was of the poorest; in fact, the study of zoology was at its worst during the Middle Ages; it had fallen far lower than in classical days. The "Physiologus" had its origin in Alexandria in early Christian times, and was translated into many tongues, including Coptic. It was sometimes fathered upon Ambrose, but is older than his day.

During the eleventh century a certain "Episcopus incertus," one Theobaldus, made a metrical version of the descriptions of twelve of the animals dealt with in this little volume. This was published under the name "Physiologus Theobaldi Episcopi de naturis duodecim animalium," the earliest printed edition being that issued at Delft in 1487. Numerous editions were published in many countries for the following century or two, but the contents of the volume were in a state of flux, additions and omissions appearing in many of the issues.

But the chief book on natural history in the Middle Ages was an encyclopædia entitled "Liber de Proprietatibus Rerum," compiled by the English Franciscan, Bartholomew often called Bartholomaeus Anglicus, who probably wrote some time about 1250, certainly before 1267, and in all probability before 1260. Both before and after the invention of printing this work had a wide circulation. The "Liber" was translated into French by the order of Charles V., into Spanish in 1372, then into Dutch, and in 1397 into English. It was also the first book printed on paper which had been made in England. This book is believed to have been the source of much of Shakespeare's knowledge of natural history. In 1582 the Rev. Stephen Bateman, D.D., domestic chaplain to Bishop Parker, re-issued the English translation made by John of Trevisa which had been printed in 1494 by Wynkyn de Worde at Westminster. The book was entitled:

> "Bateman uppon Bartholome. His Booke De Proprietatibus Rerum: newly corrected, enlarged, and amended, with such Additions as are requisite, unto every severall Booke. Taken foorth of the most approved Authors, the like heretofore not translated in English. Profitable for all Estates, as well for the benefite of the Mind of the Bodie." Lond. 1582, fol. Dedicated to Lord Hunsdon.

Incomplete translations of Pliny from the French had appeared in 1565, and again in 1587. In 1601 Philemon Holland, M.D. (1552–1637), in later life headmaster of Coventry Grammar School—"the translator generall in his age," as Fuller calls him—published a more complete version of Pliny under the title "The History of the World, commonly called the Natural Historie of Caius Plinius Secundus."

This treats of all phases of nature, and contains a record of all natural knowledge up to the time of the younger Pliny. Nor must it be forgotten that the writings of Pliny and the "Georgics" of Virgil were in constant use in the schools.

In the middle of the thirteenth century Roger Bacon had pointed out that "There are two ways of knowing, viz., by means of argument and by experiment," but for three centuries onward it was "argument" which held the field. Not that the sixteenth century failed to produce enlightened men who were to preach a new doctrine. In his educational work "De Tradendis Disciplinis" (1523) Vives[1] advocates "nature study" and even uses the expression. He tells us "That although the writings of the old Greeks and Romans are the opinions of learned men, yet not even all these opinions and judgments are to be accepted." Vives recommends that the pupil should first be shown what he can most readily perceive by the senses :

> "So will he observe the nature of things in the heavens, in clouds and in sunshine, in the plains, on the mountains, in the woods. Hence he will seek out and get to know many things from those who inhabit those spots. Let him have recourse, for instance, to gardeners, husbandmen, shepherds, and hunters, for this is what Pliny and other great authors undoubtedly did; for any one man cannot possibly make all observations without help in such a multitude and variety of directions. But whether he observes anything himself, or hears anyone relating his experience, not only let him keep eyes and ears intent, but his whole mind also, for great and exact concentration is necessary in observing every part of nature."

We can but judge the state of zoology in Queen Elizabeth's time by the books and writings that have come down to us, and if we inquire what books and writings were available, they will be found to fall under the three headings, Medicine, Fieldcraft, and Heraldry. From these subjects the paths of progress in that science were advancing and converging.

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[1] A Spanish educationalist who came to England in 1523 and was attached to Henry VIII.'s Court. Later he lectured at Oxford and became a Fellow of Corpus Christi College there

The year that saw the birth of Shakespeare witnessed in the remote island of Zante the death of Vesalius, who, as a medical student at a hospital in Venice, had rubbed shoulders with a young soldier, Ignatius Loyola, who six years later founded the Order of the Jesuits. Vesalius, who was born at Brussels on the last day of the year 1514, was the first biologist to abandon authority. Dispensing with the aid of unskilled barbers, he dissected the human body with his own hands. Like Harvey, whose discovery of the circulation of the blood dates but three years after Skakespeare's death, he

> "Sought for Truth in Truth's own Book,
> The creatures, which by God Himself was writ,
> And wisely thought 'twas fit,
> Not to read Comments only upon it,
> But on the original itself to look."

At the beginning of his scientific career, like his master Sylvius, Professor at the College of France, Vesalius trusted the written word of Galen more than he trusted his own eyesight, but in the end his sight and his reason conquered, and at last he taught only what he himself could see and make his students see.

Vesalius was the founder of modern anatomy, physiology, and, I think we may say, also of modern zoology and botany, for the methods of these sciences are one. His great work on "The Structure of the Human Body" appeared at Basle in 1543, and was beginning to have influence in England, but only amongst the learned, well before the middle of the sixteenth century.

His English pupils, amongst whom was John Caius, the third founder of Gonville and Caius College, helped to spread his methods and principles in this country. Amongst the many pupils of John Caius we may mention Thomas Moffett. Comparatively few men in those days lived much over fifty years, and Moffett, born in 1553, died in 1604. He joined Trinity College in 1569, but migrated to Caius in 1572, where he was nearly poisoned by eating mussels. After taking his M.A. degree, he, as was the habit of the time, studied abroad and received in 1578 the degree of M.D. at Basle where he was a pupil of Felix Plater and of Zwinger.

The following year he travelled in Spain and Italy, and in these countries he made an elaborate study of the silk-worm, which doubtless led him to the study of insects in general. He not only wrote a poem on the silk-worm, but collected notes on the natural history of the Insecta. These were published thirty years after his death under the title "Insectorum sive Minimorum Animalium Theatrum—ad vivum expressis Iconibus super quingentis illustratum." An English translation entitled the "Theater of Insects" was published as an appendix to Topsell's "History of Four-Footed Beasts and Serpents" in 1658.

Moffett was a many-sided man of science, a practising physician, a traveller who at Copenhagen had known Tycho Brahe, a courtier who took part in both diplomatic and military service abroad, a poet and writer of epitaphs and epigrams, a keen critic of diet, and for some time a member of the House of Commons.

A friend of Moffett's was Thomas Penny, who entered Trinity College, Cambridge, in 1550, and later became not only a Prebendary of St. Paul's, but a sound botanist and entomologist. Like so many men of the time, Penny travelled extensively on the Continent. He visited Majorca, lived in the south of France, and worked in Switzerland with Gesner. He is believed to have been with Gesner when he died, and he certainly helped to arrange the natural history specimens which the great master left. It was probably through Penny that Gesner's drawings of butterflies passed into the care of Moffett, whose "Theatrum" states on its title-page that it was begun by Edward Wotton, Conrad Gesner, and Thomas Penny.

The contents of books revealing new knowledge diffused themselves among the ordinary public in Queen Elizabeth's time far more slowly than at present. On the other hand, studies were then far less specialized than they now are. For example, we find Milton placing medicine in the curriculum of a liberal education, and John Evelyn studying "Physics" at Padua. Lord Herbert of Cherbury insists on the necessity of a gentleman being able to diagnose and treat disorders, and thinks he should have a knowledge of anatomy. "Whosoever considers anatomy, I believe, will never be an atheist," was one of his recorded sayings. Dealing with the matter broadly, I think we may endorse the statement of Mr. Foster Watson: "It is noteworthy, that in both botany and zoology the main advances were made by professed physicians," and we must not forget that Elizabethan botany was more advanced than Elizabethan zoology.

Something, however, was learned from husbandry and field sport. "Let the student," says Vives in the above-quoted passage, "have recourse, for instance, to gardeners, husbandmen, shepherds, and hunters," and in "De rebus rusticis" he says: "Let the boy read Cato, Varro, Columella, Palladius." "Vitruvius is important for naming with the greatest purity and accuracy most objects of the country." Virgil with his marvellous account of apiculture and other agricultural pursuits was much read during this period.

The gentlefolk also in Queen Elizabeth's time were much interested in the study of heraldry, for, indeed, it was a very gentlemanly pursuit. Gerard Legh's "Accedens of Armory" (1562) and John Guillim's "Display of Heraldry" (1610) included descriptions of creatures which enabled the owners of animal crests and supporters to appreciate the nature of what they bore and of what supported them.

In Elizabethan times, although a knowledge of physiology and human anatomy was beginning to emerge; such objects as comparative anatomy, morphology, and embryology were non-existent. In dealing with the animal kingdom, the first need of the earlier writers on zoology was to make some sort of classification, and even in the later Tudor times such attempts at classification rested almost wholly on external characteristics. These arid catalogues of animals were usually lightened by the addition of notes on their habits—often of the quaintest and most bizarre description—and by short accounts of such medical properties as the fantastic pharmacy of the sixteenth century attributed to various beasts.

With one or two exceptions—astronomy on the physical side, human anatomy on the biological—the reawakening in science lagged a century or more behind the renascence in literature and in art. What the leaders of thought and of practice in the arts of writing, of painting and of sculpture in western Europe were effecting in the latter part of the fifteenth and throughout the sixteenth century began to be paralleled in the investigations of the physical laws of Nature only at the end of the sixteenth century and throughout the first three quarters of the seventeenth.

Writing broadly, we may say that, during the Stewart time, the sciences, as we now class them, were slowly but surely separating themselves out from the general mass of learning, segregating into secondary units; and from a general amalgam of scientific knowledge, mathematics, astronomy, physics, chemistry, geology, mineralogy, zoology, botany, agriculture, even physiology (the offspring of anatomy and chemistry) were beginning to assert claims to individual and distinct existence. It was in the Stewart reigns that, in England at any rate, the specialist began to emerge from those who hitherto had "taken all knowledge to be" their "province." Certain of the sciences, such as anatomy, physiology and, to a great extent, zoology and botany, had their inception in the art of medicine; but the last two owed much to the huntsman and the agriculturist.

The great outburst of scientific enquiry which occurred during the seventeenth century was partly the result, and partly the cause, of the invention of numerous new methods and innumerable new instruments, by the use of which advance in natural knowledge was immensely facilitated.

The barometer, the thermometer and the air pump, and, later, the compound microscope, all came into being at the earlier part of the seventeenth century, and by the middle of the century were in the hands of whoever cared to use them. Pepys, in 1664, acquired:

> "a microscope and a scotoscope. For the first I did give him £5 10s., a great price, but a most curious bauble it is, and he says, as good, nay, the best he knows in England. The other he gives me, and is of value; and a curious curiosity it is to discover objects in a dark room with."

Two years later, on August 19th, 1666, "comes by agreement Mr. Reeves, bringing me a lantern"—it must have been a magic lantern—"with pictures in glass, to make strange things appear on a wall, very pretty."

As we pass from Elizabethan to Stewart times, we pass, in most branches of literature, from men of genius to men of talent, clever men, but not, to use a Germanism, epoch-making men. In science, however, where England led the world, the descent became an ascent. We leave Dr. Dee and Edward Kelly, and we arrive at Harvey and Newton.

The gap between the mediæval science which still obtained in Queen Elizabeth's time and the science of the Stewarts was bridged by Francis Bacon, in a way, but only in a way. He was a reformer of the scientific method. He was no innovator in the inductive method; others had preceded him, but he, from his great position, clearly pointed out that the writers and leaders of his time observed and recorded facts in favour of ideas other than those hitherto sanctioned by authority.

Bacon left a heritage to English science. His writings and his thoughts are not always clear, but he firmly held, and, with the authority which his personal eminence gave him, firmly proclaimed, that the careful and systematic investigation of natural phenomena and their accurate record would give to man a power in this world which, in his time, was hardly to be conceived. What he believed, what he preached, he did not practise. "I only sound the clarion, but I enter not into the battle"; and yet this is not wholly true, for, on a wintry March day, in 1626, in the neighbourhood of Barnet, he caught the chill which ended his life while stuffing a fowl with snow, to see if cold would delay putrefaction. Harvey, who was working whilst Bacon was writing, said of him: "He writes philosophy like a Lord Chancellor." This, perhaps, is true, but his writings show him a man, weak and pitiful in some respects, yet with an abiding hope, a sustained object in life, one who sought through evil days and in adverse conditions "for the glory of God and the relief of man's estate."

Though Bacon did not make any one single advance in natural knowledge—though his precepts, as Whewell reminds us, "are now practically useless"—yet he used his great talents, his high position, to enforce upon the world a new method of wrenching from Nature her secrets and, with tireless patience and untiring passion, impressed upon his contemporaries the conviction that there was "a new unexplored Kingdom of Knowledge within the reach and grasp of man, if he will be humble enough, and patient enough, and truthful enough to occupy it."

To turn to other evidence, the better diaries of any age afford us, when faithfully written, as fair a clue as do the dramatists of the average intelligent man's attitude towards the general outlook of humanity on the problems of his age, as they presented themselves to society at large. The seventeenth century was unusually rich in volumes of autobiography and in diaries which the reading world will not readily let die. The autobiography of the complaisant Lord Herbert of Cherbury gives an interesting account of the education of a highly-born youth at the end of the sixteenth and the beginning of the seventeenth century. Lord Herbert seems to have had a fair knowledge of Latin and Greek and of logic when, in his thirteenth year, he went up to University College, Oxford. Later, he "did attain the knowledge of the French, Italian and Spanish languages," and, also, learnt to sing his part at first sight in music and to play on the lute. He approved of "so much logic as to enable men to distinguish between truth and falsehood and help them to discover fallacies, sophisms and that which the Schoolmen call vicious arguments"; and this, he considered, should be followed by "some good sum of philosophy." He held it also requisite to study geography, and this in no narrow sense, laying stress upon the methods of government, religions and manners of the several states as well as on their relationships *inter se* and their policies. Though he advocated an acquaintance with "the use of the celestial globes," he did "not conceive yet the knowledge of judicial astronomy so necessary, but only for general predictions; particular events being neither intended by nor collected out of the stars." Arithmetic and geometry he thought fit to learn, as being most useful for keeping accounts and enabling a gentleman to understand fortifications.

Perhaps the most characteristic feature of Lord Herbert's acquirements was his knowledge of medicine and subjects allied thereto. He conceived it a "fine study, and worthy a gentleman to be a good botanic, that so he may know the nature of all herbs and plants." Further, "it will become a gentleman to have some knowledge in medicine especially the diagnostic part"; and he urged that a gentleman should know how to make medicines himself. He gives us a list of the "pharmacopæias and anechodalies" which he has in his own library, and certainly he had a knowledge of anatomy and of the healing art—he refers to a wound which penetrated to his father's "pia mater," a membrane for a mention of which we should look in vain among the records of modern ambassadors and gentlemen of the court. His knowledge, however, was entirely empirical and founded on the writings of Paracelsus and his followers; nevertheless, he prides himself on the cures he effected, and, if one can trust the veracity of so self-satisfied an amateur physician, they certainly fall but little short of the miraculous.

John Evelyn, another example of a well-to-do and widely cultivated man of the world, fond of dancing and skilled in more than one musical instrument, was acquainted with several foreign languages, including Spanish and German, and was interested also in hieroglyphics. He studied medicine in 1645 at Padua, and there acquired those "rare tables of veins and nerves" which he afterwards gave to the Royal Society; while at Paris, in 1647, he attended Lefevre's course of chemistry, learned dancing and, above all, devoted himself to horticulture.

But Evelyn's chief contribution to science, as already indicated, was horticultural. He was devoted to his garden, and, both at his native Wotton, and, later, at Sayes Court, Deptford, spent much time in planting and planning landscape gardens, then much the fashion.

In the middle of the sixteenth century, the fact that "nitre" promoted the growth of plants was beginning to be recognized. Sir Kenelm Digby and the young Oxonian John Mayow experimented *de Sal-Nitro;* and, in 1675, Evelyn writes: "I firmly believe that where saltpetre can be obtained in plenty we should not need to find other composts to ameliorate our ground." His well-known "Sylva," published in 1664, had an immediate and a widespread effect, and was, for many years, the standard book on the subject of the culture of trees. It is held to be responsible for a great outbreak of tree-planting. The introduction to Nisbet's edition gives figures which demonstrate the shortage in the available supply of oak timber during the seventeenth century. The charm of Evelyn's style and the practical nature of his book, which ran into four editions before the author's death, arrested this decline (" be aye sticking in a tree; it will be growing, Jock, when y're sleeping " as the laird of Dumbiedykes counselled his son), and to the " Sylva " of John Evelyn is largely due the fact that the oak timber used for the British ships which fought the French in the eighteenth century sufficed, but barely sufficed, for the national needs.

Pepys, whose naïve and frank self-revelations have made him the most popular and the most frequently read of diarists, was not quite of the same class of student to which Lord Herbert of Cherbury or John Evelyn belonged. But, gifted as he was with an undying and insatiable curiosity, nothing was too trivial or too odd for his notice and his record; and, being an exceptionally able and hard-working Government servant, he took great interest in anything which was likely to affect the Navy. He discoursed with the ingenious Dr. Kuffler " about his design to blow up ships," noticed " the strange nature of the sea-water in a dark night, that it seemed like fire upon every stroke of the oar "—an effect due, of course, to phosphorescent organisms floating near the surface—and interested himself incessantly in marine matters.

Physiology and mortuary objects had, for him, an interest which was almost morbid. He is told that " negroes drounded look white, and lose their blackness, which I never heard before," describes how " one of a great family was . . . hanged with a silken halter . . . of his own preparing, not for the honour only " but because it strangles more quickly. He attended regularly the early meetings of the Royal Society at Gresham College, and showed the liveliest interest in various investigations on the transfusion of blood, respiration under reduced air pressure and many other ingenious experiments and observations by Sir George Ent and others. On January 20th, 1665, he took home

"Micrographia," Hooke's book on microscopy—"a most excellent piece, of which I am very proud."

Although Pepys had no scientific training—he only began to learn the multiplication table when he was in his thirtieth year, but, later, took the keenest pleasure in teaching it to Mrs. Pepys—one could have wished that Mrs. Pepys' views had been recorded—he, nevertheless, attained to the Presidentship of the Royal Society. He had always delighted in the company of "the virtuosos" and, in 1662, three years after he began to study arithmetic he was admitted a Fellow of their—the Royal—Society. In 1681 he was elected President. This post he owed, not to any genius for science, or to any great invention or generalization, but to his very exceptional powers as an organizer and as a man of business, to his integrity and to the abiding interest he ever showed in the cause of the advancement of knowledge.

It has been said that a competent man of science should be able to put into language "understanded of the people" any problem, no matter how complex, at which he is working. This seems hardly possible in the twentieth century. To explain to a trained histologist double θ functions or to a skilled mathematician the intricacies of karyokinesis would take a very long time. The introduction in all the sciences of technical words is due not to any spirit of perverseness on the part of modern savants; these terms, long as they usually are, serve as the shorthand of science. In the Stewart times, however, an investigator could explain in simple language to his friends what he was doing, and the advance of natural science was keenly followed by all sorts and conditions of men.

Whatever were the political and moral deficiencies of the Stewart kings, no one of them lacked intelligence in things artistic and scientific. At Whitehall, Charles II. had his "little elaboratory, under his closet, a pretty place,"[1] and was working there but a day or two before his death, his illness disinclining him for his wonted exercise. The king took a curious interest in anatomy; on May 11th, 1663, Pierce, the surgeon, tells Pepys "that the other day

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[1] Pepys, January 16th, 1669.

Dr. Clerke and he did dissect two bodies, a man and a woman, before the King, with which the King was highly pleased." Pepys also records, February 17th, 1662–3, on the authority of Edward Pickering, another story of a dissection in the Royal closet by the king's own hands.

CHAPTER IX

BOTANY

IT is generally conceded that the first eminent English botanist was William Turner (born probably between 1510 and 1515, died 1568), educated at Pembroke College, Cambridge. After the manner of his time, Turner was not only a botanist but a zoologist; to his work in this subject we shall return later; he was further a most polemical divine, and suffered much with the alternate ebb and flow of the varying religious faiths which prevailed in the country during the Tudor times. Turner's earliest work on botany was the "Libellus de re Herbaria novus," 1538, which may also be regarded as the first English book on Botany. In this he gives, for the first time, the locality of many of our native British plants. Ten years later he published a work on "Names of Herbes in Greke, Latin, Englishe, Duche, and Frenche, with the commune names that Herbaries and Apothecaries use." His best known work, however, was his "Herball," which was published in three parts, the first part appearing in 1551, the second when he was exiled abroad in 1562, and the third in 1568. This was by no means the first "Herball" which had appeared in English, but it had a certain originality about it and a certain independence of view. Turner was especially opposed to what he considered superstitions in science, such as the old legend about the mandrake; but at the same time he seems to have adopted and perpetuated the fable of the goose-tree which bore barnacles from which geese hatched out. He did not accept this myth without real enquiry and an effort to obtain first-hand information, and he certainly would never have written as Gerard wrote that, "he had seen these trees with his own eyes, and had touched them with his own hands." Turner's days were the days of herbals, and one cannot, perhaps, give a better description of what a herbal was than by quoting the title-page of Lyte's (1529–1607) Herbal, which was mainly a translation from the French of De L'Ecluse, which was itself a translation from the "Cruijdeboeck" of Dodoens.

> "A niewe Herball, or Historie of Plants, wherein is contayned the whole discourse and perfect description of all sortes of Herbes and Plantes; their divers and sindry kindes; their straunge Figures, Fashions, and Shapes; their Names, Natures, Operations, and Vertues; and that not only of those which are here growing in this our countrie of Englande, but of all others also of foragne Realmes, commonly used in Physicke. First set foorth in the Doutche or Almaigne tongue by that learned D. Rembert Dodoens, Physition to the Emperour, and now first translated out of Frenche into Englishe by Henry Lyte, Escuyer."

This herbal went through several editions, but apart from it Lyte made little contribution to English botany.

One especial merit which Turner had was accuracy of observation, and a determination to see what he had to describe. Hitherto, knowledge largely depended upon the written word of the classical philosophers. Turner preferred to record his own experiences rather than to repeat "Pliny's Hearsay." He named many British plants, and, as Pulteney tells us, "allowing for the time when specifical distinctions were not established, when almost all the small plants were disregarded, and the *Cryptogamia* almost wholly overlooked, the number he was acquainted with was much beyond what could easily have been imagined in an original writer on the subject."

