STEPHEN HALES*
(1677–1761)

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STEPHEN HALES was born at Bekesbourne in Kent, September 7, 1677, the sixth son of Thomas and Mary Hales. Only meager information is obtainable in regard to his early life and training. In 1696, at the age of nineteen, he entered Bennet College, Cambridge. Although we have no definite record we may assume that he applied himself earnestly to the study of religion and natural philosophy. He took a Bachelor of Arts degree and was elected to a fellowship about 1702. In 1703 he was granted a Master of Arts degree. William Stukeley (1687–1765) afterwards M.D., F.R.S., went to the college in 1704. A friendship arose between him and Hales although Hales was Stukeley's senior by ten years. From Francis Darwin we learn that these two college friends roamed the surrounding country together. Hales carried an often-thumbed copy of Ray's "Catalogue of Plants." Everything from fossils to butterflies was eagerly studied by the young philosophers. They dissected frogs, dogs and other animals together. John Francis Vigani (1650–1712) who became the first professor of chemistry at Cambridge in

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1703, seems to have attracted them. In a room at Trinity College, the laboratory of Sir Isaac Newton, they repaired to repeat some of Boyle's experiments and to watch the demonstrations of Vigani. They prepared various substances, "some of use, some of curiosity." Hales studied astronomy. He knew well the Newtonian System.

Stephen Hales (1677–1761).

While yet in college he constructed a machine of brass to show the movements of all the planets. After having been in college some twelve years (1696–1708–9) we next hear of him being made perpetual curate of Teddington, about 1710. He took orders and in 1711 became a Bachelor of Divinity. The next fifty years, until his death in

1761, his home was in Teddington, Middlesex, where Alexander Pope was a friend and neighbor and Peg Woffington one of his parishioners.

He was married to Mary, daughter and heiress of Dr. Newce, rector of Halisham, about the year 1719, the exact date is uncertain. Mary died two years later, 1721, leaving no children. He never married again.

Although we have none of his experimental data before 1719 there can be little doubt that Hales was busy, as evidenced by the fact of his election to the Royal Society in 1718. In 1719 he reported to the Society some recent experiments on the effect of the sun's warmth in raising the sap in trees. For this he received the thanks of the Society with encouragement to continue the research. This Hales did, reporting before the Society at different times, and in June, 1725, he gave an account of his progress in the form of a treatise. At the request of the Society the work was published in 1727 under the title of "Vegetable Staticks; or, an Account of Some Statical Experiments on the Sap in Vegetables; being an essay towards a Natural History Vegetation. Also a specimen of an attempt to analyse the air by a great variety of chymio-statical experiments, which were read at several meetings of the Royal Society." The work was well received and a second issue was published in 1731. The Society further honored him by making him a member of the council, 1727. Hans Sloane (1660–1753) was at that time president of the Society. Upon the death of Sloane, 1753, Hales was elected to the French Academy to fill his place.

"Vegetable Staticks," as the more elaborate title indicates, deals with the flow of sap in plants of various kinds and the effect of moisture, temperature and types of soil on the pressure under which sap rises. The mercury manometer was used for these determinations, which were always carefully and accurately worked out. The book contains many drawings which prove the ingenuity and care with which the experiments were conducted. In all there are 124 experiments, painstakingly recorded. They represent the original work on vegetable statics and opened at the time a new and fascinating field of plant physiology. Buffon (1707–1788), the French naturalist, translated the work into French. German and Italian translations soon followed. No doubt this work early fell into the hands of Linné (1707–1778), then a young man preparing his first work, "Systema Naturae" (1735). Sachs (1832–97), the well-known German botanist, writes that of the study of plant physiology that took place in the eighteenth century, the work of Hales was the most original and the most important contribution. In honor of Hales, John Ellis, whom Linnaeus termed "The bright star of Natural History," named a newly discovered genus, Halesia.

Intending at first only to make additional observations and experiments to the volume on "Vegetable Staticks" he found in 1733 that these had grown to the size of another volume. This he called "Haemastaticks," or Volume II of the "Statical Essays."

The following paragraphs give an insight into his purpose:

As the animal Body consists not only of a wonderful texture of solid Parts, but also of a large proportion of Fluids, which are continually circulating and flowing, thro' an inimitable Embroidery of Blood-Vessels, and other inconceivably minute Canals: And as the healthy State of the Animal principally consists, in the maintaining of a due Equilibrium between those Solids and Fluids; it has, ever since the important Discovery of the Circulation of the Blood, been looked upon as a matter well worth the inquiring into, to find the Force and Velocity with which these Fluids are impelled; as a likely means to give a considerable Insight into the animal Oeconomy.

