Stephen Hales: Physiologist and Botanist, 1677-1761.¹

By Dr. A. E. CLARK-KENNEDY.

STEPHEN HALES was born at Bekesbourne in Kent on Sept. 17, 1677. He was admitted a pensioner of Corpus Christi College, Cambridge, in 1696 and elected a fellow in 1703. At the University he studied theology, chemistry, physics, and astronomy. In 1709 he was appointed minister of Teddington in Middlesex. Soon after, he commenced a long series of researches on the physiology of plants and animals, in which he applied his knowledge of physics and mechanics acquired at Cambridge to the problems of biology.

Hales's first scientific endeavour was to make a complete quantitative investigation of the dynamics of the circulation. "Since we are assured," he wrote, "that the animal fluids move by *hydraulic* and *hydrostatical* laws, the likeliest way therefore to succeed in our inquiries into the nature of their motions is by adapting our experiments to those laws." He therefore devised his 'hæmastatical' method, which consisted of the application of the principle of the manometer to animal physiology, and performed a vast number of vivisection experiments of great technical difficulty in the parsonage at Teddington in pre-anæsthetic days. By tying tubes into the arteries and veins of living animals, he was the first man to record blood-pressure. By counting the pulse-rate during life, and then injecting the heart with wax, he computed the circulation rate in horses, cattle, deer, and dogs, showing that in large animals the blood-flow is relatively less than in small. He estimated the actual velocity of the blood-stream in the different arteries and veins. He measured the velocity of the blood in the tissue capillaries by observation with a microscope, and compared it with indirect calculations of the velocity of the blood in those of the lungs. Studying blood-flow in the tissues, he estimated the capillary blood-pressure, and demonstrated vaso-constriction by cold, vaso-dilation by heat. Lastly, by pointing out that the heart responds to increased venous return by increased systolic output, he laid the foundation of the conception now known as 'Starling's Law.'

Hales was essentially a comparative physiologist. Observations on the physiology of plants suggested corresponding experiments on animals. Observations on animals suggested other experiments on the physiology of plants. "About twenty years since," he writes, "I made several hæmastatical experiments on dogs in order to find out the real force of the blood in the arteries: at which times I wished I could have made the like experiments to discover the force of the sap in vegetables; but despaired of ever effecting it, till by mere accident I hit upon it while I was endeavouring to stop the bleeding of an old stem of a vine which was cut too near the bleeding season, which I feared might kill it. Having tied a piece of bladder over the transverse cut of the stem, I found the force of the sap did greatly distend the bladder;

whence I concluded, that if a long glass tube were fixed there in the same manner as I had before done to the arteries of several living animals, I should thereby obtain the real ascending force of the sap in that stem, which succeeded according to my expectation: and hence it is that I have been insensibly led on to make farther and farther researches by variety of experiments." Applying this method, he found the sap pressure in the vine in the bleeding season to be "five times greater than the force of the blood in the great crural artery of a horse; seven times greater than the force of the blood in the like artery of a dog; and eight times greater than the blood's force in the same artery of a fallow doe."

In the field of physiological botany Hales was certainly a pioneer, as he made the first proper scientific investigation of the flow of sap in plants and trees. He measured the rate of transpiration of water from unit surface area of leaves, the rate of absorption of water by unit area of root surface, and calculated the rate of flow of sap along the stem and branches. He measured the sap pressure in stems with, and in stems without, their leaves and branches. Finding that the sap pressure was upwards in all circumstances, he argued against the current theory of a circulation of the sap, and attributed its elevation to transpiration by the leaves, aided at certain seasons by a force exerted by the roots. Of this work he wrote: "I have been careful in making, and faithful in relating the results of these experiments; and wish I could be as happy in drawing the proper inferences from them." But his theory is now regarded as correct in its main essentials.

Hales also invented the present-day method of studying the growth of plants; that of marking stems and leaves at equal intervals. These experiments of his led him to perform a fundamental experiment on the growth of the bone. "As in vegetables, so doubtless in animals, the tender ductile bones of young animals are gradually increased in every part that is not hardened and ossified; but it was inconsistent with the motions of the joints to have the ends of the bones soft and ductile, as in vegetables, therefore Nature makes a wonderful provision for this at the glutinous serrated joining of the heads to the shanks of the bones; which joining, while it continues ductile, the animal grows; but when it ossifies, then the animal can no longer grow: as I was assured by the following experiment, viz., I took a half-grown *chick*, whose leg-bone was then two inches long; with a sharp-pointed iron, at half an inch distance, I pierced two small holes through the middle of the scaly covering of the leg and shin-bone; two months after I killed the *chick*, and upon laying the bone bare I found on it obscure remains of the two marks I had made at the same distance of half an inch: so that that part of the bone had not at all distended lengthwise since the time that I had marked it; notwithstanding the bone was in that

¹ From an address delivered at Corpus Christi College, Cambridge, on June 16.

time grown an inch more in length, which growth was mostly at the upper end of the bone, where a wonderful provision is made for its growth at the joining of its head to the shank, called by anatomists *symphyses*." This experiment, usually attributed to John Hunter, born in 1728, was actually performed by Hales some years before that date.