Although other distinguished herbalists who followed in Turner's path in the main disregarded his work, there is no doubt that he started a new era in the study of plants, and we shall see later he did the same in the study of animals.

Another noted herbalist was John Gerard (1545–1612). Unlike Turner, he was brought up to be a surgeon, and in his youth travelled extensively in Russia, Sweden, Norway, and other parts of the Continent. To some extent he regarded plants from the medical point of view, and in what was then the village of Holborn, he grew nearly 1,100 various species of "simples." "The Herball or Generall Historie of Plantes" is Gerard's claim to fame. Like Lyte's book, it was based upon the works of Dodoens, and there was a bitter quarrel as to the exact amount of credit due to the author of the English edition. Being a physician, Gerard naturally attached considerable importance to the medicinal side of plants, but he was also a practical gardener, and the popularity of his book probably depended to some extent upon the fact that it was the first published in English of practical use to horticulturists and gardeners.

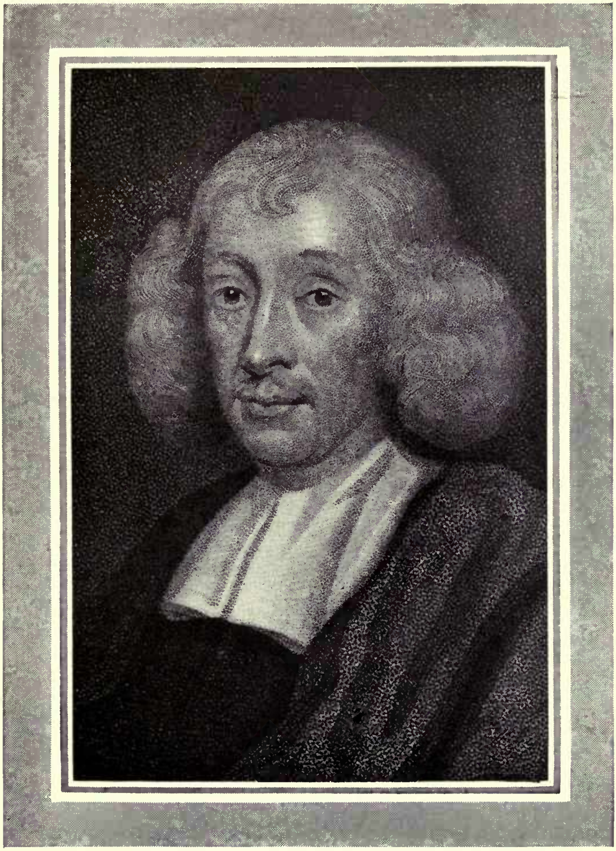
One last herbalist may be mentioned, Thomas Johnson, again a medical man with a physic garden of his own. He was a botanist who travelled in the country inspecting and recording the local flora, in fact his first publication was on the flora of the county of Kent. But his claim to mention depends upon his new edition of Gerard's "Herball," which he enlarged, re-edited, and published in 1633. He added some 800 plants which were unknown, or at any rate unrecorded, by Gerard, and increased the number of figures by 700, raising the total to over 2,700. Further and detailed information on herbals may be found in Mrs. Arber's delightful book on the English herbalists.

At the best, however, these herbals were full of superstitious and often nonsensical statements. They must merely be regarded as catalogues, compilations as a rule alphabetically arranged, for in the time when they mostly flourished, plants had not been systematically sorted out. Their affinities had not been established; as Professor Green says, "a herbal may be compared to a dictionary rather than to any other form of book."

The next outstanding man in the history of British botany is John Ray (1628–1705). He dealt with both animals and plants, and what little space we can afford for biographical details will be found under the chapter dealing with Zoology. Like Turner and like so many other botanists, Ray was a clergyman. He marks a new era in the history of the science of Botany, partly on account of his efforts towards a natural classification of plants, and partly on account of his extreme accuracy in the use of words. He was, indeed, as Sir J. E. Smith said, "the most accurate in observation, the most philosophical in contemplation, and the most faithful in description amongst all the botanists of our own or perhaps any other time." In his "Methodus Plantarum Nova" (1682), after recognizing a certain indebtedness to Cæsalpino and to Morison, the first Professor of Botany at Oxford, he expounds his system of classification and established, for the first time, the distinction between Dicotyledons and Monocotyledons. Also here he showed the true nature of buds, and indicated many of the Natural Orders which systematists now recognize.

Unfortunately, like other botanists of the time, he retained the unnatural divisions of plants into trees, shrubs, and herbs. Four years later, Ray published his first volume of the "History of Plants," and, in 1688, the second volume, the third and final volume appearing shortly before his death in 1704. This work contains a description of nearly 7,000 plants. In 1690 he re-edited the "Catalogus Plantarum Angliæ," which was the first manual of systematic botany published in England, and was in constant use for nearly a century afterwards. But Ray was far more than a systematist; in fact, he had a very wholesome and proper disinclination for the founding of new species. As far as appliances of the times went, he investigated the physiology and the histology of plants. His researches on the movements of plants and the ascent of sap were as complete as they could be under the conditions prevailing during his lifetime. He, with his colleague Willughby, studied the bleeding of fresh-severed portions of the birch and the sycamore, both of the branches and of the roots. He was inclined, though not definitely decided, to accept the sexuality of plants, and supported Grew by his knowledge of the reproductive process in the animal kingdom. However, he did not go further than "ut verisimilem tantum admittamus." But later, he admitted, the male character of the stamens which after all was giving the whole case away.

Botany, without any doubt, owes a great deal to Ray. As Miall has said, "he introduced many lasting improvements—fuller descriptions, better definitions, better asso-



John Ray

From an original portrait
in the British Museum

ciations, better sequences. He strove to rest his distinctions upon knowledge of structure, which he personally investigated at every opportunity." He sought for a natural system and made considerable steps towards one. In his classification he relied largely upon the nature of the fruit, but he insisted also upon the importance of vegetative habit. He laid stress upon the structure of the seed, appreciated the fact that it not only contained an embryo, but also the substance we now know as endosperm, but which he called " medulla " or " pulpa." He made things much easier for Linnæus, as did Linnæus in his turn for naturalists who now smile at his mistakes. Both were capable of proposing haphazard classifications, a fact which need not surprise us when we reflect how much reason we have to suspect that the best arrangements of birds, teleostean fishes, insects and flowering plants known to our own generation need to be largely recast.

A few words must be said about Robert Morison (1620–1683), a contemporary and to some extent a rival of Ray's, and whose system of classification for a time, but for a time only, outshone Ray's. Morison was an Aberdonian and a Royalist, and having been wounded at the battle of Brigg, he removed to Paris, the asylum of many of his countrymen. Here he took up the study of natural science, and ultimately became the Superintendent of the fine garden of the Duke of Orleans at Blois. On the death of the Duke in 1660, Morison returned to England with Charles II., the Duke's nephew. Charles gave him the title of " King's Physician and Royal Professor of Botany," and made him Superintendent of the Royal Gardens. Nine years later he was elected " Botanic Professor " at Oxford, where he remained until his death.

Ray, who was of humble origin, lived a simple life, and was emphatically an open air naturalist. Morison, who frequented courts and the higher walks of university life, although to a certain extent a field naturalist, more than Ray, relied on the works of his predecessors. After settling at Oxford, he gave his whole energies to the production of his " Historia Plantarum Universalis Oxoniensis." As an example of what he wished the book to be, he published a monograph on the *Umbelliferæ*, the first British monograph devoted exclusively to the elucidation of a single large Natural Order. The book was illustrated by some of the first copper plates which were produced in these islands. Morison endeavoured to trace the systematic relations of the members of the family by the aid of a linear arrangement, and even attempted a genealogical tree. He divided the flowering plants into fifteen classes; but he was only able to deal with five of these before his death, though he left the four succeeding ones finished. The remainder were completed by Jacob Bobart, the Superintendent of the Gardens at Oxford.

Morison's families were too few in number, and consequently often overcrowded with what later observation has shown to be a heterogeneous collection of plants. He worked from the particular to the general, beginning with the smallest subdivisions and working up to the larger ones. Like Ray, he accepted the division of plants into herbs, shrubs, and trees; but, unlike Ray, he ignored the distinction between monocotyledons and dicotyledons. He seems to have been a somewhat selfish man of science, self-assertive, taking every credit to himself, while allowing little to his predecessors and contemporaries.

During the latter half of the seventeenth century the second name of quite outstanding merit in the history of British Botany—second to that of Ray—is that of Nehemiah Grew (1641–1712). Like Turner, he was educated at Pembroke College, Cambridge, and he subsequently studied medicine at Leyden, where he took his doctor's degree in 1671. For a time he practised medicine at Coventry, and later removed to London. He and his contemporary, the Italian Malpighi, with whom he was always on good terms, are regarded as the founders of vegetable anatomy. He was the author of numerous works not all by any means confined to botany. The greatest of his contributions to that science was the "Anatomy of Plants," issued in 1684. Sections I., II., and III. of this volume were second editions of the "Anatomy of Vegetables Begun." The anatomy of roots and the anatomy of trunks followed. The fourth section included the anatomy of leaves, flowers, fruits, and seeds. The book was richly illustrated. Grew undoubtedly saw for the first time many structural features in plants, and although he was not always successful in interpreting their functions, he added greatly to our knowledge. His description of the bean-seed might still be used in a modern Elementary Biology Class. He notes the cotyledons, and states that the foramen (micropyle) "is not a hole casually made, or by the breaking off of the stalk; but designedly formed for the uses hereafter mentioned." He recalls that when squeezed a bean seed gives rise to many small bubbles through "the foramen." He notes the radicle, the plumule, and the two seed-lobes, and is aware that the latter are a particular kind of leaf—"dissimilar leaves" he calls them, and he finds that their parenchyma consists of an infinite number of extremely small "bladders." He also notes elsewhere that rows or files of "bladders" piled perpendicularly one above each other at times break in upon one another, and so make a "continued cavity." He recognized and understood the resin passages in a pine tree, and describes the medullary rays. He dwells upon the use of hooks in climbing plants, and the fact that the various whorls of a flower are arranged alternately. He invented the term "parenchyma" and others still in use. He was aware of the existence of stomata, and considers they were either "for the better avulation of superfluous sap or for the admission of air." To the flower itself he paid particular attention, but failed to grasp the use of pollen. He was, however, the first to point out that flowers are sexual, but unfortunately, although he is fairly definite on the subject, he made few experiments. He also described fully and completely the sporangia of a fern.

Grew, like Ray, was a man of great piety, simplicity, and undoubted modesty, and he considered that both "plants and animals came at first out of the same Hand, and were therefore the contrivance of the same Wisdom." Hence he endeavoured to find analogies and homologies between animals and vegetables, which later work could not endorse. Like most of his contemporaries he interested himself in the ascent of the sap, which he mainly attributed to capillarity. He stated that the green colour of a plant was dependent upon its exposure to air, but he missed the fact that the green colouring matter is dependent upon light. He had noticed that many vegetable juices were turned green by the addition of alkalies, and he considered that some alkaline properties of the air produced the well-known colour of leaves. He was groping after the fact that air was necessary to a plant for its nutrition, though his ideas were by no means definite. On the whole his greatest contribution to Science is his discovery of the sexuality of plants; but that is at least equalled or more than outweighed by his general contributions to our knowledge of the anatomy of plants and to the science of Botany in almost all its aspects.

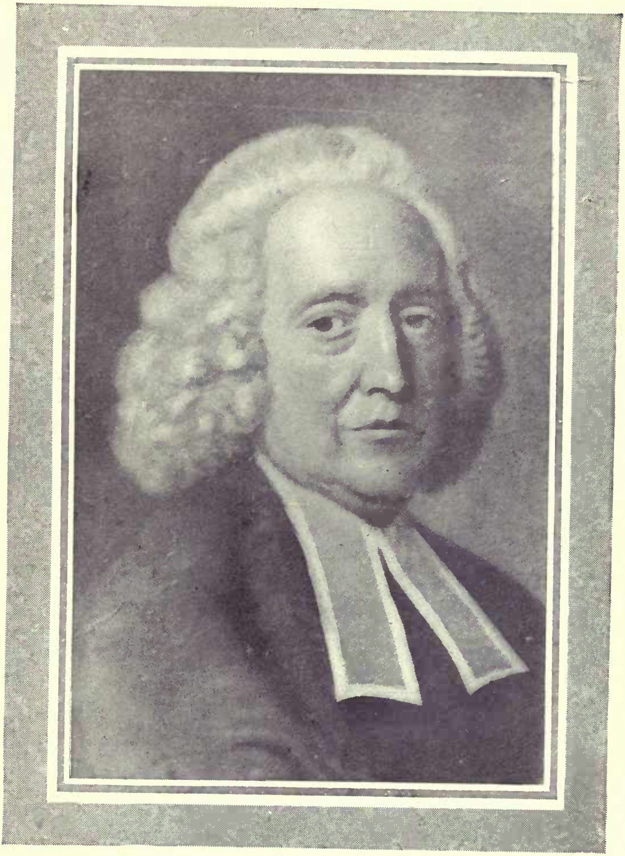
The last half of the seventeenth century is distinguished by the two names of Ray and Grew. Ray, unfortunately, had no successor. Stephen Hales, with whom we now deal, was the solitary follower of Grew until comparatively modern times.

Stephen Hales (1671–1761) was born in Kent and belonged to the same family as Sir Edward Hales, titular Earl of Tenterden, the well-known Royalist. He was educated at Corpus Christi College, Cambridge, where he was admitted a Fellow in 1602–1603. As a resident of Cambridge he "scoured the fields for Ray's plants," and worked in the "laboratory at Trinity College."

In 1708–1709 he became perpetual curate of Teddington, Middlesex, in which parish, although he held from time to time other benefices, he mainly resided. Living not far from Kew he was the friend of the royalties, and although Horace Walpole called him "a poor good primitive creature," he was greatly admired and respected by them, and was a close friend of Pope's, whose will, in fact, he witnessed.

Sir Francis Darwin draws attention to the fact that Hales' scientific work falls into two main classes: (1) physiological and chemical, (2) inventions and suggestions on matters connected with health and agriculture. It is with the former we have mainly to deal.

Hales, as we have pointed out, was the single successor in the eighteenth century of Nehemiah Grew, but in his time scientific men were less specialized than they are now, and Hales was not only a leader in vegetable physiology,



Stephen Hales

From a portrait by Thomas Hudson

but an active researcher in animal physiology. He, in fact, introduced into both fields of Physiology the process of weighing and measuring. His experiments on the loss of water which plants suffered by evaporation and on the absorption of water by roots are classic, and still remain of the greatest importance. His suggestion that the ascent of the sap is not from the roots only but must proceed from some power in the stem and branches, has recently met with a certain amount of corroboration. He introduced a new method by ever seeking a quantitative knowledge of the various physiological functions he was enquiring into. He experimented on the amount of rain and dew on special areas of the ground, and on the expansive force that peas exhibit when they absorb water, and explained variations in pressure from hour to hour on the rate of growth of the various members of the plant-organism, and all by methods which are still in use. He was one of the first to oppose the older views on the circulation of sap—views which had certainly retarded progress—and at any rate he had some inkling that air is a source of food to plants. He also had a clear idea of the importance of scientific knowledge in its practical application to agriculture. Without any doubt, the Englishman Hales must be regarded as the founder of that very important science, Plant Physiology.

Hales was a man of many inventions, and he devoted his extraordinary ingenuity largely to improving the lot of oppressed mankind. He invented various artificial ventilators which were used in granaries, ships, and prisons, and, so far as one can make out, the health of the prisoners greatly benefited by the introduction of his appliances. He also experimented on the distillation of salt water to make it fresh, on the preservation of various forms of food for sea voyages, on methods for cleaning harbours, and he devised an instrument for deep-sea dredging which, together with a large number of other mechanical contrivances, occupied his ever active mind.

Hales was evidently a lovable, kindly character, and without doubt was the greatest physiologist of his age, and of many later ages.

One other man of science, although not a botanist, must be mentioned here because of his profoundly important discovery in connexion with the function of leaves. It was the chemist Joseph Priestley (1733–1804), who, while working on the investigation of the air, states : "I have been so happy as by accident to have hit upon a method of restoring air which has been injured by the burning of candles, and I have discovered at least one restorative which nature employs for this purpose. It is vegetation." He records in 1778 that the green deposit in some vessels which he was using for his experiments gave off very "pure air," and discovered that this exhalation was given off when the algæ, as they proved to be, were exposed to sunlight.

Thomas Andrew Knight (1759–1838) was the only outstanding physiologist between Hales and the rise of the modern school, and even he was more prominent as a horticulturist than as a physiologist. He was educated at Balliol College, Oxford, and, being in the possession of ample means, settled first in Herefordshire and later at Downton, where he resided until his death. He made the acquaintance of Sir Joseph Banks, who was at that time seeking, on behalf of the Board of Agriculture, certain correspondents who would answer questions relating to agriculture in their several districts.

Knight was the second President of the Horticultural Society, which had been founded in 1804. He was elected in 1810, and occupied the Presidential Chair until his death.

His physiological investigations began with enquiries as to the circulation of sap, and one of the methods of his investigations was ringing the trees. He failed, however, to appreciate the part that the leaf plays in nutrition, and that the "function of the sap is to supply nutritive materials to the various tissues and to circulate the manufactured products of the leaf."

But, as Professor Green reminds us, Knight's work on the ascent and descent of sap "did much that was not only instructive for the time," but "was destined to remain with little modification among the fundamental facts of science." He made certain anatomical discoveries in connexion with these physiological experiments, and he incidentally investigated the transpiration or, as it was then called, "the perspiration," of the leaf, and showed that it was chiefly carried on by the under surface. His most important work was, however, his investigations into the relation of plants and their growth to the condition of their environment. He had noticed that, however seeds are placed during germination, the radicle attempts to descend into the earth and the shoot attempts to ascend into the air. He used a water-mill wheel in his garden, a wheel which revolved rapidly on a horizontal axis on the edge of which he placed his germinating seeds. He found that the shoots, no matter how they were pointed at first, gradually turned their points outwards from the circumference of the wheel, whilst the radicles grew inwards, so that "in a few days their points all met in the centre wheel." By this device Knight added a new apparatus in the investigation of growth. Later he paid much attention to the tendrils of *Ampelopsis* and the clasps of ivy, noting that they showed a tendency to grow away from the light. Much of his scientific work had a utilitarian bias, and he published many papers of a strictly horticultural nature.

In the management of his estate at Downton he experimented continually on the raising of hybrids, and bred a large number of new varieties of fruits and vegetables, many of which still bear his name.

Knight was a man of great patience and great perseverance, and seems to have had a charming personality, warm-hearted and generous, a little hasty at times, but of great kindness.

Although Linnæus (1707–1778) does not come within the scope of this volume, a few lines must be devoted to the great influence his views had on English thought. Without being a great investigator he remodelled the art of description. He introduced new and concise terms. He re-established the binomial nomenclature of plants, and he devised an artificial method of classification by means of which a competent botanist could determine the genus and species of almost any flower. But he was more of a co-ordinator than an investigator. He added few new facts to science, and, as Professor Green states, "we cannot find that either he nor any of his immediate pupils made a single discovery of any importance." His great talents lay in organization. He had a gift for sorting out things and putting them into what he considered the right place. His sexual system of classification was, as he himself felt, a merely temporary one, but it caught on and for fifty years did much to hinder the progress of real scientific enquiry into the natural relationships of plants *inter se.*

His name leads us on to Sir J. E. Smith (1759–1829), a friend of Sir Joseph Banks. In fact it was at his breakfast table that the news came that the mother of Linnæus had recently died, and that his collections were offered for sale. Smith, who was a man of considerable means, purchased the collections for a thousand guineas, and although the Swedish Government are said to have sent a man-of-war to retrieve them whilst they were yet at sea, they eluded the pursuit—if there was a pursuit—and were landed in England and arranged as speedily as possible by Smith, with the aid of Sir Joseph Banks and his librarian Dryander. This episode decided Smith to abandon the study of medicine and take up that of botany, and to him the foundation of the Linnæan Society is due. He was the author of many books, and in 1790 he collaborated with Sowerby in the production of Sowerby's "English Botany," which extended over thirty-six volumes, and in which he was responsible for practically all the letter-press. Another notable work of his, published in 1807, was an "Introduction to Physiological and Systematic Botany," and the last seven years of his life he devoted to the "English Flora."

We now turn to a class of men of science in which England has always been pre-eminent—the scientific explorer and collector.

One of the earliest of these, Sir Hans Sloane (1660–1753), started life as a doctor, having studied medicine at Paris and Montpellier. He was well acquainted with the leading men of science of his period, and for a time lived with Thomas Sydenham. His great opportunity came in 1687, when he accompanied, as physician, the Duke of Albemarle, Governor of Jamaica, to the West Indies. Owing to the death of the Duke, his stay in the islands was curtailed, but he came back in 1689 with 800 species of plants and settled down to medical practice. He became Secretary to the Royal Society in 1693, and, while he was busily at work on his collections, found time to contribute a number of papers to the Philosophical Transactions.

On the death of Sir Isaac Newton he followed him as President of the Royal Society, and occupied the chair for twenty-eight years, until 1740. Perhaps his greatest contribution to botany was in connexion with the Physic Garden of Chelsea. He had purchased the manor of that village in 1712, and on retiring from practice settled on his estate. This included the site of a " Physic " garden established, in 1673, by the Apothecaries' Society, and Sloane handed, in 1722, the fee simple of the property to that body, subject to certain conditions. His name is commemorated on the Cadogan Estate in the West End of London by Sloane Square and Hans Place.

A second explorer, " the greatest Englishman of his time," traveller and prominent collector, was Sir Joseph Banks (1743–1820), who was educated both at Harrow and Eton. At school he was so immoderately fond of play that his masters found great difficulty in fixing his attention on his studies, but at the age of fourteen, impressed by the beauties of flowers in the country lanes, he decided to study botany, and probably his real education was largely due to the women who were then, as they are now, collecting " simples " for druggists' shops. At Oxford, where he found no lectures were being delivered on his favourite subject, he obtained permission to procure a teacher to be paid by the students, and coming over to Cambridge he brought back with him to his own university Israel Lyons, the astronomer and botanist. I wonder if any student has ever attempted such an enterprise since !