It may not be improper here to take notice, that being about twenty-seven years since, reading the unsatisfactory conjectures of several, about the cause of muscular motion, it occurred to me, that by fixing tubes to the arteries of live animals, I might find pretty nearly, whether the blood, by its mere hydraulic energy, could have a sufficient force, by dilating the fibres of the acting muscles, and thereby shortening their lengths, to produce the great effects of muscular motion. And hence it was, as I mentioned in the preface to Vol. I, that I was insensibly led on from time to time into this large field of statical and other experiments.

He then proceeds to describe the classical experiments by which blood-pressure was first measured:

In December I caused a mare to be tied down alive on her back; she was 14 hands high, and about 14 years of age; had a fistula on her withers, was neither very lean nor yet lusty; having laid open the left crural artery about three inches from her belly, I inserted into it a brass pipe whose bore was one-sixth of an inch in diameter, and to that, by means of another brass pipe which was fitly adapted to it, I fixed a glass tube, of nearly the same diameter, which was nine feet in length: then untying the ligature of the artery, the blood rose in the tube 8 feet 3 inches perpendicular above the level of the left ventricle of the heart; . . . when it was at its full height, it would rise and fall at and after each pulse 2, 3 or 4 inches; . . . Then I took away the glass tube, and let the blood from the artery mount up in open air, when the greatest height of it's jet was not above 2 feet.

I measured the blood as it ran out of the artery, and after each quart was run out, I refixed the glass tube to the artery to see how much force the blood was abated; this I repeated to the 8th quart, and then its force being much abated, I applied the glass tube after each pint had flowed out.

Three horses in all were used in this manner, all of which were to have been killed as unfit for service. From one of the horses he measured the blood lost by bleeding and after adding the probable amount in the large veins estimated the total as five wine gallons, which he recognized as low, remarking that: "There is doubtless considerably more, but it is not easy to determine how much." The jugular pressure in one of the horses he found to be twelve inches when quiet, but this rose to fifty-two inches when the animal struggled.

Experiments similar to these were done on sheep and dogs and he says: "Whatever experiment I principally intended to make on any dog, I usually began with fixing a tube first to the jugular vein and then to the carotid artery."

He filled a number of hearts with melted wax, later cutting away the tissue and estimating carefully the inner surface of the ventricles. Knowing the volume and inner surface of the ventricles, the blood pressure, heart rate, the diameter of the aortic orifice and of the aorta itself, he calculated for horses and various other animals including man, the mean velocity of the blood in the aorta, the velocity of the systolic output and the pressure sustained by the heart during contraction. Although we now know such an estimate would be more or less inaccurate, nevertheless this carried the study of the circulatory system beyond Harvey's work and introduced the method of quantitative investigation. Hales himself appreciated the complexity of the situation regarding the velocity. He says:

Now this velocity is only the velocity of the blood at its first entering into the aorta, in the time of the systole; in consequence of which the blood in the arteries, being forcibly propelled, with an accelerated impetus, thereby dilates the canal of the arteries, which begin to contract at the instant the systole ceases; by which curious artifice of nature the blood is carried on to the finer capillaries, with an almost even tenor of velocity, in the same manner as the spouting water of some fire engines is contrived to flow with a more even velocity, notwithstanding the alternate systoles and diastoles of the rising and falling embolus or force . . .

For tho' the velocity of the blood at its first entrance into the aorta, depends on the proportion the area of its orifice bears to the quantity thrown into it at each systole, and also on the number of these systoles in a given time; yet the real force of the blood in the arteries, depends upon the proportion which the quantity of the blood thrown out of the left ventricle in a given time, bears to the quantity which can pass thro' the capillary arteries, into the veins in that time.

He showed where the greatest resistance to the blood existed by slitting a dog's gut opposite the mesentery and running warm water through from the aorta. The time was recorded for a given amount of water to make its escape in this manner. The vessels in the mesentery were then cut and the time for the escape of the same quantity of water was reduced from six to two minutes. By calculating, he found that this resistance must be greater in the intact animal and accounted for this difference by:

1. The greater fluidity of water as compared with blood.

2. The absence of the back pressure of the veins in one case and its presence in the other.

3. The greater distensibility of the dead arteries.

4. In the case of the slit gut the fluid is no longer obliged to pass through the fine capillaries but runs out through the larger vessels which have been severed.