An accidental observation that bubbles of air ascended with the sap was responsible for Hales leaving the comparatively simple problem of the circulation of the blood to attack a much more difficult subject—the chemistry of respiration. Applying his 'statical method,' Hales demonstrated that plants absorb considerable quantities of 'air.' By distilling vegetable substances he showed that plants contained 'air.' He came to the conclusion that 'air' enters into the constitution of plants, and that an important function of the leaves was absorption of this form of nourishment. "It is by this amphibious property of air," he wrote, "that the main and principal operations of Nature are carried on." As Michael Foster pointed out, Hales was the first man to give a clear enunciation of the existence of gases in both a combined and a free state.

True to his comparative physiology again, from absorption of air by plants Hales turned his attention to respiration in man. Mayow had shown that animals absorb a part of the air they breathe, but Hales carried things a step further when he came to the conclusion that respiration in some way modifies the properties of the air left over so as to make it unfit for life and for combustion. Thus he was led to experiment on himself, and to perform the first re-breathing experiment. Taking a well softened bladder, and closing his nostrils, he proceeded to breathe in and out of it. "In less than half a minute," he wrote, "I found a considerable difficulty in breathing, and was forced after that to fetch my breath very fast, and at the end of the minute the suffocating uneasiness was so great that I was forced to take away the bladder from my mouth." Then in an attempt to find "some means to qualify and rebate the deadly noxious quality of these [expired] vapours," he constructed a more complicated form of rebreathing, apparatus with inspiratory and expiratory valves, so arranged that his expired air had to pass through diaphragms of cloth before being inspired again. He could rebreathe the air contained in this apparatus for one and a half minutes only when there were no diaphragms. When, however, these were moistened with a solution of 'sal tartar,' and then replaced, rebreathing could be continued for five to eight minutes. Moreover, the diaphragms increased in weight to a greater extent than he could account for by absorption of water only. If Mayow can be said to have discovered oxygen, surely Hales described carbon dioxide!

Throughout Hales's writings there is no mention of the phlogiston theory. By this silent refusal to follow Stahl, he kept alive the spark of truth that Mayow had lit, to be rekindled more than a century later by Black, Priestly, and Lavoisier. If only he had followed Mayow a little more literally, and

conceived, as he had, of different kinds of gases, instead of one 'air' with variable properties, he might well have arrived at a true conception of respiration. Be this as it may, Hales's researches had a great practical outcome in his work on ventilation.

In 1740 troops lay embarked off Spithead for an expedition to America. Hales suddenly conceived the notion that large ventilators would be very serviceable in making the air in ships more wholesome. These ventilators were to take the form of large bellows to be worked by hand, which would suck out the foul air from between decks. But he was not alone in this idea. A few months later, Martin Triewald, Captain of Mechanics and Military Architect to the King of Sweden, devised a similar machine. As Hales remarked, "It were indeed a very extraordinary Circumstance, that two Persons at so great a Distance from each other, without getting a Hint of it, one from the other, should happen to hit on inventing a like very useful engine." But it was even more remarkable than this, because at the same time Sutton, a coffee-house keeper in Aldersgate Street, contrived a method of drawing off the bad air on board ship by means of the cook-house fire. Sutton's invention remained in obscurity, but Hales's ventilators at once attracted the attention of the Admiralty and they were fitted on board H.M.S. *Captain*, a seventy-gun man-of-war. His ventilators, however, were received with "coolness by some, and contempt by others." But if they did not find favour at first in the Royal Navy, they met with great success in convict ships and the vessels of the slave trade. Five Nova Scotia ships were equipped with them by the Earl of Halifax. Only one slave died in the ventilated ships for every twelve in those unventilated. In a letter to Hales, Captain Thomson wrote as follows: "We found this good Effect from Ventilation, that though there were near 200 Men on board, for almost a Year, yet I landed them all well in *Georgia* notwithstanding they were pressed Men, and delivered me out of Gaols with Distempers upon them."

Entering the City of London from the west, the traveller of those days must have been confronted by a curious spectacle. Newgate, the ancient gate of London, had been rebuilt with considerable magnificence. "It consisted of a carriage archway in the centre; on the side, the footpath was continued through it, which supplied a shelter for two or three old women, who fried small sausages for sale: and in the centre of it was an entry to the chief prison of the city: the mendicant prisoners for debt stood within the iron-grated door, vociferating their constant supplication for benefactions to a leathern bag which they drew in as often as it was touched: the upper chambers of the buildings constituted the prisons for felons, for whom a door was opened on the South side adjoining the old wall, and it was from this door that the malefactors were received into the cart for their last journey to Tyburn. Upon the summit was a machine for air, invented by Dr. Hales."