Banks was a wealthy man and was able to indulge his passion for travelling. His first journey was to Newfoundland, and after his return, *viâ* Lisbon, he came across Dr. Daniel Solander, the faithful pupil of Linnæus, who subsequently accompanied him in his voyage round the world, for Banks left England in August 1768 on Captain Cook's *Endeavour*. The scientific part of the expedition was financed by Banks, and he was accompanied not only by Dr. Solander but by two artists and two attendants. It would take too much space to dwell upon that remarkable voyage, Banks was collecting not only plants, but animals, and noted, as an ancient writer said, "ye beastlie devices of ye heathen." At a spot they christened Botany Bay, owing to the wealth of plant life in the district, kangaroos were observed for the first time.

The *Endeavour* returned in the spring of 1771, and Banks very shortly afterwards made arrangements (which ultimately fell through) to accompany Captain Cook on a second voyage in the *Resolution*. Being disappointed over this expedition, Banks visited Iceland with his scientific staff and Dr. Solander. This was the last of his travels.

He became President of the Royal Society in 1778, and held that distinguished office until his death. For a time his reign was a troubled one. The secretaries had assumed, as secretaries often do, a power which belonged to others, and Banks was determined to put this right. The dissensions that followed led to a secession of several members, but the majority remained and harmony was once more restored.

The contributions that Banks made to science by personal investigation were comparatively few, but he was a great patron of Natural History, and although he wrote little, he was the cause of much writing by others. He made his collections accessible to men of science, and his house in Soho Square was a rallying spot for those interested in Natural History. His library was one of the finest then existing, the catalogue of it by Dryander exists in five volumes. The library is still kept in a room by itself in the British Museum. Although apparently a bit of an autocrat, he was a generous and far-seeing man, and those who knew him best undoubtedly loved him most.

The Linnæan system was destined to disappear, and during the first decades of the nineteenth century it was being gradually replaced by a more natural and scientific scheme of classification. In this, England practically led the way, and, indeed, Professor Green tells us that with Robert Brown began "a long line of taxonomists of the greatest brilliance, who not only outshone all their predecessors, but carried the nation's prestige in botany to a pitch that had not been reached even under the influence of Ray."

Brilliant and stimulating as were the speculations of the French School from De Jussieu to De Candolle, the

English were at least their levels in the study of the herbarium. Where they outshone all other nations was in their world-wide explorations, their vast collections of extra-European plants, which laid the foundation of the science of geographic botany and afforded the material which was destined to form the basis of the speculations as to the "Origin of Species" which were so prominent a feature in the latter part of the nineteenth century.

Robert Brown (1773–1858), one of the most brilliant men of science Europe has produced, was the son of the Episcopalian minister in Montrose. He was educated partly at Aberdeen and partly at Edinburgh, where, for the first time, he showed the interest which never afterwards failed him in the science of botany. In 1795 he obtained a double commission as Ensign and Assistant Surgeon in the Fifeshire Regiment of Fencible Infantry, and proceeded to Ireland. In 1798, being sent to England on a recruiting service, he became the friend of Sir Joseph Banks, who was destined to help him in no common measure. It was owing, indeed, to Banks that he resigned his commission and started on his memorable voyage to Australia and Tasmania. He left Portsmouth in 1801 under the command of Captain Flinders, and was away about four years. The South Coast of Australia, the tropical part of the East Coast and part of the North were explored before Flinders was compelled to return to England by the bad state of his ship. The botanists, however, remained in Australia for another year and a half, and extended their investigations to Tasmania and other islands. Altogether about 4,000 species of plants were collected, and on his return to England in 1805 these great collections, added to those which Sir Joseph had brought back from Captain Cook's circumnavigation of the globe, and those due to other explorers, were now thoroughly worked out by Brown. As Asa Gray remarks:

> "It was the wonderful sagacity and insight which he evinced in these investigations which, soon after his return from Australia, revealed the master mind in botanical science, and ere long gave him the position of almost unchallenged eminence, which he retained without effort for more than a century."

The result of these researches was the work "Prodromus Floræ Novæ Hollandiæ et Insulæ Van Dieman," a work marked by singular accuracy of detail set forth in precise and clear language; it showed, moreover, a profound mastery of the principles of classification.

Another important publication of Brown was his monograph on the *Proteaceæ,* which contained one of his first great contributions to Histology, namely, that dealing with the structure of the seed. Brown was also the first to recognize the true nature of the seed in Gymnosperms. He paid much attention to the structure of the flower and the methods of pollination, especially in the Natural Orders *Orchideæ* and *Asclepiadeæ.* In fact, so important did his work appear to foreigners, that Humboldt dedicated his "Synopsis Plantarum Orbis novi" to him in the following words: "Roberto Brownio Britanniarium gloriæ atque ornamento." We have no space to follow further his tireless work on classification.

Brown, who had succeeded Dryander as librarian to Sir Joseph Banks in 1810, at the latter's death in 1820 succeeded to the use and enjoyment of his collections and library, together with the house in Soho Square, where for nearly sixty years he had pursued his investigations. More than once during his life he had been offered professorships, but he was essentially a researcher, and preferred the quiet of Soho Square, which has been so well described by Dickens in the "Tale of Two Cities." Indeed, the character of Dr. Manette might almost have been drawn from Brown, for, as a friend wrote of him, "I loved him for his truth, his simple modesty, and, above all, for his more than woman's tenderness. Of all the persons I have known, I have never known his equal in kindliness of nature."

Before passing on, one must not omit to mention that in his monograph on the *Orchideæ* Brown first announced the discovery of the nucleus in the vegetable cell. He is also the discoverer of the so-called Brownian movement—an irregular trembling motion of very small particles suspended in liquids—which becomes visible under the microscope, when high magnifying powers are applied. It is connected with the thermal motion of the molecules of the liquids, and has gained some importance in recent years.

Although Brown did much to undermine the Linnæan system, it was not by a frontal attack so much as by courteously and consistently ignoring it.

John Lindley (1799–1865) took more direct action. Lindley was born near Norwich, where he was educated. His father was a nurseryman, and throughout his life Lindley showed a particular interest in all horticultural matters. In 1819 he went to London, and shortly afterwards was appointed Garden Assistant Secretary to the Horticultural Society, and in 1830 Secretary to the Society. It was his efforts, combined with those of Bentham, which rescued the Society from financial disaster, and organised the very successful series of exhibitions of flowers and vegetables, the first "flower-shows" recorded in Great Britain.

In 1829 he was elected Professor of Botany at University College, London, and was the first occupant of that Chair. His lectures were singularly concise and clear, and attracted large classes. Throughout his life he was a constant advocate of a natural system of classification as opposed to the artificial one of Linnæus, and in 1829 he published a "Synopsis of the British Flora," which was one of the first attempts to arrange British plants on a basis of natural affinity. The following year, in an Introduction to the "Natural System of Botany," he put forward, tentatively, his natural classification. He helped Loudon to bring out his "Encyclopædia of Gardening," wrote much for the "Penny Encyclopædia," collaborated with Hutton in the "Fossil Flora of Great Britain," and with Sir Joseph Paxton in a work entitled "Paxton's Flower Garden," and in 1821 started the well-known "Gardener's Chronicle," which he edited for twenty-five years.

Although experts do not admit that Lindley achieved any permanent success in framing his classification, he was undoubtedly a great taxonomist. He was celebrated for the completeness of his descriptions of the several Natural Orders and valued for his clear discussions on their inter-relationships. He was an extremely hard worker, and took a large share in administrative work; towards the end of his life he acted for the Government in the preparation for the Great Exhibition of 1851, and undertook the entire charge of the Colonial Department in the following Exhibition of 1862. Lindley's only son is the present Lord Lindley.

Born in the same neighbourhood and educated at the same school a few years before Lindley, Sir William Jackson Hooker (1785–1865) was another example of a biologist who commenced his scientific life as a traveller. In 1809, on the advice of Sir Joseph Banks, he visited Iceland, but unfortunately lost his collections by the burning of the ship on the return voyage. He wished to accompany Sir Robert Brownrigg, the recently appointed Governor of Ceylon, but the disturbed state of the Island prevented his carrying out his intentions.

In 1820 he accepted the Professorship of Botany at Glasgow, where he was singularly successful as a teacher. In 1841 he was appointed Director of the Royal Gardens at Kew, and we shall have to consider later his work there. He had always been a great collector, and his herbarium, which was far the richest ever accumulated in his lifetime by any one man, was bought by the nation after his death. Though much engaged in official duties, he was, nevertheless, a great writer, and produced over one hundred memoirs and volumes on Economic and Systematic Botany. He was particularly happy in his relations with the officials in the Greater Britain beyond the seas, and inaugurated a series of Colonial floras, which have proved of great value. He was one of those men always anxious to help others, and he readily placed his knowledge and his collections at the disposal of younger men. So busy a life left little time for society, but Darwin records "his remarkably cordial, courteous, and frank bearing."

Another contemporary was George Bentham (1800–1884), a nephew of Jeremy Bentham. He was brought up abroad, and had a wide acquaintance with the flora of Southern France. In 1821 he returned to England, and at once made the acquaintance of the leading botanists of the time, and very soon took a prominent position himself as a systematic botanist. He contributed the "Flora of Hong Kong" and the "Flora Australiensis" to Sir William J. Hooker's

Colonial Floras. But his great work was the "Genera Plantarum," in the execution of which he was associated with Sir Joseph D. Hooker. One must not forget to mention his "Handbook of the British Flora," published in 1858. He was a man endowed with a gift of accuracy, discrimination and precision, and with infinite powers for hard work. He handled collections of plants from every quarter of the globe, and, as one of the most distinguished contemporaries remarked, he possessed "an insight, of so special a character as to be genius, into the relative value of characters for practical systematic work—a sure grading of essentials and non-essentials."

Bentham was an untiring worker, and it was characteristic of him that having finished, after a year's incessant work for the "Genera Plantarum," whose publication extended from 1862–1883, the *Orchidaceæ* on a certain Saturday afternoon, he bade the attendant at the Herbarium to bring down the material for commencing the much more difficult group of the Grasses. It is impossible here to enumerate the numerous papers and memoirs which Bentham published, and one can only sum him up by saying that he was one of the greatest systematic botanists who ever lived; his colleague, Hooker, said of him "There is scarcely a Natural Order that he did not more or less remodel."

A contemporary of Bentham and the younger son of Sir W. J. Hooker was Sir Joseph Dalton Hooker (1817–1911). The younger Hooker is another example so common in British biological science of men who approach their subjects through extensive travel. Inspired by his father he, as a boy, took an intense interest in botanical research, but, like all young men, he was eager to travel, to see the world. He qualified as a Doctor of Medicine at Glasgow, and was delighted when Sir James Clark Ross offered to take him as assistant surgeon and analyst on his ship the *Erebus* to the Antarctic. When the expedition returned in 1843, Hooker devoted himself to publishing the botanical results of the voyage. These filled six quarto volumes.

At about this date the intercourse between Darwin and the younger Hooker became closer, and there was a constant interchange of correspondence between the two contemporaries.

Hooker's researches, especially on the flora of the Galapagos, had convinced him that there was an evolution in space. On the one hand he found that the plants of neighbouring hills, though related, differed in detail; on the other hand, identical species were often found on hills separated by many thousand miles of ocean. Hooker was the first to whom Darwin confided his theories of natural selection, and he read for his friend the proofs of the first sketch of the "Origin of Species." In fact, Darwin wrote to him "for years I have looked on you as a man whose opinion I valued on any scientific subject more than anyone else in the world."

In 1845 J. D. Hooker was appointed Botanist to the Geological Survey, and for a time turned his attention to fossil botany. But his love of travel was not yet sated, and in 1847 he started to explore the Himalayas. He spent part of two years in exploring Sikkim, and for a time was imprisoned. He also explored part of Nepal, and visited territory which has not even yet been re-investigated. He penetrated some way into Tibet, and one afternoon at his house in Sunningdale he received a telegram from the Lhassa Expedition of 1903, stating that they had got as far as he had previously penetrated, and congratulating him upon the usefulness of his survey. Having explored Eastern Bengal and the Khasia Hills, he returned to England in 1851, and in 1855 he was appointed Assistant Director to his father at Kew, and ten years later succeeded his father as Director.

On his return form India, he immediately commenced, in conjunction with Thomas, the first volume of the "Flora Indica," which, however, also proved to be the last, as it was planned on too ambitious a scale. In 1860 he visited and examined considerable areas of Syria, and about this time he was contemplating his celebrated "Genera Plantarum." But the call of the world still held him, and in 1871 this indefatigable traveller, accompanied by John Ball and Maw, made an expedition into Morocco. They were the first Europeans to ascend the Tagherot Pass, nearly twelve thousand feet high.

In 1873 Hooker became President of the Royal Society, and he made a real effort to bring that Institution into closer touch with the social life of the community. He was successful in raising the sum of £10,000 to aid the somewhat exiguous resources of the Society. In 1877 he obtained leave of absence to visit the Rocky Mountains of Colorado and Utah, and added much to our knowledge of the fossil flora of those districts, and later he returned to his first love and made a determined effort to complete his "Flora of British India," which was accomplished in seven volumes during the next fourteen years. In 1885 he retired from the Directorship of Kew, and was succeeded by Sir William Thiselton-Dyer, but he never ceased working.

Hooker was the recipient of numerous honours, including the O.M., which was personally presented to him at Sunningdale, to which village he had retired, on behalf of King Edward VII. on his ninetieth birthday.

Hooker stands out as the greatest authority the world has yet produced on the subject of the Distribution of Plants; although he did much other work, this alone confers on him immortality.

Hooker was capable of enduring great physical fatigue, capable of working continuously with very short intervals of sleep. Somewhat highly strung he disliked public functions, though when forced to do so he could make an eloquent and stirring speech. He was extremely kind and courteous, and always ready to help the younger men. He retained his faculties to the last, and continued to work to the end of his long, laborious, and successful life.

We have seen that most of the progress of the physiology of plants was due to British workers; but naturally in the last quarter of the eighteenth century Great Britain had to some extent remained isolated from the science of the continent, and the currents of botanical thought flowed at somewhat different angles on the two sides of the Channel. We shall see later how Huxley inaugurated a new departure in the teaching of biology, and with him came the laboratory. Hitherto the botanists had been content with their botanic gardens, their herbaria, and with a few roughly devised physiological instruments. With "the coming of the laboratory," however, things altered. Huxley had round him an ardent body of young workers. His first demonstrators were Michael Foster, Ray Lankester, and Rutherford, and later Newall Martin (who collaborated with his chief in the production of the "Elementary Biology"), Thiselton-Dyer, and Vines. The coming of the laboratory was slower at the Universities, but with the arrival of Foster at Cambridge, and the return for a time of the old Cambridge men, Martin and Vines, laboratory instruction became part of the normal course.

The modern study of Cryptogamic Botany in England may almost be said to begin with the works of Miles Joseph Berkeley (1803–1889). Like so many English botanists he was in Holy Orders. Coming from Oundle and Rugby to Christ's College, Cambridge, he came under the influence of Henslow, and took his degree in 1825. At first he worked on the Algæ, but in 1836 he published, in connexion with Smith's "English Flora" the section which dealt with the fungi, and this was the earliest of his many contributions on this group. He was the first to throw light upon the fungoid organism *Phytophthera infestans*, which caused the potato disease connected with the appalling famine in Ireland in 1846.

Between 1844 and 1856 his "Decades of Fungi" were published and were amongst the most conspicuous of contemporary publications on this subject. Berkeley paid particular attention to the diseases of plants, and contributed a series of articles to Lindley's newly-established "Gardener's Chronicle." For many years he was the authority at Kew on Cryptogamic Botany. He described the fungi collected by his fellow-collegian, Darwin, on the *Beagle*, and his classical knowledge was of great use to Bentham and Hooker in their "Genera Plantarum." His large collections of algæ were left to Cambridge, whilst his fungi went to Kew.

During his lifetime he was easily leader in the taxonomy of the subject, and he may almost be said to have started a new line of research. His most distinguished successor was Marshall Ward, who will be dealt with more fully under the Cambridge School.

The great majority of the earlier botanists hitherto mentioned lived and worked in London, but a small minority carried on their researches in country houses or, more often, in country parsonages. But there are other centres of activity in England, though none of them, till the re-awakening of science at the end of the nineteenth century, produced men of very outstanding talent.

We have seen that Morison was the first Professor of Botany at Oxford—he was appointed Professor in 1669—although when he was appointed the Botanic Garden at Oxford had already been in being for thirty-seven years. His successors, however, were people of comparatively little importance; the Professorship was always very inadequately endowed. In 1728 William Sherard (1659–1728), who was more of a patron of science than a man of science, left by will a sum to re-endow the Professorship, which was now named after him, and this was at first occupied by the German Dillenius (1687–1747), who was undoubtedly one of the great botanists in Great Britain during the eighteenth century; but his work, though painstaking and laborious, showed little originality and insight. His knowledge, however, was great, and was recognized by his contemporaries at the time. Perhaps his greatest work was the "Historia Muscorum," which appeared in 1741. As Professor Green says, "it is a work of colossal labour, but it is impossible to avoid a certain feeling of disappointment with the "Historia," not that it was not good but that it might have been so much better." Dillenius was, however, conservative in his thought, and a man without a great faculty for new enterprise. After his death, botany again fell under a cloud at Oxford, and for a time at any rate Cambridge took the lead.

One must, however, mention Sibthorp (1758–1796), who, always impressed with the relation of his science to agriculture, founded the Professorship of Rural Economy which now bears his name.

In 1834 the School of Botany at Oxford woke up. Professor Charles Giles Daubeny (1795–1867) of Magdalen College was, as men of science were in those days, very versatile, he was almost equally distinguished as a geologist, a chemist, and a botanist. And again, after the manner of those times, he did not hesitate to hold contemporaneously three professorships. For in 1822 he became Professor of Chemistry, and only resigned it in 1855, and in 1834 Sherardian Professor of Botany, and in 1840 Sibthorpian Professor of Rural Economy. It is not our intention in this volume to deal with agriculture, but one might at least indicate that he was one of the earliest to throw light on the principles involved in the rotation of crops, to investigate the constituents of plant ashes, to show the difference between " the total amount of the salts contained in the soil and the amount available for use by the plant," and above all he had a keen appreciation of the part that the fungi play in diseases of plants.

Daubeny remodelled the beautiful Botanic Gardens at Oxford and founded the Botanic Museum. He was a keen supporter of Darwin's views of Natural Selection, and spoke strongly in their favour at the meeting of the British Association in 1860.

If we now turn to Cambridge we again find no name of absolutely outstanding merit until the revival of science at the end of the nineteenth century.

A few words should, however, be said about the second Martyn, who succeeded his father to the Professorship in the year 1761. Thomas Martyn (1735–1825) was a parson, and in 1762 he was elected to succeed his father to the Chair of Botany, which he held for the astonishing period of sixty-three years. He was, however, as professors were apt to be in those times, largely non-resident, and he ceased lecturing altogether in 1796. But for many years before that date he had been out of residence, and only returned from time to time to what was obviously an uninterested audience.

Henslow (1796–1861), who succeeded Martyn, was a different kind of man, and did much to encourage the advance of science in many directions. For a time he held the Chair of Mineralogy, having been appointed at the age of twenty-six, together with the Chair of Botany, but he devoted most of his energy to the latter subject, and his lectures attracted large audiences. He used many illustrations, and for the first time introduced what was later destined to develop into practical laboratory work. He reorganized the Botanic Garden, and during his time it was moved to its present site, and for the first time organized systematic excursions in the neighbouring country. His success in interesting Suffolk farmers in his parish in the application of Botany to Agriculture was notable. He is renowned not for any strikingly remarkable original contributions to science, but for taking a leading part in reorganizing the scientific spirit of Cambridge.

The only other botanist of eminence connected with Cambridge was Professor Marshall Ward (1854–1906). He was, in a way, a successor of Berkeley, and although he always was very nervous of the encroachment of what is known as "technical research" on the purer kind, his own researches were without exception of practical utilitarian value. Ward, like Berkeley, was educated at Christ's College, and afterwards studied in Germany. For a time he was teaching at Owens College, Manchester, and later he was Professor of Botany in the Forestry Department of the Royal Engineering College at Cooper's Hill; he was appointed Professor at Cambridge in the year 1895. One of his earliest researches involved a visit to Ceylon, where he investigated the life-history of the fungus that attacks the leaves of the coffee plant, which in fact destroyed the coffee trade of that island. He worked out the life-history of this pathogenic fungus, and was largely instrumental in inducing the planters to take up the planting of tea.

Throughout his life Ward was largely occupied with the study of bacteria and fungi, to which he contributed much of first-rate importance. During his professorship the present School of Botany was erected and equipped, and at the time of its erection it was, and still is, second to none in Great Britain in size and completeness of equipment.

The history of Botany in Scotland and in Ireland shows, as at first was the case in Cambridge and Oxford, no particularly outstanding names. The University Chair in Edinburgh was founded in 1695, and was first filled by James Sutherland (1639–1719), who, in 1667, had succeeded in establishing and stocking a small botanic garden. At Glasgow, from the year 1719, Botany no longer had a distinct professor, the subject being taught by the Professor of Anatomy, a separate Chair reappearing only in the year 1818. The first occupant of this double chair was Thomas Brisbane, a man who entertained so strong a dislike to dissection, that it is believed he never taught anatomy at all. It cannot be said that his teaching in botany in any way compensated for this silence in anatomy. The curious conjunction of the two professorships did not produce anyone of any particular eminence in botanic science. R. K. Greville (1794–1866), who held no official post, was, however, establishing a great reputation for his knowledge of cryptogamic botany, in which subject he is said to have done more than any botanist of his times.

Hooker, whose work is mentioned elsewhere, succeeded Graham as Professor of Botany at Glasgow, and for a time the chief activity in this science was in the western rather than the eastern university.

On Graham's succeeding to the Chair in Edinburgh, Botany again revived, for he was an able lecturer, a man of great activity, and he organized botanical excursions for his pupils.

He was succeeded by J. H. Balfour (1808–1884), a brilliant teacher and a most genial man, called by his pupils "woody fibre." He was known best, perhaps, as a teacher than as an investigator, and, as was usual during the times in which he lived, his researches were largely of a systematic kind. He was the first, however, to introduce the use of the microscope into the Class-room.

The Irish records of botanical research are at least as scanty as those of Scotland. The first authentic authority on plants was Caleb Threlkeld (1676–1728), but his book, under the ambitious title of "Synopsis Stirpium Hibernicarum," was little more than a herbal.