He appreciated the fact that end pressures are necessarily too high and devised a scheme by which the vessels were placed between two grooved pieces of wood which were later cemented together and to the vessels by means of warm pitch. Through a hole bored in one of the pieces of wood he punctured the vessel, screwed a tube in the hole and allowed the blood to mount into it.

The effects of different substances upon the caliber of the "capillary arteries" were studied. His own description is most interesting:

> I took a young spaniel dog, opened his thorax and abdomen, and having fixed a glass tube which was 4 and ½ feet high, to the descending aorta, I then slit open his guts, from end to end. Then having poured blood warm water on them, and covered them with a folded cloth dipped in the same water, warm water was poured into the tunnel (attached to the tube) which when it had subsided to a mark on the lower part of the glass tunnel 18 cubick inches of warm water were immediately poured in, out of a pot which held just that quantity; the time it was running through the fine capillary arteries was measured by a pendulum that beat seconds . . .

I then poured on seven pots full of warm water, the first of which gradually passed off in 52 seconds, and the remaining six gradually in less time to the last, which passed in 46 seconds.

I then poured in five pots of common brandy or unrectified spirit of malt, the first of which was 68″ in passing, the last 72″.

I then poured in a pot of warm water which was 54″ in passing.

Hence we see that brandy contracts the fine capillary arteries of the guts, and that water soon relaxes them again.

A decoction of Peruvian bark contracted the vessels. A decoction of camomel flowers caused some constriction but not so much as cinnamon-water, with which the constriction was very marked. Pyremont water was also very effective.

He thought that these experiments indicated the probable action of these substances in the living body but understood that no such concentration was probably present in the living organism. His comment is:

'Tis probable that such things as constringe the vessels in any degree, do also proportionately increase the force of the arterial blood and thereby invigorate the animal. But those who much accustom themselves to drink strong spirituous liquors, do thereby destroy the tone of the fibres of their vessels, by having them thus frequently, suddenly contracted, and so soon relaxed again; which makes them like the horse-leech, be ever longing after and thirsting for more and more thereby to regain the tensity of their too relaxed fibres.

Man's blood-pressure he estimated as about seven and one-half feet. Although this is a little high we marvel that he was able to approximate it so closely.

He decided to test further the theory that muscular contraction was brought about by force of the blood dilating the muscle fibers. He soon felt convinced, however, that its force was incapable of producing so great an effect as muscular motion. A more vigorous and active energy whose force is regulated by the nerves seemed to him necessary. "But whether," he adds, "it be confined in canals within the nerves or acts along their surfaces like electrical power is not easy to determine."

Although his work indicated that he had a faint idea of the real process of digestion, his experiments were in no wise framed to the end that Spallanzani's were, a half century later. Hales, after making many hydrostatic experiments on the stomach and intestine concluded:

> So small a compressure can have very little effect in prompting the digestion of the aliments: which is therefore with good reason principally attributed to the concurrence of several other causes; such as mastication and comminution with the teeth, and mixture first with saliva (which is a leaven full of elastic air) and afterwards with the fluid, which is in plenty separated from the glands of the stomach.

Robert Boyle (1627–1691) made experiments with flames and animals *in vacuo* (1660), demonstrating that air is necessary for life as well as for combustion. Robert Hooke (1635–1703) in 1667 showed by blowing a stream of air through the exposed lung of an animal it could be kept alive without movement of chest or lungs. Blood changes were thus indicated. Two years later, 1669, Richard Lower of Cornwall (1631–1691), to whom is ascribed the first blood transfusion in the human (1668), injected dark venous blood into the insufflated lungs and as it became bright he concluded it was by reason of its having absorbed something from the air. Mayow (1643–1679) termed this substance taken from the air nitro-aerial spirit of air. Malpighi (1628–1694) had demonstrated capillary circulation in 1660 and published his "De Pulmonibus," 1661, describing how the trachea terminates in bronchial filaments. These men were pioneers in the study of respiration and their findings do not represent the common knowledge or lack of knowledge of this subject. Hales was still in doubt. He speaks of "plenty of fresh air, that genuine cordial of life." He stands between these men and those of the next generation who contributed so much to the development of our knowledge of this subject, Joseph Black[1] (1728–1799),

[1]He says in his remarks on fixed air: "For I found, that by blowing through a pipe into lime-water, or a solution of caustic alkali, the lime was precipitated, and the alkali was rendered mild. I was partly led to these experiments by some observations of Dr. Hales, in which he says, that breathing through diaphragms of cloth dipped in alkaline

Priestley (1733–1804), Laplace (1749–1827), Lagrange (1736–1813) and Spallanzani (1729–1799).