In 1750 a tragedy had occurred during the trial

of malefactors at the Sessions House in the Old Bailey. The Lord Mayor, two judges, and a total of sixty persons had died of the gaol distemper, communicated to them by the felons from Newgate. The aldermen of the City of London, naturally seriously alarmed, consulted Hales, and decided to install ventilators in Newgate to be worked by a windmill erected on the leads. Hales's ventilators were also installed in the Savoy Prison, in the gaols at Northampton, Shrewsbury, Winchester, Maidstone, Bedford, and Aylesbury: in the London Small-pox Hospitals, and at St. George's; also in hospitals at Durham, Winchester, and Bristol, and even at Naples. Later they were introduced into the naval and military hospitals and prisons at Gosport, Portsmouth, and Plymouth. So eventually even the Navy was convinced. "God be thanked," writes Hales, "they are now come into general esteem for the apparent salutary good effect of them in our fleets, hospitals, etc. In the beginning of the year 1756, the Lords Commissioners of the Admiralty ordered them to be put on board the *Royal George*, our largest ship: in which the honourable Admiral Boscawen, taking care to have them properly worked, they were found to have the desired good effect, so to refresh the whole air in the ship, as to preserve in good health 850 men: which happy event occasioned their being ordered to be put into the whole fleet."

Wherever Hales's ventilators were installed the air in the wards is said to have been rendered much purer, and the mortality among the inmates from the gaol distemper considerably reduced. But typhus is due to lice, and not to foul air as Hales supposed. No amount of ventilation, however perfect, could have abolished the gaol distemper. Hales's bellows ventilator has gone. Hospitals and prisons are so built in these days that mechanical ventilation is seldom necessary. But his idea of the forcible propulsion of air still persists, and adequate ventilation remains one of the first principles of preventive medicine. Hales must therefore stand for all time not only a great biologist, but also one of the pioneers in public health.

It may seem remarkable that scientific work like this should have been performed by a country parson. But in the study of pure science, though he sought for mechanical explanations always, Hales found confirmation of his faith. "Nature works according to the Laws established at her first Institution," he wrote. "The farther researches we make into this admirable scene of things, the more beauty and harmony we see in them: and the stronger and clearer convictions they give us, of the being, power and wisdom of the divine Architect, who has made all things to concur with a wonderful conformity, in carrying on, by various and innumerable combinations of matter, such a circulation of causes and effects, as was necessary to the great ends of nature." Hales was an ardent parish priest. He made the women of his parish do public penance for irregular behaviour. He prevailed upon the Lord of the Manor to enlarge

the churchyard. He arranged for a new parish water supply. He caused a lantern to be erected on the church tower "in which to hang a loud bell to be heard at a much greater distance, not only for the benefit of the serious and the well disposed, but also as a constant memento to the careless, the negligent, and the profane, who with the wicked in Job are but too apt to say, *Who is the Almighty that we should serve him? And what profit should we have if we should pray unto him?*" He also built a new aisle, and replaced the old wooden tower by a brick one. The money for these alterations was largely raised by the sale of pews, but in addition, Hales contributed £200 himself.

Of his character one of his contemporaries wrote: "He possessed a native innocence and simplicity of manners, which the characters of other men and the customs of the world could never alter; and though he often met with many unworthy objects and uncharitable offices, yet they never once lessened his natural and unwearied disposition of doing good and relieving distress. His knowledge appeared to everybody near him to feed his mind with a nourishment that gave him, in decline of life, and even in its last stages, that vigour and serenity of understanding, and clearness of ideas, which so few possess, even in the flower of manhood: and which he used often to say, he valued as the most perfect of all human pleasures. There are two things in his character which particularly distinguish him from almost every other man: the first was, that his mind was so habitually bent on acquiring knowledge, that, having what he thought an abundant income, he was solicitous to avoid any farther preferment in the Church, lest his time and his attention might thereby be diverted from his other favourite and useful occupations. The other feature of his character was no less singular: he could look even upon wicked men, and those who did him unkind offices, without any emotion of particular indignation; not from want of discernment or sensibility, but he used to consider them only like those experiments, which, upon trial, he found could never be applied to any useful purpose, and which he therefore calmly and dispassionately laid aside."