A lectureship was established at Trinity College in 1711 and associated with it was a small Physic Garden. In 1786 the lecturer, who was at that time Edward Hill, was raised to the status of a professor. His chief work seems to have laid in the botanic garden and in starting the herbarium. Amongst his successors perhaps Professor William Allman should be mentioned. He was succeeded by a succession of able men, but none of them pre-eminently able.

This brief survey of the history of British Botany shows that there is ever a steady current of research and investigation going on in these islands and with here and there a temporary lull, men of world-wide importance were constantly emerging from the high level of their contemporaries. Hales, no doubt, laid the foundation of scientific plant physiology, even Sachs has said that his " Vegetable Staticks " " was the first comprehensive work the world had seen which was devoted to the nutrition of plants and the movement of their sap . . . Hales had the art of making plants reveal themselves. By experiments planned and cunningly carried out he forced them to betray the energies hidden in their apparently inactive bodies." Grew was one of the earliest and greatest investigators of plant anatomy, and, as we have said above may be regarded as joint founder with Malpighi of the science of vegetable anatomy. Robert Brown was regarded by his contemporaries as the first botanist of his age, and he it was who for the first time took into account the development of plants as well as the structure of the mature and adult forms. He and John Lindley did much to establish a natural system based on the widest investigation possible in their times. Sir Joseph Hooker may almost be said to be the inventor of phyto-geography. Professor Bower writes of him :—" and so we have followed . . . this great man into the various lines of scientific activity which he pursued. We have seen him excel in them all. The cumulative result is that he is universally held to have been, during several decades, the most distinguished botanist of this time. He was before all things a philosopher. In him we see the foremost student of the broader aspects of plant-life at the time when evolutionary belief was nascent."

In the Stewarts' time, as we have seen, British science led the world, and ever since our men of science have held their own in comparison with the men of science of the nations which can boast of an old civilization and far surpassed, both in amount and in originality, that of nations whose civilization only dates back to a few hundred years.

CHAPTER X

ZOOLOGY

IN 1544 William Turner, the leading naturalist of his time, published his "Avium Praecipuarum quarum apud Plinium et Aristotelem mentio est, brevis et succincta historia," dedicated to Edward Prince of Wales, afterwards Edward VI. Turner had been educated at Pembroke College, Cambridge, where he knew Latimer and learned Greek from Ridley. He travelled much abroad, and became an M.D. of Ferrara and subsequently of Oxford. Later in life he was ordained, and in 1550 he was appointed Dean of Wells, a post he was compelled to quit on the accession of Queen Mary. His business in life was theological controversy and he wrote many polemical works, but his pleasure was in natural history. He contributed a letter on British fishes to his friend Conrad Gesner, with whom he had worked at Zurich, and with whom he constantly corresponded. As an example of the zoology available in the Great Eliza's times, we may quote Turner's description of the grouse.

"*Of the Lagopus,*" *from Pliny.*

> "The Lagopus is in flavour excellent, its feet shaggy as in a hare have given it this name. Otherwise, it is white, in size as the Columbi; it is not eaten except in the land of which it is a native, since it is not tameable while living, and when killed its flesh soon putrefies. There is another bird of the same name, differing but in size from the Coturnices, most excellent for food with yellow saffron sauce. Of this Martial makes mention in the following verse :—
>
> "If my Flaccus delights in the eared Lagopodes."

Although this may seem to indicate that Turner was a mere translator and compiler, this is not the case. As Mr. A. H. Evans tells us:

> "While attempting to determine the principal kinds of birds named by Aristotle and Pliny, he has added notes from his own experience on some species which had come under his observation, and in so doing he has produced the first book on Birds which treats them in anything like a modern scientific spirit . . . nor is it too much to say that almost every page bears witness to a personal knowledge of the subject, which would be distinctly creditable even to a modern ornithologist."

A contemporary of Turner's, Edward Wotton (1492–1555), born at Oxford and elected a Fellow of Magdalen, travelled for several years in Italy. He took his M.D. at Padua, and later held high office in the College of Physicians, and has been described as "the first English Physician who made a systematic study of natural history." His book, "De Differentiis Animalium," published two years before Turner's *Historia* and dedicated to the same patron, acquired a European reputation. The copy of this book, a fine folio, in the British Museum, is said to be "probably unsurpassed in typographical excellence by any contemporary work." "De Differentiis Animalium" was deservedly praised by contemporary writers for its learning and for the elegance of its language.

Dr. Caius (1510–1573), in his terse style, wrote "De Canibus Britannicis libellus," 1570, and this was "drawne into Englishe" under the name "Of Englishe Dogges," by Abraham Fleming in 1576, and published in London. Caius wrote his little book as a contribution to Conrad Gesner's "History of Animals," but owing to Gesner's death it was not incorporated in that work. For, from the sixth year of Henry the Eighth until the death of Queen Elizabeth, all the learned men of Europe who were interested in Nature turned to Gesner, the incomparable naturalist of Zurich (1516–1565), amongst whose many works of great importance the stupendous "Historia Animalium" is perhaps the most remarkable.

In the year 1607, Edward Topsell, a member of Christ's

College and, in the matter of livings, somewhat of a pluralist, published, under the title "The Historie of Foure-Footed Beastes," an abstract of Gesner, and in the next year followed it up with "The Historie of Serpents," both illustrated with charmingly quaint, if inaccurate, woodcuts. Topsell had, what the modern zoologist must have (but the possession in his time was less common), a sound knowledge of German, and to this knowledge his books owe much. These works give us a fair idea of what the educated in those days knew of zoology in all its aspects, and that these aspects covered a far wider area than, with the present expansion of knowledge, we can now contemplate under this single science, is shown by the title-page to Topsell's magnificent quarto volume:

> "The History of Foure-Footed Beastes. Describing the true and lively figure of every Beast, with a discourse of their severall Names, Conditions, Kindes, Vertues (both naturall and medicinall), Countries of their breed, their love and hate to Mankinde, and the wonderful worke of God in their Creation, Preservation, and Destruction. Necessary for all Divines and Students, because the story of every Beast is amplified with Narrations out of Scriptures, Fathers, Phylosophers, Physitians, and Poets: wherein are declared divers Hyerogliphicks, Emblems, Epigrams, and other good Histories, collected out of all the Volumes of Conradus Gesner, and all other Writers to this present day. By Edward Topsell. London, Printed by William Jaggard, 1607."

Falconry also played a part in the Zoology of the later Tudor times. During the reign of Queen Elizabeth this sport was "much esteemed and exercised." People of all classes eagerly took part in it. To quote Mr. Harting:

> "The rank of the owner was indicated by the species of bird which he carried. To a king belonged the gerfalcon; to a prince, the falcon gentle; to an earl, the peregrine; to a lady, the merlin; to a young squire, the hobby; while a yeoman carried a goshawk; a priest, a sparrowhawk; and a knave, or servant, a kestrel."

The sport was, however, expensive, for it took much time and devotion to train the birds. The falcon, in those times, as the flying machine is in ours, was in the air, and just as one now hears our undergraduates discussing carburetters, air-locks, sparking-plugs, and various vintages of petrol, so in the times of Queen Elizabeth, the keen young men of Shakepeare's Plays discussed the various kinds of hawks and their habits.

In our last chapter we have sketched the contributions which Ray had made to the science of Botany ; but he has further claims on our regard. He and Francis Willughby, both of Trinity College, Cambridge, attacked similar problems in the animal kingdom. Willughby was the only son of wealthy and titled parents, while Ray was the son of a village blacksmith. But the older universities are great levellers, and Ray succeeded in infusing into his fellow student at Cambridge his own genuine love for natural history. With Willughby, he started forth on his methodical investigations of animals and plants in all the accessible parts of the world. Willughby died young and bequeathed a small benefaction and his manuscripts to his older friend. After his death, Ray undertook to revise and complete his "Ornithology," and therein paid great attention to the internal anatomy, to the habits and to the eggs of most of the birds he described. Further, he edited Willughby's "History of Fishes," but perpetuated the mistake of his predecessors in retaining whales in that group. In rather rationalistic mood, he argues that the fish which swallowed Jonah must have been a shark. Perhaps the weakest of their three great histories—"The History of Insects"—was such owing to the fact that Ray edited it in his old age. The Ray Society for the publication of works on Natural Science was founded in his honour in 1842.

Robert Hooke, a Westminster boy and, later, a student at Christ Church, was at once instructor and assistant to Boyle. The year that the Royal Society received their charter, they appointed Hooke curator, and his duty was "to furnish the Society" every day they met with three or four considerable experiments. This formidable task he fulfilled in spite of the fact that "the fabrication of instruments for experiments was not commonly known to workmen," and that he never received "above £50 a year and that not certain." Hooke was a man of amazing versatility, very self-confident, attacking problems in all branches of science, greatly aiding their advance, but avid of fame.

> "In person but despicable, being crooked and low in stature, and as he grew older more and more deformed. He was always very pale and lean and latterly nothing but skin and bone."

His book "Micrographia" is the record of what a modern schoolboy newly introduced to the microscope would write down. Yet he was undoubtedly, although not a lovable character, the best "mechanic of his age."[1] (*See also* p. 55.)

John Tradescant (?—— ?1637) is by some believed to have been a Dutchman, but his name is an English name, and he seems from an early age to have owned land in Essex, a most English county. One of his earliest works was entitled: "A voiag of ambasad ondertaken by the Right honourabl Sr Dudlie Digges in the year 1618," which is a narrative of a voyage round the North Cape to Archangel, where they arrived at the neighbouring monastery of St. Nicholas on the 16th July 1618, when Tradescant immediately began botanizing, collecting, and ultimately sending a number of northern plants to various friends abroad and making notes upon some twenty-four wild species. This was the first account published of the plants of Russia. In 1620 he voyaged south instead of north, having joined the expedition of Mansell and Sir Samuel Argall against the Corsairs of Algiers, and amongst other rarities brought back by him was the Algerian apricot. In 1625 he was in the service of the Duke of Buckingham, and writes to an agent in Virginia that it was the Duke's wish that he should "deal with all merchants from all places, but especially from Virginia, Bermudas, Newfoundland, Guinea, Binney, the Amazon, and the East Indies, for all manner of rare beasts, fowls, and birds, shells, furs, and stones." On the death of the Duke, Tradescant became gardener to the King and Queen, and it is suggested that it was about this time that he established his physic garden and museum at South Lambeth. The physic garden was one of the first established in our kingdom, and Pulteney recalls that Tradescant was the first who brought together any considerable collection of subjects of natural history. His name is immortalised in the genus *Tradescantia*, a spider-wort which he had introduced from Virginia. Parkinson, in his "Paradisus terrestris," speaks of the elder Tradescant as "a painful industrial searcher and lover of all nature's varieties," and having "wonderfully laboured to obtain all the rarest fruits he can hear of in any place of Christendom, Turkey, yea, or the whole world."

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[1] Waller's "Life of Hooke," 1705.

His only child, John Tradescant (1608–1662), was born at Meopham, Kent, and apparently succeeded his father as gardener to Queen Henrietta Maria. In 1637, the younger Tradescant was in Virginia gathering all varieties of ferns, plants, and shells for the museum at Lambeth, and in 1656 he published his "Museum Tradescantianum: or collection of rareties preserved in South Lambeth, near London." In this task he was assisted by his friend Ashmole, and the book, which runs into 179 pages, contains lists of birds, mammals, fish, shells, insects, minerals, war instruments, utensils, coins, and medals. It is interesting to note that he had a complete "dodar" from the island of Mauritius. This was the celebrated stuffed dodo of which the head and foot are still preserved at Oxford. The complete body had been studied by Willughby and Ray. On the 12th December 1659, Ashmole notes in his diary that "Mr. Tradescant and his wife told me they had been long considering upon whom to bestow their Closet of Curiosities when they died, and at last had resolved to give it unto me." Ashmole had built himself a large brick house near Lambeth adjoining that which had been Tradescant's, and shortly after its completion removed the collection to his new house, and in 1677 he announced his intention of giving his collection to the University of Oxford, on condition that a suitable building be built to receive it. This was erected from the design of Sir Christopher Wren, and the collections were transferred to Oxford in 1683, when the name of Tradescant was rather unjustly sunk in that of Ashmole.

There was a lull in Zoological Science during the eighteenth century in our islands, and only the names of one or two outstanding zoologists appear. That of Thomas

Pennant (1726–1798) must not, however, be forgotten. In his boyhood he received a copy of Francis Willughby's "Ornithology," and to that he attributed his interest in natural history. He was for a time an undergraduate at Queen's College, Oxford, but did not proceed to a degree. Shortly after leaving Oxford he travelled through Cornwall and studied the minerals and fossils of the county, and in 1754 he travelled in Ireland, but here he kept a very imperfect diary, "such," he adds, "was the conviviality of the country." In 1765 we find him visiting France and staying with Buffon. He also visited Voltaire at Ferney, whom he found "very entertaining and a master of English oaths"; on his return journey at the Hague he met the celebrated Pallas. The first part of his "British Zoology" appeared in 1766, and his "Synopsis of Quadrupeds" five years later.

At various times in his life, Pennant thoroughly explored much of the British Islands, and made copious notes on the fauna, especially on the birds of the coast. In 1781 he published "A History of Quadrupeds," which was a new and enlarged edition of his "Synopsis," and three years later his "Arctic Zoology" appeared. Arctic exploration has always fascinated our British naturalists.

Pennant certainly occupies a leading position amongst the zoologists of the eighteenth century, and although he did not reach such a high standard as Buffon, he was a really learned man, and he had an undoubted faculty for making dry and obscure things readable and plain.

Although, as we have said above, British zoology suffered under a lull during the eighteenth century, the two Hunters, William and John, helped with Pennant to keep the sacred flame alight.

William Hunter (1718–1783) was born in Lanarkshire and educated at Glasgow University. He first came to London as dissector to Dr. James Douglas, whose son he tutored, and with him he travelled on the Continent. Later, he was remarkably successful as a lecturer, being eloquent, competent, and capable of illustrating his discourses with practical dissections. His success as an obstetric surgeon was great, and he was appointed Physician Extraordinary to Queen Charlotte in 1764.

During his comparatively long life he had accumulated a notable collection of anatomical and pathological specimens, and in 1765 he proposed to build a museum to house them, and to spend several thousands of pounds on the building, in addition to which he was prepared to endow a professorship. The offer which he had made to the Government, however, fell through, and subsequently he undertook, at his own expense, to carry out the project without Government aid, and he built his well-known institution in Great Windmill Street. By 1783 he reckoned that his collections had cost him over £20,000.

Unfortunately he and his brother John quarrelled, or at least differed, the cause being that William claimed the credit of more than one discovery which John seems to have made. His collections, which by the time of his death included minerals, shells, corals, coins, rare manuscripts and books, together with his great obstetrical collection, were ultimately left to the University of Glasgow. William Hunter's claim to a place in these pages is that he was both a great collector, a great investigator, and a great teacher.

His younger brother, John Hunter (1728–1793), came to London in 1748 to assist William, and soon showed a real genius for anatomy. He became a " Master of Anatomy " of the Surgeons' Corporation and a pupil at St. George's Hospital, where for a time he was house surgeon. Also he resided for some terms at Oxford, where, he says, " they wanted to make an old woman of me, or that I should stuff Latin and Greek at the University, but," he added significantly, pressing his thumb on the table, " these schemes I cracked like so many vermin as they came before me."

John was more of an investigator than William, but a far less able teacher. He traced the descent of the testis in the fœtus, as Aristotle is said to have done before him, he investigated the placental nerves, studied the nature of pus, investigated the absorbing power of veins, and in conjunction with his brother endeavoured to determine the course and function of the lymphatics.

After abandoning his partnership with William he served abroad with the British Army in Portugal and elsewhere, and became a great authority on gun-shot wounds. On returning to London in 1763, he began to practise as a surgeon in Golden Square, and here he first started on his famous collections. The menagerie at the Tower and other private zoological gardens served him with material, and he spared neither time nor money to add to his museum. In 1764 he built himself a house at Earl's Court, Kensington, which was properly fitted for macerating, injecting, and dissecting the bodies of animals, and was also provided with cages for keeping them alive. His sympathy was in no way confined to the vertebrates, for he had ponds in which he tried artificially to produce pearls in oysters, and he was very fond of bees, though in truth his real passion was for the fiercer kind of carnivora.

John Hunter helped a number of men who have left their mark in the medical profession. Perhaps the most distinguished of these was Edward Jenner, but Astley Cooper, John Abernethy, Henry Cline, James McCartney were also of the company. In 1783 he built a large museum, with lecture-rooms, in Leicester Square, and about this time he made his well-known discovery on the collateral circulation by anastomosing branches of blood-vessels.

In character he seems to have been impatient and rather rough, incapable of readily expounding the information that he had acquired—information that was mostly from direct observation, for he read but little. He was a strong Tory, and it is stated that he would rather have seen his museum burning than show it to a democrat. Hunter stood at the head of British surgery, but he was more than a surgeon, he was an all-round anatomist, with wide and scientific views as to what life meant. His claim to appear in these pages is that he was also a great comparative anatomist, though his zoology was always secondary to his surgery. By his will his museum was offered to the British Government on reasonable terms, and in case they refused it was to be sold to some foreign State or put up to auction. National finance in 1793 was, however, at a low ebb, and Mr. Pitt showed no eagerness to complete the purchase. Six years later the Government recommended the collection should be bought for £15,000, knowing well that it was worth a great deal more. However, the purchase was completed and the collection was offered to the Royal College of Physicians. On their refusal to accept it, it was offered to and accepted by the Corporation of Surgeons, which next year became the Royal College of Surgeons, and from 1806 the Hunterian Collection has been housed in Lincoln's Inn Fields. At the present time this original nucleus of the College museum comprises one-fifth of the specimens therein exhibited.

The most dominant zoologist in the first half of the nineteenth century was Sir Richard Owen (1804–1892), who was born at Lancaster and was educated at the grammar school of that town with William Whewell, the author of the "History of the Inductive Sciences." When he was sixteen he was apprenticed to a surgeon, and here his love of anatomy at once found scope. Later he matriculated at Edinburgh, and attended the extra-mural course of lectures on anatomy given by Dr. John Barclay, who, as Owen himself testified, has an "extensive knowledge of vertebrate anatomy." In the spring of 1835 he joined St. Bartholomew's Hospital, London, having passed the examination of the Royal College of Surgeons, and later set up in private practice near Lincoln's Inn Fields. He became lecturer on Comparative Anatomy at his hospital in 1827, and after a short interval he was appointed Assistant Conservator of the Hunterian Museum of the Royal College of Surgeons. The Conservator was then William Clift, who had done so much to preserve Hunter's Museum in the long interval between his death and its transference to the Royal College of Surgeons. In 1831 Cuvier invited Owen to Paris, where he attended Cuvier's and Geoffroy St. Hilaire's lectures in the Jardin des Plantes.

Owen was well known as a writer of monographs on many rare animals, and the first of these was his memoir on the "Pearly Nautilus," which placed him, as Huxley says, "in the front rank of anatomical monographers." In the early forties, he succeeded Clift, whose daughter he had married, as Conservator to the Royal College of Surgeons. But before this, in 1836, he had been made the first Hunterian Professor of Comparative Anatomy at the College, which involved the annual delivery of twenty-four lectures, and these he continued to give for a period of twenty years.

Owing to the influence of the Prince Consort, the British Court was, in Owen's time, more interested in science than it has been since his death, and Owen became of considerable influence in court and in society circles. In 1845 he was elected a member of that exclusive body "The Club," founded by Dr. Johnson. In 1852 the Queen gave him the cottage called Sheen Lodge, in Richmond Park, where he lived for forty years.

There seems little doubt that in the middle of the last century Owen was recognized throughout the world as the first anatomist of his day; but his position at the College of Surgeons was at this time becoming difficult. Friction arose between him and the Governing Body, and in 1856 he readily accepted the offer made to him by the Trustees of the British Museum to undertake the newly created post of Superintendent of the Natural History Department in the Museum. This post he held until 1884. He added greatly to our knowledge of animal structure by his successful dissection of many rare forms, such as the Pearly Nautilus, *Limulus*, *Lingula*, *Apteryx*, and others, and, following on the lines of Cuvier, he was particularly successful in reconstructing extinct vertebrates. Another considerable advance he made in science was his introduction of the terms "homologous" and "analogous."

The accommodation afforded by the Museum at Bloomsbury for Natural History specimens was totally inadequate, and as early as 1859 Owen submitted a report to the Trustees setting forth his views as to the proper housing of the National collections. After the usual delays attendant upon all Government action, land was purchased at South Kensington, on which ten years later the present buildings rose. They were opened to the public in 1881. Owen failed, however, to achieve many of his desires. A lecture theatre, such as exists in the Metropolitan Museum of Natural History in New York, is even now still lacking, and, he adds, "no collection of zoological specimens can be regarded as complete without a gallery of physical ethnology." This also is still wanting. A third of his wishes, a gallery of

Cetacean skeletons, was only achieved under his successor, Sir William Flower. The fact was, as Sir William pointed out, that the division of the Museum into four departments, each with its own head, left Owen practically powerless. Increased age added to the difficulties, and in 1883 he resigned his post and spent the remaining nine years of his life in retirement in his beautiful cottage at Sheen Lodge.

Owen was widely read, fond of music and the drama, and a man of striking personality. But, owing to his faculty for acrimonious controversy, he was rather an isolated zoologist, standing alone and going his own way. His power of work was prodigious: not only did he publish innumerable papers in all the scientific journals, but a large number of books, the titles of which are set forth in the "Dictionary of National Biography."

On the same day, the 12th February 1809, upon which Abraham Lincoln first saw the light, was born, at the "Mount," Shrewsbury, a little child destined as he grew up to alter our conceptions of organic life perhaps more profoundly than any other man has ever altered them, and this not only in the subjects he made his own, but in every department of human knowledge and thought.

As to the man, two estimates of his character may be quoted, one by a student who lived on terms of close intimacy with Darwin when at Christ's College, Cambridge, the other the considered judgment of one who knew and loved and fought for Darwin in later life.

Mr. Herbert says:

> "It would be idle for me to speak of his vast intellectual powers . . . but I cannot end this cursory and rambling sketch without testifying, and I doubt not all his surviving college friends would concur with me, that he was the most genial, warm-hearted, generous, and affectionate of friends; that his sympathies were with all that was good and true; and that he had a cordial hatred for everything false, or vile, or cruel, or mean, or dishonourable. He was not only great, but pre-eminently good, and just, and lovable."