Hales had the exact amount of refrigeration action of the lungs calculated after having determined the quantity of blood passing through the lungs per minute, the amount of air breathed during the same time, and the difference in temperature of the inspired and expired air. This was found to be enough in two minutes to raise all the blood of the body 0.101928 degrees. He describes carefully the circulation of the lungs. He showed that air in the blood-vessels was fatal; that one side of the thorax might be opened without danger to the animal, but evidently did not recognize the negative pressure there. He calculated the quantity of moisture carried off by respiration. Finally he concludes his discussion of the functions of the lungs with this statement:

> It is probable also that the blood may in the lungs receive some other important influences from the air, which is in such great quantities inspired into them. It has long been the subject of inquiry of many, to find of what use it is in respiration, which tho' it may in some respects be known, yet it must be confessed that we are still much in the dark about it.

In 1739 he was granted the Copley medal and the same year appeared "Philosophical Experiments" with the following title page:

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solution made the air last longer for the purposes of life."

PHILOSOPHICAL EXPERIMENTS

containing

Useful, and Necessary Instructions for such as undertake long Voyages at Sea.

Shewing how sea-water may be made Fresh and Wholsome: And how Fresh-water may be preserved sweet.

How Biscuit, Corn, etc., may be secured from the Weevel, Maggots, and other Insects.

And Flesh preserv'd in hot climates, by salting animals whole.

To which is added

An account of several experiments and observations on Chalybeate or Steel-Waters: With some attempts to convey them to distant places, preserving their Virtue to a Greater Degree than had hitherto been done.

Likewise a Proposal for cleaning away Mud, etc. out of Rivers, Harbours and Reservoirs.

Which were read before the Royal Society, at several of their Meetings.

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The practical side of these experiments is obvious. Hales was ever conscious that he was not a physician and upon matters clinical he was very careful of his statements. He had the greatest respect for physicians but for quacks he had no sympathy. The following quotation from this volume leaves no doubt of his position and gives us some indication of the amount of quackery in England in the eighteenth century:

> Did I indeed hereby seek only popular applause and not the real benefit of Mankind; the more ignorant I was in Physick, the better chance I should have, to be much cryed up by the unknowing Many: The Truth of this, we may have had full proof of, of late Years, in the Instances of several most ignorant Quacks; who have in their turns had a more general Cry of Applause given them, than has come to the share of the most eminent and skilful Physicians, with many of which that Faculty abounds. But the Physicians may well be content to take this contempt more patiently, when they reflect that a petulant fondness for Quackery is the epidemical Disease of this Age; not only in opposition to theirs, but also to other Professions.

In May, 1741, he read before the Royal Society an account of a method for ventilating ships. In November of the same year Cromwell Mortimer, M.D., secretary of the Royal Society, had a letter from Martin Triewald, F.R.S., captain of mechanics and military architect to the King of Sweden, saying that in the past spring he had invented a machine for the use of his Majesty's men-of-war in order to draw out all bad air from under their decks. His treatise was laid before the Royal Academy of Sweden, April 3, 1742, eleven months after Hales' plan was laid before the Royal Society. Neither knew of the work of the other, yet their plans were almost identical. Each consisted of a box-like bellows for drawing out the foul air. They were eventually adopted by all the nations having sea-going vessels. Vessels carrying African negroes to the United States, for example, often lost as much as twenty-five per cent of their cargo. This loss was reduced to five per cent or less. One French vessel saved 308 out of 312 slaves in spite of a most tedious calm and a long voyage.

In April, 1752, ventilators were fixed in Newgate prison. These were operated by a windmill. The death rate was reduced in this prison by the one measure alone from eight to two per month. Other prisons adopted the method of ventilating used at Newgate. Louis xv was persuaded to introduce this system of ventilating into the French prisons in which British soldiers were confined. On this occasion Hales is credited with saying: "He hoped nobody would inform against him for corresponding with the enemy." The ventilator was found very useful in aerating granaries to prevent the grain from spoiling.