Hales had been elected a fellow of the Royal Society and awarded the Copley Medal, but his reputation as a scientist was now international. In 1753 he was elected one of the eight foreign members of the Royal Academy of Sciences in Paris. Three years later war was declared with France. Hales laboured unceasingly to get Louis XV. to order the installation of ventilators into the French hospitals and prisons where British soldiers were confined. Exerting all his influence through Duhamel and the Duc de Noailles, he was at last successful, and his ventilators were installed into some at least of the French gaols, with, it is said, considerable reduction in the death-rate among the British prisoners. On this occasion the minister of Teddington was heard to say that he hoped no one would inform against him for corresponding with the enemy!

Hales was now more than eighty years of age.

He had advanced science by fundamental experiments on the circulation of the blood, the flow of sap, the chemistry of respiration, and the growth of bone. By his work on ventilation he had established one of the first principles of preventive medicine. He had ministered faithfully to his parish for more than fifty years. In the last scene of his active life we see him triumphant, reducing the mortality among British prisoners exiled in the gaols of France. Thus did Hales serve science and humanity, his King and his country. "He delighted to promote the honour of his God by advancing the best welfare of man-

kind. In this employment, blessed with serenity of temper, he calmly met his death as an acquaintance long familiarised to his mind." Stephen Hales died in 1761 in the eighty-fourth year of his age. His monument stands in Westminster Abbey, but his body lies buried under the tower which he had built himself for the church he had loved so well. There is no epitaph written on his grave, but 250 years after the birth of this great son of this College, let us adapt the words John Wesley wrote of him:

"How well did Science and Religion agree in this man of sound understanding!"

A National Bureau of Information.

By Dr. S. C. BRADFORD, The Science Library, South Kensington.

A READY means of ascertaining what information has been published on any subject is of the highest importance to every worker in science and technology. As Sir Philip Cunliffe-Lister said in a foreword to the Report of Proceedings of the first Conference on Information Bureaux and Special Libraries, in 1924, "The growth of knowledge during living memory has been remarkable and its application evident in every direction. Whilst it is generally recognised that knowledge is power, it is none the less true that a considerable proportion of accumulated knowledge is lying dormant and untapped. An immense amount of extremely valuable information is in existence, if only one knows where to find it. The volume of modern knowledge being far beyond the mental grasp of any individual, it becomes a vital necessity to provide a master-key whereby the common storehouse may be unlocked."

To this end much bibliographical work has been carried out. Perhaps the earliest suggestion to prepare a comprehensive catalogue of scientific papers was made to the British Association in 1855 by Prof. Henry of Washington. Afterwards, the suggestion bore fruit in the production of the "Catalogue of Scientific Papers" issued by the Royal Society from 1867 and onwards, and later, of the "International Catalogue of Scientific Literature" from 1902, which came to an end with the volume for 1914. Both these indexes covered pure science only. However, the increasing importance of science in every-day life has led to a growing demand for a comprehensive index to the printed records of both scientific and technical activity. Many applications for information or lists of books and papers on special subjects have been received at the Science Library from time to time, and recently such demands have increased in number considerably. These applications have been answered so far as possible from the subject-matter catalogue of the books, monographs, and separate papers which are in the Library, and from the extensive collection of bibliographies of every kind that has been gathered together for this purpose; but the labour of preparing such lists is very considerable, and the need for a comprehensive subject-matter card-index from which the desired information

could be ascertained immediately has long been realised.

An information service covering the whole field of science and technology has been in process of organisation for some years, and recently the acquisition of a very large collection of subject-matter index-cards relating to articles and books on science and applied science, published during the period 1902-1914, together with an almost equally large collection of bibliographical slips, which require only to be mounted on cards to bring this index up to date, has placed the Science Library in possession of an exceptionally large card repository which is now being arranged.

The Library now possesses:

1. A large and increasing collection of the scientific literature of the world, both books and periodicals, which are available for consultation in the Library or for loan to scientific institutions and research associations in Great Britain. (The catalogue of books is in the form of a card-index only, but a list of current periodicals is available, price 1s. 3d. post free.) The Library contains already more than 6000 of the scientific and technical journals recorded in the "World List" and, together with the older series and those acquired after the marking of the List, now possesses more than 7000 such periodicals, which are being added to at the rate of about 1000 periodicals annually.

2. A comprehensive subject-matter card-index to papers in scientific and technical books and periodicals, to be used as a key to recorded information and for the supply of lists of papers on given subjects. This index, which will soon include about one and a quarter million cards, is classified according to the Brussels Extension of the Dewey Decimal Classification, so that all references to information on a given subject can be found in one place under a single classification number, and this can be ascertained from the alphabetical index of subjects.

Bibliographies of special subjects are in course of preparation at very many institutions, but much of the labour expended in this work is only partially effective, because most of these bibliographies are classified on different systems, so that it is impossible to amalgamate them into a single index. To consult them, many volumes and parts must be