Professor Huxley, speaking of the name of Darwin, says:

> "They think of him who bore it as a rare combination

of genius, industry, and unswerving veracity, who earned his place among the most famous men of the age by sheer native power, in the teeth of a gale of popular prejudice, and uncheered by a sign of favour or appreciation from the official fountains of honour; as one who, in spite of an acute sensitiveness to praise and blame, and notwithstanding provocations which might have excused any outbreak, kept himself clear of all envy, hatred, malice, nor dealt otherwise than fairly and justly with the unfairness and injustice which was showered upon him; while, to the end of his days, he was ready to listen with patience and respect to the most insignificant of reasonable objectors."

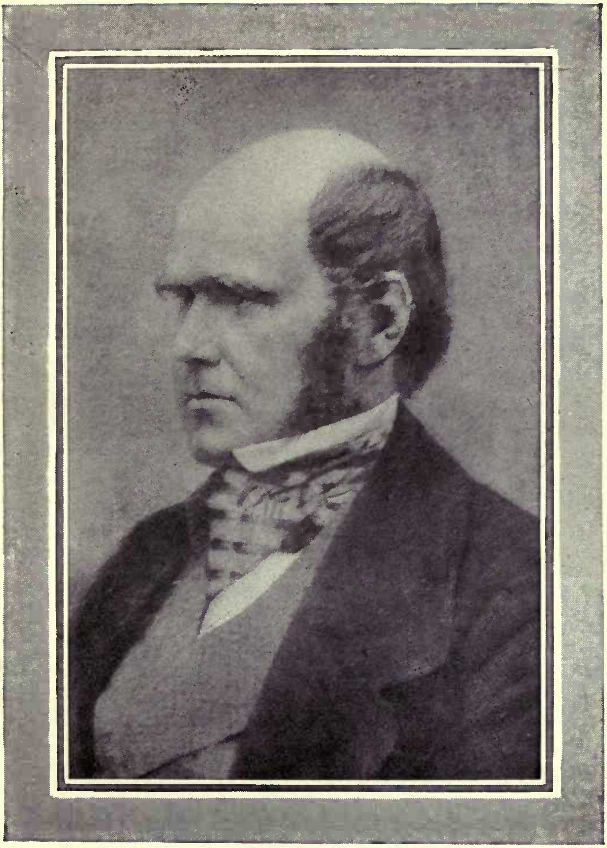
Although the Darwin family trace their ancestry to about the year 1500, we need not, here, go further back than Charles's grandfather, Erasmus (1731–1802). This distinguished physician, the author of the "Loves of the Plants" and of "Zoonomia," transmitted to his grandson his benevolent and sympathetic character and a remarkable charm of manner, as well as his great stature.

In many respects Erasmus Darwin was in advance of his times. He was, for instance, a great advocate of temperance, and Mr. Lucas has lately reminded us of his inhuman advice: "If you must drink wine, let it be home-made," surely the shortest cut to total abstinence yet devised by the wit of man.

He wrote innumerable verses in the somewhat stilted style of the period. They were immensely admired by his contemporaries, and Cowper, who could have had little or no sympathy with most of Darwin's views, wrote in conjunction with Halley a poem in his honour which begins:—

"No envy mingles with our praise,
Tho' could our hearts repine
At any poet's happier lays,
They would, they must, be thine."

The third son of Erasmus, Robert Waring Darwin, was the father of Charles. Like his father, he was a physician, and for many years he enjoyed a large practice at Shrewsbury. He married Susannah, the daughter of his father's friend,



Charles Darwin

From a photograph by

Josiah Wedgwood, of the well-known pottery works at Etruria, Staffordshire.

In his charming and frank fragments of autobiography Darwin recalls many incidents of his own childhood. As a boy he early developed a taste for collecting plants, shells, minerals and other natural objects, and he was at pains to learn their names. He tells a curious story of himself pretending that he could alter the colour of flowers by watering them with coloured fluids, curious because at his age boys are not as a rule interested in such problems of vegetable physiology. It is characteristic that in the earliest portrait of him, a charming crayon sketch in which his youngest sister Catherine also appears, he is depicted holding a pot of flowers in his hands. At the age of nine he was sent to the school at Shrewsbury, then in its picturesque old buildings in the town; he was a boarder there, and thus had, as he says, "the great advantage of living the life of a true schoolboy." He remained at school until he was sixteen, and then his father, thinking he was not doing much good, sent him to join his elder brother, who was studying medicine at Edinburgh University. At this period, like his grandfather, his father and his brother, Darwin was destined to study medicine, and he attended the medical course, which consisted entirely of lectures, all of them, with but one exception, "intolerably dull." Apart from the lectures, which were evidently almost useless, Darwin acquired a good deal of miscellaneous information whilst at Edinburgh; he did much collecting along the shore, learnt the art of the bird-stuffer, frequented two or three societies, and doubtless, as is the habit of those of his age, took part in many and interminable discussions. He also became an ardent sportsman and was especially enthusiastic about shooting. Apparently, however, his heart was not in his medical work, and in 1827 his father proposed that he should become a clergyman, and with this in view decided to send him to Cambridge.

The Admission Book at Christ's College contains the following entry:—

> "Admissi sunt in Collegium Christi a Festo Divi Michaelis 1827 ad Festum eiusdem 1828:

[No. 3.]
Octobris 15. Carolus Darwin admissus est pensionarius minor sub Mro Shaw."

Charles Darwin came into residence in the Lent Term of 1828.

Late in life men are apt to look back upon their College days with a somewhat exaggerated regret for lost opportunities, and Charles Darwin felt that at Cambridge his "time was wasted, as far as his academical studies were concerned, as completely as at Edinburgh and at school." But this must not be taken too literally. He seems to have passed his University examinations with ease, and a letter recording his joy at getting through the "Little-Go" shows that he at any rate took them seriously.

Apparently Darwin's experiences at Edinburgh had given him a distaste for lectures, and it is unfortunate that this distaste kept him away from the teaching of Sedgwick. He attended, however, the botanical lectures of Henslow, which were then crowded with students as well as with senior members of the University, and he revelled in the excursions which Henslow used to conduct, on foot or in coaches, or down the river in barges, "or to some more distant place, as to Gamlingay, to see the wild lily of the valley and to catch on the heath the rare natterjack." He was, in fact, known to the senior members of the University as "the man who walks with Henslow," and the man who walked with Henslow did not spend three years at Cambridge wholly in vain.

Amongst other absorbing pursuits was that of collecting insects, especially beetles. He was first interested in entomology by his cousin, W. Darwin Fox, of Christ's, who had kindred tastes and with whom he frequently corresponded—in fact, most of the letters written from Christ's College that remain were addressed to him.

Darwin received his degree on April 26, 1831, and it was during this term and the subsequent Easter term, when he was still in residence, that Henslow persuaded him to begin the study of geology. There must have been something unusual about Darwin, for he seems to have made friends with men much older than himself, and some of them, one would imagine, not very approachable. He records how he used to walk home at night with Dr. Whewell; and rejoices in his friendship with Leonard Jenyns. He became the friend of Adam Sedgwick, and in August 1831 he accompanied him on a geological survey in North Wales. It was on returning from this trip that he found a letter from Henslow informing him that Captain Fitzroy was willing to give up part of his cabin to any young man who would volunteer without pay to act as naturalist on the classical voyage of the *Beagle.* Captain Fitzroy was going out to survey the southern coast of Tierra del Fuego and to visit some of the South Sea Islands, returning by the Indian Archipelago.

Captain Fitzroy, like Mrs. R. Wilfer, was a "disciple of Lavater," and took exception to the shape of Darwin's nose. "He doubted whether any one with my nose could possess sufficient energy and determination for the voyage." But on acquaintance his doubts soon vanished, and the captain and his naturalist became close friends.

Space forbids any account of the voyage of the *Beagle.* As far as Darwin is concerned, it took place at what is, perhaps, the period of life when the mind is most original. Many of the great creative ideas of thought appear to be engendered between the age of twenty and thirty years, and although much may be added later, the foundation of man's life work is usually laid then. Darwin, as he records, "worked to the utmost during the voyage from the mere pleasure of investigation and from" his "strong desire to add a few facts to the great mass of facts in Natural Science."

He returned to England in October 1836, and two months later, on December 13, Darwin settled again in Cambridge, but only for three months.

Whatever feeling Darwin had about the education that he received at Cambridge, he had a real love for the place, to which he sent all but one of his sons; and it is good to read the following lines in his autobiography: "Upon the whole, the three years I spent at Cambridge were the most joyful of my happy life."

Early in the year 1839 Darwin married his cousin, Emma Wedgwood, and for nearly four years they kept house in

Upper Gower Street. The sustained toil and the discomforts of the voyage had injured Darwin's health, and he and his wife led a life of "extreme quietness." During this period, he states, "I did less scientific work, though I worked as hard as I possibly could, than during any other equal length of time in my life. This was owing to frequently recurring unwellness and to one long and serious illness." His health, indeed, prevented his regular attendance at scientific and other gatherings which are among the few attractions London can offer over the country, and in 1842 he removed to the secluded Kentish village of Down. The chief attraction of the place was its quietness, "its chief merit," as Darwin writes, "is its extreme rurality." The house stands a quarter of a mile from the village, whose peaceful charm has been but little altered in the last sixty-seven years. And here it was he says: "I can remember the very spot, whilst in my carriage, when to my joy the solution occurred to me." The "solution" was "natural selection by means of the survival of the fittest."

Here for forty years Darwin lived and laboured, in spite of ill-health which often laid him aside for weeks, his daily task always confined to very few hours of work. We need not follow further the details of this happy life, but one event, and that a well-known one, may briefly be referred to. Darwin's work was so catholic, its bulk so great and its effect so stimulating, that few have realised how vast was the output of scientific work which, though often an invalid, he gave to the world. The extent of the work has been perhaps a little overshadowed by the immense importance of that great generalization known as Natural Selection. Sir Wm. Thiselton-Dyer has reminded us that Darwin lies beside Newton in Westminster Abbey, and he adds: "It is the singular fortune of an illustrious University that of two of her sons, one should have introduced a rational order into the organic and the other into the inorganic world."

In 1908 was celebrated the Jubilee of the reading of a Paper at the Linnean Society entitled, "On the Tendency of Species to form Varieties; and on the Perpetuation of Varieties and Species by Natural Means of Selection." This was the joint production of Charles Darwin and of Alfred

Russell Wallace, and was laid before the Society by Sir Joseph Hooker and Sir Charles Lyell. The history of this Paper is well known, but it is so creditable to both these high-minded and honourable men that I may briefly repeat it, and in doing so I cannot do better than use the noble words[1] of Wallace :—

> "The *one fact*," said Wallace, "that connects me with Darwin, and which, I am happy to say, has never been doubted, is that the idea of what is now termed 'natural selection' or 'survival of the fittest,' together with its far-reaching consequences, occurred to us *independently*, and was first jointly announced before this Society fifty years ago.
>
> "But what is often forgotten by the press and the public is, that the idea occurred to Darwin in October 1838, nearly twenty years earlier than to myself (in February 1855); and that during the whole of that twenty years he had been laboriously collecting evidence from the vast mass of literature of Biology, of Horticulture, and of Agriculture; as well as himself carrying out ingenious experiments and original observations, the extent of which is indicated by the range of subjects discussed in his 'Origin of Species,' and especially in that wonderful store-house of knowledge—his 'Animals and Plants under Domestication,' almost the whole materials for which works had been collected, and to a large extent systematized, during that twenty years.
>
> "So far back as 1844, at a time when I had hardly thought of any serious study of nature, Darwin had written an outline of his views, which he communicated to his friends, Sir Charles Lyell and Dr. (now Sir Joseph) Hooker. The former strongly urged him to publish an abstract of his theory as soon as possible, lest some other person might precede him—but he always refused till he had got together the whole of the materials for his intended great work. Then, at last, Lyell's prediction was fulfilled, and, without any apparent warning, my letter, with the enclosed Essay, came upon him, like a

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[1] The Darwin-Wallace Celebration. The Linnean Society, London, 1908, pp. 5–7.

> thunderbolt from a cloudless sky! This forced him to what he considered a premature publicity, and his two friends undertook to have our two papers read before this Society.
>
> "How different from this long study and preparation —this philosophic caution—this determination not to make known his fruitful conception till he could back it up by overwhelming proofs—was my own conduct. The idea came to me, as it had come to Darwin, in a sudden flash of insight: it was thought out in a few hours—was written down with such a sketch of its various applications and developments as occurred to me at the moment,—then copied on thin letter-paper and sent off to Darwin—all within a week. *I* was then (as often since) the 'young man in a hurry': *he,* the painstaking and patient student, seeking ever the full demonstration of the truth that he had discovered, rather than to achieve immediate personal fame."

It is a remarkable fact that both naturalists owed their inspiration to the same source. Both had read the "Essay on Population," written by a modest clergyman named Malthus, a book which on its appearance was met with a storm of execration; both saw in it the demonstration of that "struggle for existence" which surrounds us on all sides, and both and they alone of all the readers of Malthus) saw that the necessary consequence of this struggle for existence was that the fittest alone survive. This conception, "an essentially new creative thought," as Helmholtz described it, explained the method of that evolution which since the time of the Greeks has been at the back of man's mind. It thus rendered the fact of evolution acceptable and even inevitable in the minds of all intelligent thinkers and brought about changes in our attitude to the organic world and indeed in our whole relation to life greater, perhaps, than have ever been produced by any previous thought of man.

There were, of course, many British evolutionists before Darwin, amongst whom may be mentioned Charles Darwin's grandfather, Erasmus Darwin, Wells, Patrick Matthew, Pritchard, Grant, Herbert—all these writers advocated, and some even hinted at, natural selection. Above all, Robert

Chambers, whose "Vestiges of Creation" remained anonymous until after his death, strongly pressed the view that new species of animals were being evolved from simpler types.

During the incubatory period of Darwin's great work, as Alfred Newton has remarked, systematists, both in zoology and botany, had been feeling great searchings of heart as to the immutability of species. There was a general feeling in the air that some light on this subject would shortly appear. As a recent writer has reminded us,

> "in studying the history of evolutionary ideas, we must keep in mind two distinct lines of thought, *first*, the conviction that species are not immutable, and that by some means or other new forms of life are derived from pre-existing ones. *Secondly*, the conception of some process or processes by which this change of old forms and new ones may be explained."

Now, as we have seen, the first of these lines of thought had been accepted by many writers. Darwin's great merit was that he conceived a process by means of which this evolution in the organic kingdom could be explained.

It has been somewhat shallowly said, said in fact on the day of the centenary of Darwin's birth, that "we are upon very unsafe ground when we speculate upon the manner in which organic evolution has proceeded without knowing in the least what was the variable organic basis from which the whole process started." Such statements show a certain misconception, not confined to the layman, as to the scope and limitations of scientific theories in general, and to the theory of organic evolution in particular. The idea that it is fruitless to speculate about the evolution of species without determining the origin of life is based on an erroneous conception of the true nature of scientific thought and of the methods of scientific procedure. For Science, the world of natural phenomena is a complex of procedure going on in time, and the sole function of Natural Science is to construct systematic schemes forming conceptual descriptions of actually observed processes. Of ultimate origins Natural Science has no knowledge and can give no account. The question whether living matter is continuous or not with what we call non-living matter is certainly one to which an attempted answer falls within the scope of scientific method. If, however, the final answer should be in the affirmative we should then know that all matter is living, but we should be no nearer to the attainment of a notion of the origin of life. No body of scientific doctrine succeeds in describing in terms of laws of succession more than some limited set of stages of a natural process; the whole process—if, indeed, it can be regarded as a whole—must for ever be beyond the reach of scientific grasp. The earliest stage to which Science has succeeded in tracing back any part of a sequence of phenomena itself constitutes a new problem for Science and that without end. There is always an earlier stage and to an earliest we can never attain. The questions of origins concern the theologian, the metaphysician, perhaps the poet. The fact that Darwin did not concern himself with questions as to the origin of life nor with the apparent discontinuity between living and non-living matter in no way diminishes the value of his work. The broad philosophic mind of the great Master of inductive method saw too fully the nature of the task he had set before him to hamper himself with irrelevant views as to origins.

No well-instructed person imagines that Darwin spoke either the first or the last word about organic evolution. His ideas as to the precise mode of evolution may be, and are being, modified as time goes on. This is the fate of all scientific theories; none are stationary, none are final. The development of Science is a continuous process of evolution, like the world of phenomena itself. It has, however, some few landmarks which stand out exceptional and prominent. None of these is greater or will be more enduring in the history of thought than the theory associated with the name of Charles Darwin.

But in reading his writings and his son's admirable "Life" one attains a very vivid impression of the man. One of his dominant characteristics was simplicity—simplicity and directness. In his style he was terse, but he managed to write so that even the most abstruse problems became clear to the public. The fascination of the story he had to tell was enhanced by the direct way in which he told it.

One more characteristic. Darwin's views excited at the time intense opposition and in many quarters intense hatred. They were criticised from every point of view, and seldom has a writer been more violently attacked and abused. Now what seems so wonderful in Darwin was that—at any rate as far as we can know—he took both criticism and abuse with mild serenity. What he wanted to do was to find the truth, and he carefully considered any criticism, and if it helped him to his goal he thanked the critic and used his new facts. He never wasted time in replying to those who fulminated against him, he passed them by and went on with his search.

It is a somewhat remarkable fact that whilst the works of Darwin stimulated an immense amount of research in Biology, this research did not at first take the line he himself had traced. With some exceptions, the leading zoological work of the end of the last century took the form of embryology, morphology, and palæontology; and such subjects as cell-lineage, the minute structure of protoplasm, life-histories, teratology, have occupied the minds of those who interest themselves in the problems of life. Among all these lines of research man has been seeking for the solution of that secret of nature which at the bottom of his heart he knows he will never find, and yet the pursuit of which is his one abiding interest. Had Francis Balfour lived we should, probably, have sooner returned to the broader lines of research as practised by Darwin, for it was Balfour's intention to turn himself to the physiology—using the term in its widest sense—of the lower animals. Towards the end of the nineteenth century, stimulated by Galton, Weldon began those series of measurements and observations which have culminated in the establishment of a great school of Eugenics and Statistics in London. With the beginning of the twentieth century came the rediscovery of the neglected facts recorded by Gregor Mendel, Abbot of Brünn, some years before, and with that rediscovery an immediate and enormous outburst of enthusiasm and of work. Mendel had placed a new instrument in the hand of the breeder, an instrument which, when he has learnt to use it, may give him a power over all domesticated animals and cultivated crops undreamt of before. We are getting a new insight into the workings of Heredity and we are acquiring a new conception of the individual. The few years which have elapsed since men's attention was redirected to the principles first enunciated by the Abbot of Brünn have seen a School of Genetics arise at Cambridge, and an immense amount of practical experiment on inheritance has also been done in France, Holland, Austria, and especially in the United States. As the work has advanced new ideas have arisen and earlier formed ideas have had to be abandoned; this must be so with every advancing science. But it has now become clear—at any rate to some competent authorities—that mutations occur, and occur especially in cultivated species; and that these mutations may breed true seems now to be established. In wild species also they apparently occur, but whether they are as common in wild as in cultivated species remains to be seen. If they are not, in my opinion, a most profitable line of research would be to endeavour to determine what factor exists in cultivation which stimulates mutation.

To what extent Darwin's writings would have been modified had Mendel's work come into his hands we can never know. He carefully considered the question of mutation, or as they called it then, saltation, and as time went on, he attached less and less importance to these variations as factors in the origin of species. Ray Lankester has recently reminded us that Darwin's disciple and expounder, Huxley, "clung to a little heresy of his own as to the occurrence of evolution by saltatory variation," and there must have been frequent and prolonged discussion on the point. That "little heresy" has now become the orthodoxy of a number of eager and thoughtful workers who have been at times rather aggressive in their attacks on the supporters of the old creed.

The publication of "The Origin of Species" naturally aroused immense opposition and heated controversy. But Darwin, as we have said, was no controversialist. Huxley wrote shortly after his death:

> "None have fought better, and none have been more fortunate, than Charles Darwin. He found a great truth trodden underfoot, reviled by bigots, and ridiculed by all

> the world; he lived long enough to see it, chiefly by his own efforts, irrefragably established in science, inseparably incorporated with the common thoughts of men, and only hated and feared by those who would revile, but dare not. What shall a man desire more than this?"

Darwin, also, was fortunate in his supporters, though some of the leading biologists of the time—conspicuous among them was Owen—rejected the new doctrine. In Hooker, on the botanical side, in Huxley, on the zoological side, and in Lyell, on the geological side, he found three of the ablest intellects of his country and of his century as champions. None of these agreed on all points with their leader, but they gave more than general adherence to his principles, and a more than generous aid in promulgating his doctrine. Lyall was an older man, and his "Principles of Geology" had long been a classic. This book inspired students who became leaders in the revolution of thought which was taking place in the last half of the nineteenth century. One of these writes:

> "Were I to assert that if the 'Principles of Geology' had not been written, we should never have had 'The Origin of Species,' I should not be going too far: at all events, I can safely assert, from several conversations I had with Darwin, that he would have most unhesitatingly agreed to that opinion."[1]

Sir Joseph Hooker, whose great experience as a traveller and a systematic botanist, and one who had at his time the widest knowledge of the distribution of plants, was of invaluable assistance to Darwin on the botanical side of his researches. Those who knew Hooker will remember him as a man of ripe experience, sound judgment, and a very evenly-balanced mind. But all these high and by no means common qualities were combined with caution, and with a critical faculty, which was quite invaluable to Darwin at this juncture. Huxley was of a somewhat different temperament. He was rather proud of the fact that he was named after the doubting apostle; but, whatever Huxley doubted, he never doubted himself. He had clear-cut ideas, which he was capable of expressing in the most vigorous and the most cultivated English. Both on platform and on paper he was a keen controversialist. He contributed much to our knowledge of morphology. But never could he have been mistaken for a field-naturalist. In the latter part of his life he was drawn away from pure science by the demands of public duty, and he was, undoubtedly, a power in the scientific world. For he was ever one of that small band in England who united scientific accuracy and scientific training with influence on the political and official life of the country.

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[1] J. W. Judd.