Among the many other tracts by Hales was one entitled, "A Friendly Admonition to Drinkers of Brandy and other Distilled Spirits," which was widely distributed even many years after his death. A few of the titles taken from the *Philosophical Transactions of the Royal Society* are: "A Proposal to Bring Small Passable Stones Soon and with Ease out of the Bladder"[2]; "Remarks concerning Some Electrical Experiments"[3]; "Of the Strength of Several of the Principal Purging Waters, Especially That of Jessop's Well"[4]; "Of Some Trials to Keep Water and Fish Sweet, with Limewater,"[5] and "A Description of a Sea Gage, to Measure Unfathomable Depths."[6]

Hales was familiar with Franklin's experiments with electricity. When he was contriving a means to abate hurricanes by exploding the sulphurous air (the collection of which he thought the cause) by shooting bombs or grenades into the air, he says: "In Pennsylvania, Mr. Franklin having fixed a vessel of spirit of wine and iron wire to the tail of a kite, the spirit of wine was fixed in a sulphurous and consequently a highly electrical state of the air." He studied earthquakes and ascribed to them the same cause, volcanic sulphurous charged air. In this consideration he quotes Buffon and Borelli. About Lord Berkeley's "Tar Water" he had little to say; however, he thought it beneficial in murrain among cattle.

Hales was ever faithful to his mission as a minister. His flock always had his solicitude. He helped them to get a supply of good water (1754). He enlarged the church yard "by prevailing upon the lord of the manor." He aided his parishioners in the construction

[2] *Phil. Tr.*, Lond., IX, 159.
[3] *Ibid.*, IX, 543.
[4] *Ibid.*, X, 48.
[5] *Ibid.*, X, 551.
[6] *Gentleman's Magazine*, May, 1754, XXIV, 215.

of a lantern on the church (1748). Later (1754) the timber tower on which the lantern stood was torn down and a brick one put in its place, a large share of the cost of which he himself bore. Under this tower his bones rest in accordance with his request.

Regarding his personality; we have the following remark from Pope: "I shall be very glad to see Dr. Hales, and always love to see him; he is so worthy and good a man."

Others spoke of "his constant sincerity and cheerfulness of mind." The wicked he "considered 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."

In a trembling hand his signature appears on the parish register for the last time in November, 1760. After a short illness, the nature of which we do not know, he died January 4, 1761. The *Gentlemen's Magazine* of that date writes in part:

> On Sunday the 4th instant, died, at his parsonage-house at Teddington, universally lamented, in the 83rd year of his age, the Rev. Dr. Stephen Hales, F.R.S., member of the royal academy of sciences of Paris and clerk of the closet to her Royal Highness the Princess Dowager of Wales. If any man might ever be said to have devoted his whole life to the public, to all mankind, it was Dr. Hales.

Hales' philosophy was of the most practical type. He enjoyed his work because of the benefit he might be able to render his fellow men. It was not solely a pastime to him. In the dedication to his book on ventilators[7] we find this:

> The study of natural philosophy is not a mere trifling amusement as some are apt to imagine; for it not only delights the mind, and gives it the most agreeable entertainment in seeing in everything the Wisdom of the great Architect of Nature: But it is also the most likely means to make the gift of kind providence to us by teaching us how to avoid what is hurtful and to pursue what is most useful and beneficial to us.

Again in the introduction to "Haemastaticks" we read:

> In natural philosophy, we cannot depend on any mere Speculations of the Mind; we can only with Mathematicians reason with any tolerable Certainty from proper Data, such as arise from the united Testimony of many good and credible Experiments.
>
> Yet it seems not unreasonable on the other hand tho' not far to indulge yet to carry our Reasonings a little further than the plain Evidence of Experiments will warrant; since at the utmost boundaries of those Things which we clearly know, there is a kind of Twilight cast from what we know, on the adjoining Border of Terra incognita, it seems therefore reasonable in some degree to indulge Conjecture there; otherwise we should make very slow Advances in future Discoveries, either by Experiments or Reasoning.

A clergyman of the church of England, not having taken a medical degree nor

[7] Hales, S. A. Treatise on Ventilators, Lond., Pt. I and II, 1734, 1758.

having studied medicine, Hales stands out a unique figure in medical history. He drank deep of his religion and in it he saw nothing that would obstruct the progress of man and his civilization. In him there was perfect blending of religion, philosophy and science. In breadth of detail and accuracy of investigative procedure he stands unparalleled. His work was always quantitative. Hygiene and sanitary engineering made marked advances by his efforts. He is the undisputed father of the science of hemodynamics, a contribution which gives him rank with Harvey in the history of physiology.

In Westminister Abbey there stands a monument erected in his memory by the Princess of Wales. On the tablet at the old church in Teddington is this inscription:

Here is interred the body of Stephen Hales, D.D., clerk of the closet to the Princess of Wales, who was minister in this parish 51 years. He died the 4th of January, 1761, in the 84th year of his age.

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