As has already been said, the immediate effect of the publication of " The Origin of Species " and of the acceptance of its theories by a considerable and ever-increasing number of experts did not lead to the progress of research along the precise lines Darwin himself had followed. The accurate description of bodily structure and the anatomical comparison of the various organs was the subject of one school of investigators: Rolleston's " Forms of Animal Life," re-edited by Hatchett Jackson, Huxley's " Vertebrate and Invertebrate Zoologies," and Milnes Marshall's " Practical Zoology " testify to this. Another school took up with great enthusiasm the investigation of animal embryology, the finest output of which was Balfour's " Text-book of Embryology," published in 1880. Members of yet another school devoted themselves to the minute structure of the cell and to the various changes which the nucleus undergoes during cell-division. Animal histology has, however, been chiefly associated with physiology and, as this chapter is already greatly overweighted, we have had to leave physiology on one side. The subjects of degeneration, as shown, by such forms as the sessile Tunicata, the parasitic Crustacea and many internal parasitic worms, with the last of which the name of Cobbold is associated, also received attention, and increased interest was shown on the pathogenic influence of internal parasites upon their hosts.

Towards the end of our period, a number of new schools of biological thought arose. As Judd tells us:

> " Mutationism, Mendelism, Weismannism, Neo-Lamarckism, Biometrics—with which the name of W. F. R. Weldon will ever be associated—' Eugenics ' began to

> be exploited. But all of these vigorous growths have their real roots in Darwinism. If we study Darwin's correspondence, and the successive essays in which he embodied his views at different periods, we shall find that variation by mutation (or *per saltum*), the influence of environment, the question of the inheritance of acquired characters, and similar problems, were constantly present to Darwin's ever open mind, his views upon them changing from time to time, as fresh facts were gathered."

Like everything else, these new theories were deeply rooted in the past.

We have already alluded to Alfred Russell Wallace (1823–1913) and to the magnanimity with which he and Darwin treated each other in the matter of their simultaneous discovery of the causes which had brought about "The Origin of Species." Wallace was one of the last of the great travelling naturalists and collectors. He explored the Amazon with his friend Bates in the years 1848–1852. Two years later he visited and lived for some years in the Indo-Malay Islands, and in both parts of the globe he accumulated a vast series of facts from which some of his widest generalisations sprang.

Wallace had a fine gift for writing, and his "Malay Archipelago" is one of the most fascinating books in a naturalist's library. Perhaps his most celebrated books are his "Geographical Distribution of Animals" and "Island Life," published in 1876, for, as Professor H. F. Osborn reminds us, "Wallace takes rank as the founder of the science of zoo-geography." "Wallace's Line" between Bali and Lombok, the frontier between the Indian and Australian regions, will ever recall his fame in this branch of science.

He was a man of strong humanitarian instincts and devoted a considerable amount of time in trying to devise plans to help mankind and the state, and although many of his views did not commend themselves to the majority his sincerity was always fully recognized.

We must now return to many zoologists of about Darwin's period who more than held their own as compared with some continental claimants of scientific superiority.

Although George James Allman (1812–1898) was Professor of Botany at Dublin, he achieved his most marked success as a zoologist. He left Dublin in 1856 on his appointment to the Regius Professorship of Natural History in the University of Edinburgh. He was, like so many men of science, a good artist, and had exceptional skill in drawing on the blackboard, and was a very popular lecturer, and he took especial pleasure in taking his pupils on dredging expeditions in the Firth of Forth and inducing them to study marine organisms in the living state. His great work on the Gymnoblastic Hydrozoa, published by the Ray Society, is stated by his biographer to have been without doubt the most important systematic work dealing with the group of Cœlenterata that has ever been produced. "The excellence of the illustrations alone would almost justify us in placing this work in the first rank of zoological treatises." But he was equally an authority on certain groups of Polyzoa, and it should be recalled that he it was who invented the terms "ectoderm" and "endoderm," besides a great many other useful expressions, such as "cœnosarc," "trophosome" and "gonosome," and many others. But above all he did much to clear up the difficulty of defining species in the Cœlenterata.

Thomas Henry Huxley (1825–1895), a few years younger than Wallace, was, as we have seen, another of Darwin's supporters. He started life as a surgeon and, like Darwin, owed much of his early reputation to a sea voyage. He made a four years' cruise in H.M.S. *Rattlesnake*, 1846–1850, during which he especially devoted himself to the study of marine organisms. He was the first to dissociate the hydrozoa from the star fishes, and the parasitic worms and the infusoria, which had formed portions of Cuvier's old group *Radiata*. He did much to clear up the relations of the Medusa to the Hydroid, and he dwelt especially on the two-layered condition of their body wall, pointing out its analogy with the gastrula. Shortly after his return to England in 1850, he was elected a Fellow of the Royal Society at the unusually early age of 26.

As a morphologist, Huxley made immense advances. Apart from his work on Cœlenterates, he investigated the structural life-history of the Ascidians, wrote on the Mollusca, and undertook a series of investigations into fossil vertebrate forms, researched on *Aphis* and on crocodiles, cleared up the mystery of the vertebrate skull, and, in fact, covered an extremely wide area of investigation. But Huxley was not only a great morphologist, he was a great teacher and a great organiser. His text books on the comparative anatomy of the Vertebrate and of the Invertebrata were the starting points of many a zoologist's career. His "Elementary Biology," which he wrote in collaboration with Newall Martin, marks an epoch. He was also a great lecturer, and although not fond of public speaking, he was remarkably able, concise, and even eloquent. He spared no pains, and would write and re-write an address until he had got it into what he considered a satisfactory form. Further, as he himself wrote of Priestley, he was "a man and a statesman before he was a philosopher," and Huxley took a leading part in public affairs, sat on a large number of Royal Commissions and departmental committees. He was a member of the first School Board of the City of London, and by his popular lectures made a real attempt to interest the working men and all others in the importance of science. He was, for a time, the Biological Secretary of the Royal Society, and in this post took a large part in organizing the *Challenger* Expedition of 1872–1876. He was elected President of the Royal Society, but four years later was compelled to resign on account of ill-health. He was the recipient of innumerable honorary degrees and memberships of foreign societies, and in 1892 was honoured by being made a Privy Councillor.

Owen's successor, Sir William Flower (1831–1899), was trained at the University of London as a medical man, and after touring on the Continent, he joined the army, and was assistant surgeon in the 63rd Regiment during the Crimean Campaign, the trials of which were so severe that his health was affected, and he had to retire from the army and return to London. For a time he practised, but in 1861, was appointed Conservator of the Museum of the Royal College of Surgeons, and here he found his career. This unique museum was greatly increased under Flower.

The President of the Royal Society said, when presenting Sir William with a royal medal, " it is very largely due to his incessant and well-directed labours that the Museum of the Royal College of Surgeons at present contains the most complete, the best ordered, and the most accessible collections of materials for the study of vertebrate structures extant."

Flower succeeded Huxley in the Hunterian Professorship at the Royal College of Surgeons, and his lectures met with great success, in fact, he was soon becoming the foremost authority on mammals, and his work on " Mammals, Living and Extinct," which he published in London in conjunction with Lydekker, is still regarded as a classic. Perhaps if he had a favourite group it was the Cetacea, and when he succeeded Owen as Superintendent of the Natural History Museum at Kensington, he took the greatest pleasure in having a large room specially constructed to house their gigantic skeletons. His well-known " Osteology of Mammals," in which he was assisted by Dr. Hans Gadow, was, even if a little dry, one of the most accurate and complete of student's books. Another side of his work was Anthropology. He published innumerable papers on the various races of mankind, fully utilising the valuable material he had at the Royal College of Surgeons. In 1879 he was elected President of the Zoological Society, and held the position until his death. His energy greatly increased the value and use of the gardens. In 1898 failing health compelled him to retire from the position. Sir William was a handsome, well-set-up man, always courteous to strangers, with a ready, fluent address.

One of the unexpected results of Darwin's investigations was to induce a number of the younger school of zoologists to take up the study of Embryology. The most brilliant of these was Francis Maitland Balfour (1851–1882). He was educated at Harrow and at Trinity College, Cambridge. Even as a student—acting under the advice of Michael Foster, at that time Praelector of Physiology in Trinity College—he devoted himself to clearing up some points in the development of the chick. After taking his degree in 1873, he worked on the embryonic history of the Elasmobranch fishes at the Zoological Station at Naples. This research gained him a Fellowship at Trinity College.

He was appointed lecturer on Animal Morphology at Cambridge, and soon became the founder of an extremely vigorous and active school of zoologists. His best known work is, of course, his "Treatise on Comparative Embryology," the first volume of which appeared in 1880, and the second in the following year. It was a masterly review of an enormous number of observations scattered over a world-wide literature, and its production involved a wide and careful reading of multitudinous papers. He had remarkable critical faculty, and a wonderful gift of insight and intuition, so that his book threw light on many a doubtful point. When he was but 27, he was elected a Fellow of the Royal Society, and, if he had chosen, he might have succeeded Rolleston as Professor at Oxford. Edinburgh also coveted him; but he remained faithful to his own University, and, in the spring of 1882, a special Professorship of Animal Morphology was instituted for him at Cambridge.

Balfour died by a tragic accident in the Alps in the summer of 1882, and in him died a young man of great performance, and even greater promise. He was a man of singular charm, and, as Professor Michael Foster wrote, "he was high-minded, generous, courteous, a brilliant fascinating companion, a steadfast friend. He won, as few others did, the hearts of all who were privileged to know him."

We must necessarily deal but shortly with a few more names :—

George John Romanes (1848–1894), whose researches on the physiology of the nervous and locomotor system of jelly-fishes and echinoderms, and whose speculations on the principle of Selection will preserve his name.

Adam Sedgwick (1854–1913), a great nephew of the geologist, by his researches on *Peripatus* did much to elucidate the mystery of the Cœlom in Arthropods, and so show a possible connexion between this group and lower animals. His views on the cell theory are now coming to their own. For a year or two he was Professor of Zoology at Cambridge, and at the time of his death he was Professor at the Royal

College of Science and Technology, in London, and though he was by no means a fluent lecturer, he was a stimulating and inspiring teacher.

Walter Frank Raphael Weldon (1860–1906), another Cambridge man, succeeded Moseley as Professor at Oxford. He was a brilliant teacher, full of enthusiasm, and did much sound morphological work. The last years of his life he devoted to the subject of Biometrics, and he was the co-founder with Karl Pearson of *Biometrika*.

The mention of Biometrics recalls the name of one who, though not a zoologist in the strict sense of the word, deserves a distinguished place in the history of our subject. Francis Galton (1822–1911) began active life as a student of medicine, but, on his father's death, inherited independent means and abandoned the professional career. He spent some time on an extensive journey in Africa, but his mind soon turned to science. It was, probably, his experiences as a traveller that directed his attention, at first, to meteorology, and he did some useful work in that subject. On the publication of the "Origin of Species," Galton at once adopted the views advocated by Charles Darwin, who was his cousin. He then became interested in the laws of heredity, and during a series of years endeavoured to introduce scientific measurements into the study of a subject in which previously qualitative estimates were considered sufficient. Feeling the want of proper statistics, he instituted, during the National Health Exhibition in 1884, an anthropometric laboratory, for the purpose of collecting satisfactory data. This was the forerunner of the present biometric laboratory at University College, London. Following up suggestions by Sir William Herschel and Dr. Foulds, who had proposed the use of "finger-prints" as a means of identifying persons. Galton proved the method to be reliable, and devised a workable scheme for classifying the prints so as to make them serviceable for rapid identification. He was also the originator of the word "Eugenics" for the study of the methods of improving the human race by breeding from the best, and restricting the offspring of the worst; and he must be considered to be the founder of that branch of science. Endowed with exceptional originality and a sympathetic mind that allowed him to co-operate effectively with other men, he rendered many useful services to science. He was knighted in 1909, two years before his death. By his will he left a sum amounting to about £45,000 for the foundation of a chair of Eugenics in the University of London, expressing the wish that Karl Pearson should be the first occupant of the chair.

One of the rules laid down for the writers of this book is that living authors should only be mentioned when their work is so much interwoven with that of others whose activities have been noticed that a wrong impression would be created by omitting all reference to them. Professor Sir E. Ray Lankester has added so much to our conceptions of the morphology of the animal kingdom, so much more than any other living man, that a short account of his researches must be given. Mention must be made of his investigation into the embryonic cell gland of the Mollusca, his researches in the distribution of hæmoglobin in the Invertebrata, the wonderful way in which he, in collaboration with one of his pupils, cleared up the structure of the Lamellibranch gill, his work on the anatomy of the Limpet, and the even more important series of investigations which led to the assignment of *Limulus* to its proper position amongst the Arachnids. He was the first to observe an intracellular parasite (in the red corpuscle of the frog), but from the scales of fossil fishes to the details of the Okapi, there are few subjects in Zoology that do not owe something to the investigations carried on by Lankester from 1862 to 1905. His name will ever be associated with the very important and fundamental conception of the cœlom, and his views on this subject are set forth at length in Part II. of his Treatise on Zoology. With this theory must be associated his views on Phleboedesis, a name given to the theory that the lacunar blood-holding spaces forming the hæmocoel of the Mollusca and the Crustacea have no connexion with the cœlom, although they encroach in certain animals on the space occupied by the cœlomic cavity. The discussion of how his theory differs from that given in " Die Coelom Theorie " of the Hertwigs is set out in the above-mentioned treatise.

In addition to these fundamental conceptions which have done so much to clear up the structure of widely differing animals, Lankester has introduced many new terms which have proved of permanent value in the science of zoology. Amongst these may be mentioned "nephridium," "blastoderm," "stomodeum," "proctodeum." Further, he introduced the terms "homogeny" and "homoplasy," to distinguish between the two very different senses in which "homology" had previously been used.

As a maritime nation, Great Britain has led the way in exploring the plant life and animals of the sea, the chemical and physical nature of the sea water, and the geological structure of the subaqueous earth. As long ago as 1749 Captain Ellis found that a thermometer, lowered on separate occasions to depths of 650 fathoms and 891 fathoms respectively recorded, on reaching the surface, the same temperature, namely, 53°. His thermometer was lowered in a bucket ingeniously devised so as to open as it descended and close as it was drawn up. The mechanism of this instrument was invented by the Rev. Stephen Hales, D.D., to whom we have referred above. Dr. Hales was an ingenious soul and the author of many inventions, amongst others, he is said to have suggested the use of the inverted cup placed in the centre of a fruit-pie in which the juice accumulates as the pie cools. His device of the closed bucket with two connected valves was the forerunner of the numerous contrivances which have since been used for bringing up sea-water from great depths. The colour of the sea and its salinity had also received attention in early days, notably at the hands of the distinguished chemist, Robert Boyle.

The invention of the self-registering thermometer by Cavendish in 1757, provided another instrument essential to the investigation of the condition of things at great depths, and it was used in Lord Mulgrave's expedition to the Arctic Sea in 1773. On this voyage attempts at deep-sea soundings were made, and a depth of 683 fathoms was registered. During Sir James Ross's Antarctic Expedition (1839–1843) the temperature of the water was constantly observed to depths of 2,000 fathoms. His uncle, Sir John

Ross, had, twenty years previously, on his voyage to Baffin's Bay, made some classical soundings. One, two miles from the coast, reached a depth of 2,700 feet, and brought up a collection of gravel and two living crustaceans; another, 3,900 feet in depth, yielded pebbles, clay, some worms, crustacea, and corallines. Two other dredgings, one at 6,000 feet, the other at 6,300 feet, also brought up living creatures; and thus, though the results were not at first accepted, the existence of animal life at great depths was demonstrated.

With Sir James Ross's expedition we may be said to have reached modern times; his most distinguished companion, Sir Joseph Hooker, died as recently as 1911. It is impossible to do more than briefly refer to the numerous expeditions which have taken part in deep-sea exploration during our own times

Professor Edward Forbes, who "did more than any of his contemporaries to advance marine zoology," joined the surveying ship *Beacon* in 1840, and made more than one hundred dredgings in the Ægean Sea. Mr. H. Goodsir sailed on the *Erebus* with Sir John Franklin's ill-fated Polar Expedition; and such notes of his as were recovered bear evidence of the value of the work he did. In 1868 the Admiralty placed the surveying ship *Lightning* at the disposal of Professor Wyville Thomson and Dr. W. B. Carpenter for a six weeks' dredging cruise in the North Atlantic; and in the following year the *Porcupine*, by permission of the Admiralty, made three cruises under the guidance of Dr. W. B. Carpenter and Mr. Gwynne Jeffreys.

We owe to Forbes (1815–1854) the delimitation of this zone of depth usually distinguished in European and other seas. These are the Littoral zone, the Laminarian zone, the Coralline zone, and the region of the deep sea corals. The last two zones are now generally known as the Continental Shelf and the Continental Slope, and to these must be added the floor of the deep ocean, a region which in Forbes' time was regarded as uninhabited. Forbes, after a very varied career, ultimately became a Professor at King's College, London, and Curator of the Museum of the Geological Society. His work in connexion with palæontology will be described in the chapter on Geology. He is undoubtedly the leading naturalist of the earlier half of the nineteenth century, a man of wide interests and of great popularity, one who lived a full life, one who promoted science, and who rendered a real service to every branch of Biology.

Another naturalist of the same period was Phillip Henry Gosse (1810–1888). As a young man he lived in Newfoundland, and here it was he began the serious study of Nature. His first work was on the Entomology of Newfoundland. Later, he travelled extensively in North America. On returning to England in 1839 he wrote his "Canadian Naturalist." A few years later he was in Jamaica, collecting and describing the native fauna and sending many specimens home. His "Birds of Jamaica," illustrated by a series of magnificent plates, is well known. But, perhaps, Gosse's name will live longer as a researcher on Marine Invertebrates. He particularly occupied himself with the zoophytes and made a great hit with his book "The Aquarium," which did much to stimulate amateurs to observe the littoral fauna. His most serious contribution to science, however, was his study of the sea anemones, *Actinologia britannica* (1855–1860); but it must not be forgotten that he collaborated with Dr. Hudson in the fascinating two volumes which these joint authors published in 1866 on the *Rotifera*.

Towards the end of 1872 H.M.S. *Challenger* left England to spend the following three years and a half in traversing all the waters of the globe. This was the most completely equipped expedition which has left any land for the investigation of the sea, and its results were correspondingly rich. They have been worked out by naturalists of all nations, and form the most complete record of the fauna and flora, and of the physical and chemical conditions of the deep, which has yet been published. Since the return of the *Challenger* there have been many expeditions from various lands, but none so complete in its conception or its execution as the British Expedition of 1872–1876.

The results of the exploration of the sea by the *Challenger* have never been equalled. In one respect, however, they were disappointing. It had been hoped that, in the deeper abysms of the sea, creatures whom we only know as geological, fossilized, bony specimens, might be found in the flesh; but, with one or two exceptions—and these of no great importance—these were not found. Neither did any new type of organism appear. Nothing, in fact, was dredged from the depths or found in the tow-net that did not fit into the larger groups that already had been established before the *Challenger* was thought of. On the other hand, many new methods of research were developed during this voyage, and with it will ever be associated the names of Wyville Thompson, mentioned above, Moseley, John Murray and others who, happily, are still with us.

A few words should be said as to the part played by cable-laying in the investigation of the subaqueous crust of the earth. This part, though undoubtedly important, is sometimes exaggerated; and we have seen how large an array of facts has been accumulated by expeditions made mainly in the interest of pure science. The laying of the Atlantic cable was preceded, in 1856, by a careful survey of a submerged plateau, extending from the British Isles to Newfoundland, by Lieutenant Berryman of the *Arctic*. He brought back samples of the bottom from thirty-four stations between Valentia and St. John's. In the following year Captain Pullen, of H.M.S. *Cyclops*, surveyed a parallel line slightly to the north. His specimens were examined by Huxley, and from them he derived the *Bathybius*, a primeval slime which was thought to occur widely spread over the sea-bottom and to be the most primitive form of living matter. The interest in this "Urschleim" became merely academic, when John Y. Buchanan, of the *Challenger*, showed that it is only a gelatinous form of sulphate of lime, thrown down from the sea-water by the alcohol used in preserving the organisms found in the deep-sea deposits. It was characteristic of Huxley to acknowledge his mistake and never to mention the subject again.

The important generalizations of Dr. Wallich, who was on board H.M.S. *Bulldog*, which, in 1860, again traversed the Atlantic to survey a route for the cable, largely helped to elucidate the problems of the deep. Wallich noticed that no *algæ* lived below the 200 fathom line; he collected animals from great depths, and showed that they utilize in many ways organisms which fall down from the surface of the water; he noted that the conditions are such that, whilst dead animals sink from the surface to the bottom, they do not rise from the bottom to the surface; and he brought evidence forward in support of the view that the deep-sea fauna is directly derived from shallow-water forms. In the same year in which Wallich traversed the Atlantic, the telegraph cable between Sardinia and Bona, on the African coast, snapped. Under the superintendence of Fleeming Jenkin, some forty miles of the cable, part of it from a depth of 1,200 fathoms, were recovered. Numerous animals, sponges, corals, polyzoa, molluscs, and worms were brought to the surface, adhering to the cable. These were examined and reported upon by Professor Allman, and subsequently by Professor A. Milne Edwards; and, as the former reports, we "must therefore regard this observation of Mr. Fleeming Jenkin as having afforded the first absolute proof of the existence of highly organized animals living at a depth of upwards of 1,000 fathoms." The investigation of the animals thus brought to the surface revealed another fact of great interest, namely, that some of the specimens were identical with forms hitherto known only as fossils. It was thus demonstrated that species hitherto regarded as extinct are still living at great depths of the ocean.

Throughout the century repeated attempts had been made to classify the members of the animal kingdom on a natural basis, but, until their anatomy and, indeed, their embryology had been sufficiently explored, these attempts proved somewhat vain. As late as 1869 Huxley classified sponges with *Protozoa*, *Echinoderms* with *Scolecida* and *Tunicates* with *Polyzoa* and *Brachiopoda*. By the middle of the century, much work had been done in sorting out the animal kingdom on a natural basis, and Vaughan Thompson had already shown that *Flustra* was not a hydroid, but a member of a new group which he named *Polyzoa*. He, although hardly remembered now, demonstrated that *Cirrepedia* are not molluscs by tracing their development, he established the fact that they began life as free-swimming

Crustacea; he, again, it was who showed that *Pentacrinus* is the larval form of the feather-star, *Antedon*.

The custom of naturalists to go on long voyages was still maintained, and during the nineteenth century, many other expeditions besides that of the *Challenger*, left Great Britain to explore the natural history of the world, some under public, some under private, auspices. They are too numerous to mention. But a word must be said about the wonderful exploration of Central America which has just been completed, under the auspices of F. D. Godman and O. Salvin. The results are incorporated in a series of magnificently illustrated quarto volumes which have been issued during the last thirty-six years. Fifty-two of these relate to zoology, five to botany, and six to archæology. Nearly 40,000 species of animals have been described in these volumes, about 20,000 being new species, and nearly 12,000 species of plants. There are few remote and partially civilized areas of the world whose zoology and botany are on so secure a basis, and this is entirely owing to the munificence and enterprise of the above-mentioned gentlemen.

With regard to our own shores, one of the features of the latter part of the nineteenth century has been the establishment of marine biological stations, the largest of which is that of the Marine Biological Association at Plymouth. The Gatty laboratory at St. Andrews, the laboratories at Port Erin in the Isle of Man, and at Cullercoats, have also, for many years, being doing admirable work. All these establishments have devoted much technical skill and time to solve fishery and other economic problems connected with our seas.

CHAPTER XI

PHYSIOLOGY

HARVEY (1578–1657), who, like Newton, worked in one of the two sciences which, in Stewart times, were, to some extent, ahead of all the others, was undoubtedly the second man of outstanding genius in science in the seventeenth century. Harvey, "the little choleric man" as Aubrey calls him, was educated at Caius College, Cambridge, and at Padua, and was in his thirty-eighth year when, in his lectures on anatomy, he expounded his new doctrine of the circulation of the blood to the College of Physicians, although his "Exercitatio" on this subject did not appear till 1628. His notes for the lectures are now in the British Museum. He was physician to Charles I., and it is on record how, during the battle of Edgehill, he looked after the young princes as he sat reading a book under a hedge a little removed from the fight.

In the chain of evidence of his convincing demonstration of the circulation of the blood one link, only to be supplied by the invention of the compound microscope, was missing. This, the discovery of the capillaries, was due to Malpighi, who was amongst the earliest anatomists to apply the compound microscope to animal tissues. Still, as Dryden has it—

> "The circling streams once thought but pools of blood—
> (Whether life's fuel or the body's food),
> From dark oblivion Harvey's name shall save."[1]

Harvey was happy in two respects as regards his discovery. It was, in the main, and especially in England, recognized as proven in his own lifetime, and, again, no one of credit claimed or asserted the claim of others to priority. In research, all enquirers stand on steps others have built up; but in this, the most important of single contributions to physiology, the credit is Harvey's and

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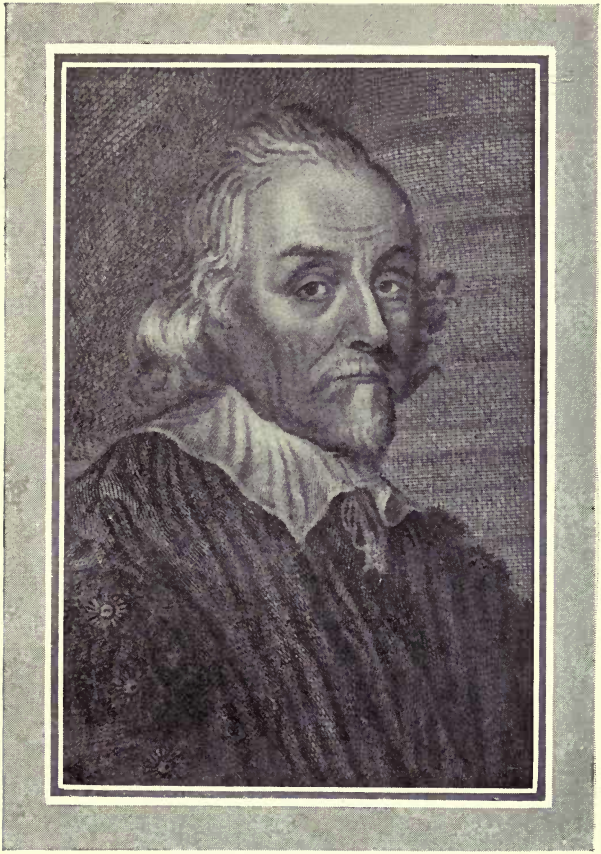
[1] Epistle to Dr. Charleton.



William Harvey

From a painting by Cornelius Janssen

almost Harvey's alone. His other great work, "Exercitationes de Generatione Animalium," is of secondary importance. It shows marvellous powers of observation and very laborious research; but although, to a great extent, it led the way in embryology, it was shortly superseded by the work of those who had the compound microscope at their command.

The poet, Cowley, a man of wide culture, wrote an "Ode on Harvey," in which his achievement was contrasted with a failing common to scientific men of his own time, and, so far as we can see, of all time:—

"*Harvey* sought for Truth in Truth's own Book
The Creatures, which by God Himself was writ;
And wisely thought 'twas fit,
Not to read Comments only upon it,
But on th' original itself to look.
Methinks in Arts great Circle, others stand
Lock't up together, Hand in Hand,
Every one leads as he is led,
The same bare path they tread,
A Dance like Fairies a Fantastick round,
But neither change their motion, nor their ground:
Had *Harvey* to this Road confin'd his wit,
His noble Circle of the Blood, had been untrodden yet."

Harvey's death is recorded in a characteristic seventeenth century sentence, taken from the unpublished pages of Baldwin Harvey's "Bustorum Aliquot Reliquiæ":—

> "Of William Harvey, the most fortunate anatomist, the blood ceased to move on the third day of the Ides of June, in the year 1657, the continuous movement of which in all men, moreover, he had most truly asserted . . .
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> *Ἕν τε τροχῷ πάντες καὶ ἐνὶ πᾶσι τροχοί*[1]

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[1] The writer is indebted for this quotation to Dr. Norman Moore's "History of the Study of Medicine in the British Isles," Oxford, 1908. He may here add a short note on the "Tabulæ Harveianæ," presented in 1823 by the Earl of Winchelsea to the Royal College of Physicians. Sir Thomas Barlow, in his Harveian Oration of 1916, threw much doubt on these "Tavole" having belonged to Harvey; and Dr. Archibald Malloch, of the Canadian Army Medical Corps, has, in his recently published lives of Sir John Finch and Sir Thomas Baines, brought forward almost conclusive evidence that these "Tavole" belonged to the former of these two gentlemen, and were brought by him from Padua, where, with his friend, he had studied medicine.

Among other great physiologists and physicians, the Swiss, Sir Theodore Turquet de Mayerne (godson of Theodore Beza), who settled in London in 1611, has left us "Notes" of the diseases of the great which, to the medically minded, are of the greatest interest. He almost diagnosed enteric, and his observations on the fatal illness of Henry, Prince of Wales, and the memoir he drew up in 1623 on the health of James I., alike leave little to be desired in completeness or in accuracy of detail.

Before bringing to a close these short notices of those who studied and wrote on the human body, whole or diseased, a few lines must be given to John Mayow (1640–1679), of Oxford, who followed the law, "especially in the summer time at Bath." Yet, from his contributions to science, one might well suppose that he had devoted his whole time to research in chemistry and physiology. He it was who showed that, in respiration, not the whole air, but a part only of the air breathed in, takes an active part in respiration, though he called this part "by a different name, he meant what we now call oxygen." [1]

Mayow showed that dark venous blood is changed to bright red by taking up this unknown substance, and thus was very near to discovering oxygen, for he fully grasped the idea that the object of breathing is to cause an interchange of gases between the air and the blood, the former giving off what he called its "nitro aero" constituent (oxygen) taking away the "vapours engendered by the blood." He was the first to find the seat of animal heat in the muscles, to describe the double articulation of the ribs and spine, and he discussed the function of the intercostal muscles in an entirely modern spirit. Had he been spared he undoubtedly would have gone far, but he died in Covent Garden at the too early age of thirty-five, having been married a little time before "not altogether to his content."

Thomas Sydenham was one of the first physicians who was convinced of the importance of constant and prolonged observation at the bedside of the patient. He passed by all authority but one—"the divine old man Hippocrates," whose medicine rested also on observation. He, first in England, "attempted to arrive at general laws about the prevalence and the course and the treatment of disease from clinical observation." He was essentially a physician occupied in diagnosis, treatment and prognosis. When he was but twenty-five years old, he began to suffer from gout, and his personal experience enabled him to write a classic on this disease, which is even now unsurpassed.

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[1] Foster, Sir Michael, "The History of Physiology," Cambridge, 1901.

Francis Glisson, like Sydenham, was essentially English in his upbringing, and did not owe anything to foreign education. His work on the liver has made "Glisson's capsule" known to every medical student, and he wrote an authoritative book on rickets. He, like Harvey, was educated at Gonville and Caius College, and, in 1636, became Regius Professor of Physic at Cambridge, but the greater part of his life he spent at Colchester.

A contemporary of Mayow was Richard Lower (1631–1691), of Cornwall. He was the first to perform the operation of directly transfusing blood from one animal to another. In 1669 he injected dark venous blood into inflated lungs, and found it became scarlet. This he attributed to something which was being absorbed from the air which was being passed through the lungs. In his "Tractatus de Corde" he gave a more accurate description than anybody had hitherto given of the structure of the heart, including its innervation, and, having at his disposal more exact apparatus, he was able somewhat to expand and complete Harvey's exposition of the physiology of that organ.

Lower was for a time assistant to Thomas Willis (1621–1675), whose name is commemorated by the "circle of Willis" at the base of the brain. The "Cerebri Anatome" of the latter (1664) was the most complete and detailed account of the nervous system that had been published up to this time, though his hypotheses as to the functions of the parts he described left much to be corrected later. In the preparation of this work he had been helped by Lower and Sir Christopher Wren, who drew the illustrations. Willis was as distinguished a physician as he was a physiologist.

A name that is sometimes overlooked in the history of British Science is that of Clopton Havers (?1650/60–1702). He was for a time educated at St. Catherine's Hall, Cambridge, but left the University without taking a degree. He took the M.D. at Utrecht in 1685, and practised in the city of London. But he was an anatomist as well as a physician, and was the first to give an adequate account of the structure of the bone, and this in his chief anatomical work "The Osteologia Nova, or some new Observations of the Bones and the parts belonging to them." His name is commemorated by the Haversian Canals, a name which is still used to designate those smaller channels of the bone through which the blood-vessels pass.

British animal physiology, which had started magnificently with Harvey, and had continued under Mayow, de Mayerne and others, was carried forward by Stephen Hales (1677–1761). He was a born experimenter, and, as a student, worked in the "elaboratory of Trinity College," which had been established under the rule of Bentley, ever anxious to make his college the leader in every kind of learning. We have said something about the contribution of Stephen Hales to vegetable physiology, but he was no less brilliant as an animal physiologist. In the second part of his statical essays, entitled "Haemadynamics" (1733), a real advance is recorded in the physiology of circulation. Hales invented the manometer, with the aid of which he was able to make quantitative estimates of blood-pressure, and measure the velocity of the blood-current. He knew how to keep blood fluid with saline solutions. He studied the shape and form of muscles in contraction and at rest, and had a considerable knowledge of secretion. He worked much on gases and paved the way for Priestley and others by devising methods of collecting them over water. Of him, Sir Francis Darwin writes:—

> "In first opening the way to a correct appreciation of blood-pressure Hales' work may rank second in importance to Harvey's in founding the modern science of physiology."

He was a master of scientific method and the greatest physiologist of his century. There were, however, many others, and Professor Langley has summarized the work of some of them in his "Sketch of the progress of the discovery in the eighteenth century of the autonomic nervous system."[1]

In the eighteenth century a most distinct advance in animal physiology was made north of the Tweed by Joseph Black, whose work in Physics and Chemistry has already been described (*see* p. 65). Investigating the properties of carbonic acid gas or "fixed air," as it was then called, he noted that "fixed air" is also present in expired air, and is physiologically irrespirable, though not toxic.

William Hewson (1739–1774), a pupil of the Hunters (*see* Chapter X.), became assistant to them, and John Hunter left him in charge of his dissecting room when abroad with the army. For a time Hewson was in partnership with William Hunter. It was he who discovered the existence of lymphatic and lacteal vessels in birds, reptiles and fishes, a fact which was of great importance in view of the opinions held by the Hunters that absorption is the function of these vessels; for hitherto the opponents of this view had pointed to the absence of these organs in the lower vertebrates. A more important work was embodied in his experimental enquiry into the properties of blood (1771). Hewson showed that when coagulation of the blood is delayed by cold or by the addition of neutral salts, a coagulable fluid may be separated from the corpuscles. He further showed this fluid was an insoluble substance which could be precipitated. According to Hewson's view, coagulation was due to the formation of this substance which he called "coagulable lymph," and which we now call "fibrinogen." For a time his work was forgotten, but now at last its value is fully recognized.

The Quaker physician, Thomas Young, whose brilliant work in Physics has been described in our first chapter, was the founder of the science of Physiological Optics. He studied under John Hunter, and amongst his early discoveries he showed that the accommodation of the eye to different distances is due to changes in the curvature of the crystalline lens. He gave the first description of astigmatism of the eye, and showed how it could be corrected by tilting the lens, through which the object is looked at; but Young had only come across a slight case of the defect. More pronounced cases require cylindrical lenses, as subsequently shown by Airy (p. 120). He also laid the basis of the theory that colour vision is due to retinal structure corresponding to red, green, and violet, and applied it to the explanation of colour blindness. Young advanced Physiology also in other directions, and in the Croonian Lecture, delivered in 1818, he stated the laws covering the flow of blood to the heart and arteries.

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[1] *Journal of Physiology*, Vol. L., 1916.

Thomas Addison (1793–1860), from Cumberland, was a brilliant pathologist, and owing to his not being a very successful practitioner, lived almost entirely on his teaching and hospital work. He was the first to employ electricity in the treatment of various spasmodic disorders and heart disease, and, together with John Morgan, he wrote the first book in our language on the action of poisons on the living body. He described pernicious anæmia, and in his work "On the Constitution and Local Affection of Disease of the Supra-renal Capsules," he described that disorder which is always associated with his name. This book is now regarded as the starting point of a long series of studies into the diseases of the ductless glands.

A third researcher from the north of England was Sir William Bowman (1816–1892), born in Cheshire, the well-known ophthalmic surgeon. He contributed much to the science of physiology. He it was who discovered and described striated muscle, basement membranes, the ciliary apparatus of the eyeball; but perhaps he is best known for his research on the kidney, his theory being that while the tubules and plexus and capillaries are the parts mostly concerned in the secretions of urea, lithic acid, etc., the malpighian bodies were the organs which separated the watery constituents from the blood.

With the arrival of Michael Foster (1816–1907) in Cambridge as Prælector in Physiology at Trinity College in 1870, began an era of great activity in biological research in that ancient University. This subject had been by no means neglected under Professor Sir George Humphry, Professor Clark, and others, but Foster brought with him new methods and new conceptions. Owing to the religious tests demanded in those times by the older Universities, Foster had been educated at the University College, London, and after practising as a country doctor for a very few years, he became a teacher in Practical Physiology at his old College, and in 1869 he was elected Professor in succession to Sharpey. He also succeeded Huxley as Fullerian Professor at the Royal Institution. For twenty-two years he acted as Biological Secretary to the Royal Society, and in 1899 he presided over the British Association at their meeting at Dover, in which year he was created a K.C.B. In the year 1900 he was elected M.P. for the University of London, but lost his seat six years later by the small majority of twenty-four votes; it makes one shudder to recall that a man of such outstanding merit should have said: "Not till I became a Member of Parliament did I understand what *power* meant."

When the new Statutes came in at Cambridge, a Professorship of Physiology was established, in 1883, and Foster was the first to hold it. He did but little in original research, but was the cause of a vast amount of research in others. Still he was to some extent a pioneer in the study of Histology and introduced the staining of sections with log-wood or hæmatoxylin. He was notable as a teacher, and founded one of the finest Schools of Physiology that has ever existed. He was a brilliant writer and a masterly organiser, and undoubtedly one of the best lecturers and after-dinner speakers in the last quarter of the nineteenth century.

On arriving in Cambridge he introduced courses of practical demonstrations modelled on those which Huxley was carrying on at about the same time in London, and from the first he was surrounded by a brilliant group of students, amongst whom were Balfour (*see* page 284), Walter Gaskell, Sheridan Lee, J. N. Langley, Newall Martin, Sherrington, George Adami, Henry Head, and many others. Foster's text-book of Physiology, the first edition of which appeared in 1876 and was followed by five others, was a classic, and, although in so changing a subject, it was almost impossible to keep pace with the advances of a growing science, it was, for its time, one of the most inspiring of authoritative books. Foster published many other books, all of them remarkable for clear and scholarly diction and a real charm of style, for, like so many men of science, Foster wrote the purest English. The latest of all, "A History of Physiology during the Sixteenth, Seventeenth, and Eighteenth Centuries," has been of the greatest use in the compilation of these chapters. In 1887 he founded the *Journal of Physiology*, the first of its kind in the English language, and remained sole editor of it till a few years before his death.

His great organizing powers were shown in the foundation of the Physiological Society and the International Congress of Physiologists. As Secretary of the Royal Society, he took a leading part in the establishment of the International Association of Academies and the International Catalogue of Scientific Papers. He was a member of numerous Royal Commissions, and had to a marked extent the ear of the Government. If Foster told the Treasury a certain thing ought to be done, it usually was done.

Amongst the most brilliant pupils of Foster was Walter Holbrook Gaskell (1847–1914), a member of the well-known Liverpool family to which Mrs. Gaskell the novelist also belonged. Gaskell came up to Cambridge in 1865, as a mathematician, at the unusually early age of 17 and some months. Four years later he took his degree as twenty-sixth wrangler. He then started to study medicine. A year later he fell under the magnetism of Foster, and immediately began a series of works which have made his name one of the best known in the history of modern physiology.

His work falls mainly under three heads. He began his researches by studying the innervation of blood vessels in striated muscles, and was gradually carried on to the investigation of the small arteries of the heart with varying reactions of the blood. He found that small additions of alkali increased their tone, and small additions of acid decreased it, and he was one of the first to recognize that there is a chemical control in the organs and tissues as well as a nervous one. Later he turned his attention to the innervation of the heart and the cause of the heart beat. At that time it was held that the nerve cells present in the tissues of the heart control its beat. But there is some evidence that the nerves were not the sole controlling cause, and in a series of masterly papers Gaskell expounded the view of the muscular origin of the beat, and showed how the beat is conducted in the four chambers of the heart. Recently great advances have been made in the application of physiological methods to the clinical examination of the heart, and this great help to suffering humanity is largely based upon Gaskell's work. His studies on nerves led him on to investigate the structure, origin, and connexions of the sympathetic nervous system. He described the relations of these ganglia with the spinal cord, and gave an accurate interpretation of their mode of action. His last book, the proof sheets of which he finished correcting the day before the stroke which ended his life, is entitled "The Involuntary Nervous System."

In the early nineties he turned away from his normal work to investigate the action of chloroform on the heart. A Commission had been formed and financed by the Nizam of Hyderabad to investigate the cause of death under chloroform. The Commission reported that death was usually due to the action of the respiratory centre. On re-investigating, with the assistance of Dr. L. Shore of St. John's College, Cambridge, it was found that chloroform had a direct weakening effect on the heart, and that respiration is not the only factor to be watched when that anæsthetic is administered.

Gaskell's work had always been rather on the morphological side, and his third line of enquiry was into the origin of vertebrates from invertebrates. His work on this subject is a monument of ingenuity and a monument of patience. In his view, vertebrates had been derived from some possible crustacean or arachnid-like ancestor, and his investigations into the structure and histology of *Limulus* and of the larval lamprey added vastly to our knowledge of these organisms. But in spite of all his ingenuity and all his patient persistence, he failed to carrry conviction to the heart of his critics, and all we can say about it is that his theory, like other theories of the origin of vertebrates from invertebrates, is still unproven.

Gaskell was a man of broad views. Every new fact he succeeded in establishing he used as a basis for further generalization. He took comparatively small part in the management of the University, but from time to time and whenever really needed, he was willing to place his services at the disposal of what was considered the reforming party in University politics.

During the first half of the nineteenth century, Physiology when it was taught at all was almost invariably taught by medical men in active practice at the various London and other hospitals. As a rule the doctor predominated over the physiologist, and physiology in those days was not so clearly defined a science as it has since become. Perhaps the most outstanding name of this period is William Sharpey (1802–1880). He was educated in Edinburgh, and was a pupil of Dr. John Barclay, Extra-mural Lecturer at that university. He subsequently studied at Paris. On returning to England he started a private practice, but he lacked a good bedside manner, and was obviously unsuited for the duties of a practitioner, so from 1826 onwards he devoted himself entirely to pure science. He spent some years abroad trudging the roads in true medieval style from one university town to another in Central Europe, and in 1829 he established himself as a teacher in Edinburgh. Later he succeeded James Quain as Professor of Anatomy and Physiology in what was then the University of London, and is now known as University College, Gower Street, and here for the first time a complete course of lectures on Physiology were delivered by one who was purely a physiologist. He was a born teacher, and his lectures were models both in matter and form. For a time he was Secretary to the Royal Society and a member of the General Council on Medical Education and Registration.

Sharpey was a master of sound judgment, extraordinary memory, and one who could deeply interest his pupils in the subject he had at heart. Amongst his scholars were Michael Foster and Burdon Sanderson, the latter of whose work at London and Oxford notably carried on the tradition of his master. Although Sharpey was a man of force and power he, like Michael Foster, was perhaps more instrumental in getting published the work of his students than of publishing his own; but the few papers, which are enumerated in the "Dictionary of National Biography" under his name, are papers of permanent value.

We have mentioned before that men of science were less specialized at the earlier part of our period than they have now become. Even the holding of professorial chairs in the earlier part of the nineteenth century usually involved teaching in more than one science. Up to the year 1866, the professor of anatomy at Cambridge was responsible for the teaching of zoology as well as for that of anatomy. In many other places, the professorship of zoology was responsible for what teaching there was in animal physiology, as at Manchester, where W. C. Williamson combined the chairs of botany, geology, zoology and animal physiology. In the London hospitals, strictly scientific subjects were taught by doctors in practice who were on the staff of the hospital.

It is quite impossible to detail the varied and successful activities of the numerous physiologists who have worked during the last forty years. Conspicuous amongst them was Wooldridge. He was a pioneer. He was convinced that many of the chemical and quasi-chemical problems presented by the processes of life had been attacked too much by laboratory methods remote from the animal itself. He turned to the coagulation of blood as a type of such processes, and decided that an analysis of the phenomenon must involve observations upon the reactions offered by the living animal. He developed the technique of injecting extracts of tissue and organs into the circulation, and rapidly obtained results which gave new conceptions to physiology.

He did not live to produce a finished theory of blood coagulation, but it is not too much to say that his work initiated the modern studies of immunity, and was the foundation of what is almost a new science.

It is not proposed to enter into the consideration of the enormous advances that English men of science have contributed to the practice of medicine and the alleviation of pain. Sir James Young Simpson (1811–1870) discovered chloroform, thereby immensely improving the possibilities of operations, and to a quite unbelievable extent reducing pain, not only of our poor suffering humanity, but of the animal creation. Edward Jenner (1749–1823) led the way with vaccines and for the first time introduced the practice of preventive innoculations. Sir Charles Bell (1774–1842) cleared up the relations between the functions of the anterior and posterior roots of the spinal column, and made numerous other discoveries on the nervous system; and Lord Lister, whose father had almost re-invented the compound microscope, made many discoveries, by far the most important of which was his definite discovery of the part played by micro-organisms in wounds. The antiseptic principle in the practice of surgery dates from him and from his time, as Dr. F. H. Garrison says, "when his body was laid to rest in Westminster, England had buried her greatest surgeon."

It is impossible to deal with more than but a very few of the distinguished physiologists who were working at the close of the last century. One of these, however, must be: Charles Smart Roy (1854–1897), who was educated at St. Andrews and the University of Edinburgh. He fought through the Turco-Serbian War, and whilst in Epirus invented his frog cardiometer. For a time he was assistant at Strassburg University, and here it was that he invented the instrument which is best known in connexion with his name, the Renal Oncometer, for the study of the variations of the blood-flow through the kidney. Later, as George Henry Lewes Student, he worked with Foster at Cambridge, and in 1884 was elected to the Fellowship of the Royal Society, and shortly afterwards was appointed first Professor of Pathology in the University of Cambridge.

Hampered by ill-health and by want of accommodation at the laboratory, he nevertheless produced work of great value, and he succeeded in training a number of students of great eminence, amongst whom J. G. Adami, W. Hunter, Alfred Kanthack, Lorrain Smith, W. Westbrook, and Lewis Cobbett, deserve record.

With Adami he carried out a long series of researches on the mammalian heart, which involved the invention of the cardiac-plethysmograph and the cardio-myograph, which greatly helped to overcome the mechanical difficulties of the subject. But he by no means confined his attention to this branch of pathology. He had been instrumental in checking a cattle plague in the Argentine Republic by protective inoculation, and in 1885 proceeded to Spain to investigate an outbreak of cholera which threatened to be serious.

As a lecturer he showed little interest in his pupils, but to a researcher he was kindness itself, and unremitting in his helpful aid. He was one of the few who at that time were convinced that aviation was coming, and he made several experiments on flying machines.

CHAPTER XII

GEOLOGY

IN tracing the progress of any line of scientific research it very often happens that our enquiries are largely centred round the life of one man. It may be that he has only collected and put into shape ideas which have been growing in men's minds when at last a flash of genius has illuminated the paths of research and the wisdom of many has been crystallized by the wit of one.

It may be that a fortuitous display of phenomena not before exhibited has appealed to the imagination of men, or combinations of opportunity and talent have started local intelligence upon the paths of observation.

The striking variety and obvious relations of surface-features and rock-characters in England have undoubtedly had much influence in starting geological observations in this country. England is only a small bit of the contorted western margin of the uplifted Eurasian continent. The great folds which brought it all up within reach of denudation are traversed here and there by belts of more sharply crumpled rock which give pause to the periodically encroaching seas. More than one such system of plications has produced the frilled edge of western Europe with its association of harder and softer rocks and has thus formed the natural breakwaters which have held back for untold ages the tremendous billows of the Atlantic Ocean hurled against them by the South-West winds. In tracing the progress of English Geology by reference to the lives of those who have done most to promote it we shall soon find that it was seldom mere accident that started them on their way.

We cannot satisfactorily discuss the influence of individuals upon Geological discovery without realising that

England's place on the globe and consequent geographical features have made her a Geological microcosm in which almost every known formation is represented in some part of the surface, and that the secrets of her structure and history are best disclosed in the mountainous regions of Scotland, the Lake District, and Wales, rather than in the less disturbed and more regularly disposed strata of the eastern and southern counties. It has thus been in the more complicated regions of the north and west that most of her prominent geologists have been born or have found the sphere and stimulus of their investigations.

Many a surveyor had observed the obvious fact that as we proceed across the country various kinds of rock appear at the surface one after another, and these have been laid down on plans and maps for economic purposes; but the careful work and shrewd intelligence of William Smith (1769–1839), in the beginning of the nineteenth century, led him to infer that these did not lie side by side like the pieces in a Chinese puzzle, but rested on one another like the tiles on a roof in regular succession, and that older rocks crept out below the newer layers in a constant order. Here we had the principle and mode of succession of rocks once and for all established.

This, however, was not all that we owe to William Smith, for though fossils had been previously collected he now discovered that different plants and animals which lived and died and were buried in the rocks were characteristic of different beds and were followed by different forms of life, and that the difference in these fossil remains enabled him to detect to which formation of the adjoining district an isolated patch of rock was most related.

Here we find the recognition of a chronological sequence of the stratified rocks and of the possibility of identification by means of the organic remains contained in them. The first account of this discovery that every bed contained characteristic and peculiar fossils by which it could be identified was issued in 1799 by William Smith, and in 1815 he embodied the results of his twenty years of observation in the field in the first Geological Map of England and Wales and part of Scotland. His work appeared to

Sedgwick of such fundamental importance that he called Smith "the Father of English Geology."[1] The majority of the names, Lias, Gault, Clunch, etc., which he applied to the sedimentary formations in England, were only names used by local workmen for certain kinds of deposit, but they have been retained and are now the alphabet of stratigraphical classification throughout the world.

As the work of examining the visible crust of the earth proceeded men must often have raised the question how did Nature bring about these vast changes?

Dr. James Hutton (1726–1797), who in qualifying himself for the Degree of Doctor of Medicine had familiarized himself with the methods of scientific research, had many interesting questions forced upon his notice in the cultivation of his estate in Norfolk. These he attacked by strict inductive methods, but the theory which has always been most especially associated with his name and which now forms the foundation of geological research relates to the manner of the building up of the crust of the earth and the production of its subsequent modifications. These, he contended, had been brought about by agents and processes still seen in active operation somewhere on the earth, and in 1785 he communicated to the Royal Society of Edinburgh these conclusions. John Playfair (1748–1819), his pupil, published in 1802 his classic work entitled "Illustrations of the Huttonian Theory of the Earth," and demonstrated the igneous origin of granite and the work of the agents of erosion in the production of scenery. It often happens that a disciple of the originator of a new idea says and writes more in defence of the theory than the original author himself. We heard more about evolution from Huxley than from Darwin.

Many fierce controversies arose around and about the principal matters in dispute between Huttonians and Wernerians as to the relative importance of fire and water in geological phenomena, all of which have had the useful effect of turning men to seek facts from Nature in support of their own several views.

The school of Catastrophists which had indulged in wild

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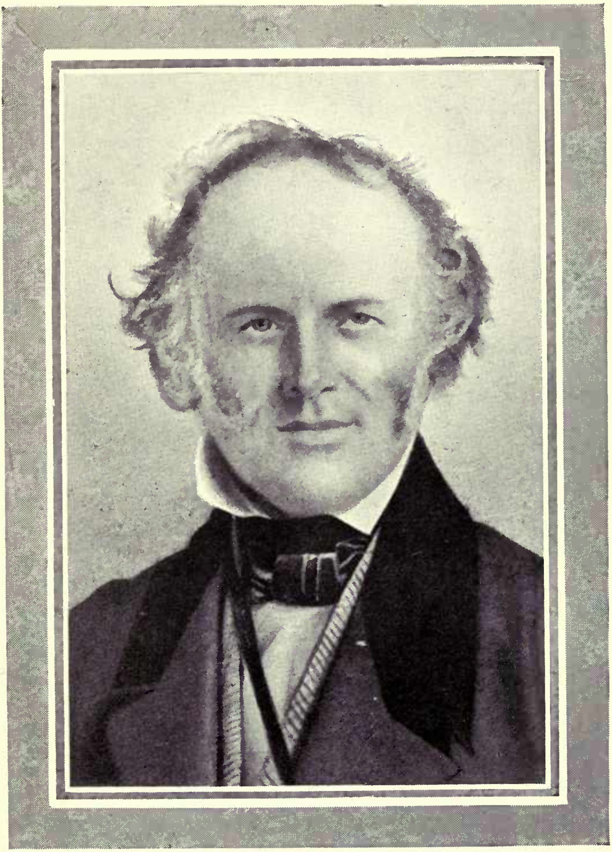
[1] Proc. Geol. Soc., Vol. I., p. 279.



Charles Lyell

From a daguerreotype by J. E. Mayal

speculations on the causes of changes in the earth's physical and organic history had their fallacies exposed by the work of the successors and followers of Hutton and Playfair. For from the seed sown on English soil by these two pioneers sprang the sound healthy tree of Uniformitarianism throwing out many branches brightened often by the flowers of genius and eloquence, laden with the rich fruit of patient research and honest criticism, sometimes warped by opposing accidents but always deep-rooted and sound at the core. Many a good workman helped to till the soil, but one name stands out in bold relief over the entrance to the garden of English Geology. Sir Charles Lyell (1797–1875) was a barrister who turned to geology when he found that an increasing weakness of sight prevented his following other pursuits for which he had been more specially trained. Lyell is the man to whom English Geology owes most. For half a century he supported the Uniformitarian theory, training the growing plant, checking unwholesome growths. Lyell watched the progress of research into the modern changes of the earth and its inhabitants, distinguished the true from the false, and dismissed the evidence for that which was not yet proven. His great work entitled "The Principles of Geology" was first published in 1833, and its publication marks an epoch in the history of Geology.

It is a long and winding way from the region of speculation in which Werner and his disciples here and abroad sought to find out how basalts were precipitated out of an aqueous mixture, to the hardly won ground on which Alfred Harker and his friends and pupils now urge with persuasive accumulation of experiment and observation how each ingredient was segregated according to its affinities out of the eutectic magma which is now regarded as an inferential fact.

Many strong men helped on the work, some, like Dr. Samuel Allport about the beginning of the 70's, quietly collecting material, others, like David Forbes, testing and criticising and giving out freely in discussions from the vast stores of knowledge thus acquired, others teaching and writing like Teall, to whom we owe the first text-book on British Petrography.

Much of the research falls within the sphere of Chemistry, but it is to the microscope and its accessories that we owe most of the advances made.

Henry Clifton Sorby (1826–1908) may be regarded as the pioneer along this line. He read a paper on the subject before the Geological Society in 1857 describing the structure of crystals as giving an indication of the origin of minerals and rocks. These he studied by means of thin slices, a method which he had previously, in 1850, applied to the study of limestones. Sorby was followed by the Rev. Prof. Bonney, an accomplished scholar and keen controversialist, who grasped at once the value of these new instruments of research, vindicated Sorby, and by his academic teaching and writings brought the new methods into the prominent and popular position which they now occupy.

"La paléontologie suive les marteaux"[1] was a phrase in which it was sought at a recent International Geological Congress[1] to point out that it generally happened that the collections of fossils which have furnished the materials for comparative study or for the discrimination of important series of strata owed their existence to the accident that they were obtainable round the home of some keen investigator who, working single-handed or gathering round him a band of like-minded friends, had availed himself of his special opportunities. In this way all available exposures in the district were well searched ; the strata were called after the localities where they were first or best seen, and genera and species were named after some one whom it was desired to honour or some character that appeared distinctive. In offering a comparative sketch of the development of stratigraphical research in Britain we may take the names of the pioneers alphabetically, chronologically, or topographically, and the above considerations will soon convince us that a biographical sketch of the founders leads us at once to a consideration of the locality in which their discoveries were made. We can hardly select a better example in illustration of this than the district round St. David's. Here the oldest rocks in the British Isles were seen, folded and contorted it is true, but still revealing a definite order of succession among the varieties of lithological character. There are there older granitoid masses succeeded by overlying volcanic series. Dr. H. Hicks (1837–1899), a young local medical practitioner, attacked this difficult problem in the latter half of the nineteenth century, and gave the latinized local names of Dimetian and Pebidian to the two principal divisions. Professor Bonney, E. B. Tawney, and others soon took up the work and were in time able to draw up a sketch of the history of that early metamorphic series. Similar rocks were discovered elsewhere in the same position with reference to the fossiliferous formations and, though differing in details, were easily co-related with the typical series of St. David's. These had been noticed by earlier stratigraphical geologists, but were passed over with only a short description. There was, however, little doubt about the Archæan Rocks (as they came to be called) of North Wales, of the Midlands, where they have been described by Callaway and others, and of North-West Scotland, where a new difficulty was introduced by the wondrous earth movements which left these as well as some newer rocks folded, broken, displaced, and crushed, often beyond recognition. The researches of Dr. Hicks and his able exposition of his progressive views on the Archæan Rocks are sufficient to prove what geologists owe to the accident of his residence at St. David's; but there was yet more left for him to discover. Resting upon the denuded surface of the Archæan Rocks were the Basement Beds of the Cambrian separated from the pre-Cambrian Rocks by a vast interval of time. The Survey had passed over the district without detecting any trace of fossils in these beds, but Hicks resided there, and his hammer left little untried. He found fossils in these early Cambrian beds and, incited to closer search, he found them in lower and lower beds till there was hardly any horizon from which he had not procured new species and new genera. This brought Salter, one of the most acute of palæontologists, to his side. These unexpected discoveries are recorded in the name given to a trilobite, seventeen inches long, which was called *Paradoxides Davidis*, the specific name connecting it with St. David's.

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[1] **Rept. International Geol. Congress, Petrograd.**

The subdivisions in which these various forms occurred were named from the localities where they were first or best revealed to the hammer of the geologist, and so the lists of the earliest fossiliferous rocks and their fossils are filled with names dear to the tourist and the artist.

The correlation of these by means of their fossils with the rocks exposed in other areas rapidly followed, as, for instance, by David Homfray, at Portmadoc, and soon the unexpected *Paradoxides* and its associates were recognized among the lowest beds of the fossiliferous rocks all the world over.

Other systems were determined in course of time: the home of T. T. Lewis (1801–1858), of Aymestry, is still marked by the Aymestry Limestone, while the position of the Llandovery Rocks as now defined by the Survey was determined by Dr. Williams, of Llandovery. The Llandovery Rocks were subsequently cut off from the Caradoc Sandstone, and their true position correctly fixed by Sedgwick under the name May Hill Sandstone. A region so full of promise as the borderland of Wales attracted Sir Roderick Murchison (1792–1871), who, in the first half of last century, collated the evidence and gave to the world in 1893, in his magnificent work, the Silurian System beautifully illustrated by Sowerby. The name Silurian is derived from the Silures of South Wales, the ancient tribe which so long withstood the invading Romans.

In the meantime Prof. Adam Sedgwick (1785–1873), stimulated by the work of Jonathan Otley in Cambria, and with a personal acquaintance from childhood with the rocks of the North of England, was attracted by the charms of a wild and almost unexplored country, and threw all his energy into the work of unravelling the succession of stratified rocks exposed in the mountains of Cambria. His results were given to the world in papers published by the Geological Society during the same period and in other works in which the fossils were figured and described by Salter and McCoy. It is to Sedgwick that Geology owes the name Cambrian for the oldest known group of fossiliferous rocks; and it was his genius which introduced order into our knowledge of the older Palæozoic rocks of the North of England and Wales, and laid the foundations for subsequent work in the complicated regions where they are developed. Sedgwick's influence on the modern school of geologists is difficult to overestimate.

At the close of the Silurian Period there was an irregular sinking of the land. The old surface was worn down and the material for new lands built up from the products of the waste. England was in the region of most constantly recurring movements; and it so happened that during the period that now supervened the British Isles formed part of the margin of Eurasia, in which there were more limited hydrographical areas. In one place corals grew in bright clear water, while, not far off, lagoons and swamps favoured the growth of a rich semi-tropical vegetation, with a fresh or brackish water fauna in which fish abounded. The beds with this later facies received the name of Old Red Sandstone. Local geologists were led to study the exceptionally rich deposits which occurred near their homes, and thus the fishes of the Old Red Sandstone in Scotland arrested the attention of Hugh Miller, one of whose fascinating books was a description of this formation.

Sir Henry Delabeche (1796–1855) was attracted to the tongue of land which runs out to meet the Atlantic on our south-west coast. He recognized that mapping, mapping, mapping, was the chief essential for the understanding and recording of the geological structure of a country. He long worked single handed at the district, and published treatises and memoirs which are still classic works. But his crowning achievement was the establishment of the Government Geological Survey, which has developed into a great school of geological research, and proved the model on which all similar institutions have been organized.

John Phillips (1800–1874), the Oxford Professor of Geology, was born on the great rim of rocks which hold the South Wales Coal field as in a basin. From its swelling hills and crags it was called the Mountain Limestone, a name by which it is still commonly known. Phillips was drawn away to Yorkshire, where he soon found himself on the very same Carboniferous rocks, on which, as well as on the secondary rocks which succeeded them, he wrote admirable treatises.

The nomenclature followed the hammers of these leaders of research, but now, alas, students cannot avail themselves as fully as they might of these geological classics, because hardly any of the fossils retain the name originally assigned to them. Names, instead of being regarded as a means of recalling the forms referred to, have become a means of forcing on the world new theories of classification which have to be changed again when later authors are impressed by the value of other similarities or differences.

In the working of coal mines and quarrying of limestones of the Carboniferous formation opportunities are offered to the hammers of the palæontologists and stratigraphists to follow the exposed rocks, and so we find the same story repeated. Witham, Binney and Williamson collected the fish and the plants from the coal measures near Manchester; and Lindley and Hutton devoted their attention to the study of the vegetable remains

At the close of the Carboniferous period there again ensued a period of local destruction of older beds, followed by the deposition of fresh rocks of the New Red Sandstone. Vast movements of continental masses were taking place and hydrographical areas became still more limited in extent and consequently more varied in their results. So much, however, did they present a general uniformity in the character of the sequence and in their prevailing colour that these basement beds of this new system, the so-called Poikilitic or Variegated series of Phillips, came to be known as the New Red Sandstone. The lower part gave rise to much controversy, as it was by some considered the equivalent of the Permian of Russia, and by some bracketed with the underlying Carboniferous rocks. Passing by these details of classification we find that the study and nomenclature of these deposits in parts of England were determined by the home of Charles Moore (1815–1881), near Gloucester and Dr. E. P. Wright (1834–1910), at Cheltenham. W. H. Fitton and G. A. Mantell in the South of England elucidated the sequence of relations of the Jurassic and Cretaceous beds and utilized their local opportunities of adding to our geological knowledge of these formations and their fossils.

Thus we see that biographical notices of the early geologists carry us to their homes round which the recreations of leisure hours enabled them to work out in detail the succession of the rocks and the distribution of their organic remains. The names attached to the formations and now in common use throughout most of the world prove that England has contributed most largely to the establishment of the sequence of events in the earth's history and to laying the foundations of a rational system of classification of the strata.

Amongst the Tertiary rocks Sir Joseph Prestwich (1812–1896) and Edward Forbes (1815–1854) traced the succession of beds particularly in the London and Hampshire basins and demonstrated the value of the now generally adopted terms Pleistocene, Pliocene, Miocene and Eocene which Lyell had first applied early in the last century.

Much good work has been done by British Palæontologists apart from the collecting of fossils in the field, where Palæontology is the handmaid of Stratigraphy.

For instance, Thomas Davidson (1817–1885) during the last decades of the nineteenth century was examining and comparing the Brachiopoda which played so large a part in the life-history of the older rocks, while field geologists far and near sent up to him the results of what their hammers had yielded, thus supplying him with more and more material and availing themselves of his every ready and untiring help to discriminate between zones by means of their fossils.

Edwards and Haime did the same for corals. J. W. Salter (1820–1869) had established many of the recognized genera of trilobites in the course of his investigations of the faunas of the older rocks between the years 1840 and 1855. McCoy's labours covered a wide field, but his chief work lay amongst the fossils of the older rocks. To James de Carle Sowerby (1787–1871) we owe many of the names of fossils which have a cosmopolitan distribution. Sir Richard Owen's (1804–1892) researches amongst fossil vertebrates gained him the reputation which was due to his remarkable acumen and minute knowledge of anatomy.

While pointing out where, how, and why British geologists were pressing on special research we must not forget those who, having acquired wide and accurate knowledge of many branches, have collected and sifted the evidence and given the results of their labours in the form of text-books, and memoirs to which students may turn for the latest and most up-to-date views on each advancing front. Here we must mention the two Geikies. Dr. James Geikie (1839–1915), besides valuable memoirs on general geology, has given us a summary of the arguments in favour of a correlation of astronomical cycles with geological periods. Sir Archibald Geikie has in text-book after text-book met the wants of every age, and, in the clear and attractive language which Scotsmen seem to have by nature, or to have evolved the method of acquiring by education, has kept generations of students supplied with accurate information as to the state of the evidence on the many questions raised in the progress of an advancing science.

This may be called an age of text-books, many of them entitling their authors to a foremost place among those who are helping on the progress of science, but we cannot here even give a list of their names.

We are too apt to attach such importance to our modern theories that we forget what a great advance an earlier hypothesis had often made on pre-existing views. It was a shrewd observation which induced the clever and courageous Dean Buckland (1784–1856) to maintain that a large part of the superficial deposits which are seen heaped up on the tops and flanks of the highest hills and filling the deepest valleys of the North of England must have had an entirely different origin from the alluvial deposits such as we see being laid down now, and to venture on the bold suggestion that there had been in quite recent times a great submergence and that the sea once swept over the land and left as the result of the deluge these tumultuous deposits hence called Diluvial.

Wider travel and more detailed work, however, showed a closer analogy between most of these so-called Diluvial formations and the masses of débris carried on, in, or under the ice and left at its foot when the glaciers or ice sheets melted. Agassiz pointed this out and a grand company of Scotch and other geologists immediately set to work on the details of every section to prove or disprove the truth of each new suggestion.

In the domain of Economic Geology William Smith's observations were primarily connected with the question of soils; while Farey's descriptions in 1811 and 1813 of the Derbyshire Coal Measures and lead mines and of the dislocation of the strata were of practical value. To questions of water-supply Prestwich's attention was specially drawn, and the possible extension of the Coal Measures beneath the South-East of England was maintained as far back as 1855 by Godwin Austen, whose geological conclusions have now been verified.

The energy of geologists still living amongst us does not slacken and the reputation of British workers in this branch of science is well maintained, while the application of the results of geological research to economic purposes is having an ever-increasing stimulus given to it.

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