to this wonderful survey of the earth, so that what appears very extraordinary to the reader may appear more likely when thus illustrated, I have been at the pains to construct this globe." The differences between this and former globes are considerable, and mark a great advance in geographical knowledge. America, instead of being broken up into many islands, as in all earlier globes, is shown as one large continent of tolerably correct shape; Florida is named for the first time in print; "the Moluccas have found a local habitation and their true places, as well as many of the real isles of the sea, while all the monsters and bogus elements of American geography are made to disappear."

THE new volume issued by Mr. Stevens opens with a long, learned, and most interesting introduction by Mr. Coote, on early American geography generally, and especially on the globes and maps of the first part of the sixteenth century. Mr. Coote also narrates the life of Schöner, and furnishes an estimate of his services to geography. One of his discoveries relating to Schöner is that the place-name *Timiripa*, from which he dates some of his letters, and which has hitherto puzzled all students, is merely the translation of part of the name of a small parish of which Schöner was pastor. The introduction is followed by a facsimile of Schöner's letter of dedication of the globe to the Canon of Bamberg, by the letter of Maximilianus, and by translations of both, as well as by a bibliography of Schöner's works. But, next to the introduction, the portion of the book which will receive most attention will be the facsimiles at the end, which are as follows: (1) the famous Hunt-Lenox globe, attributed to 1506-7: (2) the Boulonger globe, supposed to have been executed in 1514-17; (3) Schöner's first globe of 1515; (4) his second globe of 1520; (5) the third globe of 1523, "being the earliest geographical document to delineate the first circumnavigation of the earth by the Spaniards, 1519-22"; (6) the Portuguese so-called Cantino map of 1502. The reproduction of the letters of Schöner and Maximilianus Transylvanus have been done in exact facsimile by the phototypographic process, all the defects and peculiarities of the originals appearing with faithful minuteness. The long-lost globe consists of twelve gores, and its distinguishing feature is a line drawn completely round the circumference, showing the route of Magellan's fleet in the first circumnavigation of the earth.

THE following message from Mr. Joseph Thomson and Mr. Harved Crichton-Browne, transmitted by the Eastern Telegraph Company's cable from Tangier, has been sent to the Royal Society, the Royal Geographical Society, and to the friends of the explorers:—"City of Morocco, July 28.—We returned to Amsmiz across mountains, safe and well, July 24; many interesting geographical and geological notes; so far successful beyond our expectations. We were prevented going direct from Glamoa to Gundaffy by tribal revolt. We shall start on August 6 for third trip across the Atlas, further south-west this time."

THE GASES OF THE BLOOD.[1]

I.

MR. PRESIDENT AND GENTLEMEN,—The subject I have chosen is a consideration of the gaseous constituents of the blood in relation to some of the problems of respiration. This has been selected both because it deals with a province of physiology in which there are many profound problems connected with the molecular phenomena of life, and also because it gives me the opportunity of illustrating some of the methods of physiological research. I purpose to treat the subject chiefly from the physical stand-point, and to demonstrate some of the phenomena as I would endeavour to do to a class of students, believing that this will be of more interest to many of my audience than if I placed before you anything like an encyclopædic account of recent researches. I cannot help adding that as I speak in the class-room of one of the most distinguished physicists of the day, I feel the genius of the place is hovering over me, and I will be impelled to guide you to the borderland of physics and of physiology. It is in this territory that we meet with the most profound questions regarding the nature of vital activity, and it is here that the physiologist and the physicist must join hands in working out their solution.

Respiration may be shortly defined as the function or group of functions by which an interchange occurs between the gases formed in the tissues of a living being and the gases of the medium in which it lives. It is interesting to take a brief survey of the investigations which laid the foundations of our knowledge of this subject, as it illustrates to us the fact taught by the history of all sciences that those truths which we now regard as elementary were at one time unknown, and have been gained only by laborious inquiry.

The oldest writers do not appear to have had any clear notions even as to the necessity for respiration. Hippocrates dimly recognized that during breathing a *spiritus* was communicated to the body. Many of the older anatomists, following Galen, thought that the "very substance of the air got in by the vessels of the lungs to the left ventricle of the heart, not only to temperate heat, but to provide for the generation of spirits." This notion of cooling the blood was held by Descartes (1596–1650) and his followers, and seemed to them to be the chief, if not the sole, use of respiration. In addition, they supposed it aided in the production and modulation of the voice, in coughing, and in the introduction of odours. The celebrated Van Helmont (1577–1664) strongly expresses these views, and attaches particular importance to the necessity for cooling the blood, which otherwise would become too hot for the body.

About the middle of the seventeenth century clearer notions began to prevail. These rested partly on an anatomical and partly on a physical discovery. Malpighi (1621-94) discovered that the minute bronchial tubes end in air vesicles, or membranous cavities, as he termed them, on the walls of which, in the frog, he saw with his simple microscope the blood flowing through capillaries. This pulmonary plexus was for many years termed the "rete mirabile Malpighii." The physical observations were made by the celebrated Robert Boyle (1627-91), who describes in his treatise entitled "New Experiments, Physico-Mechanical, touching the Spring of the Air," published in 1662, numerous experiments as to the behaviour of animals in the exhausted receiver of the air-pump. He showed that the death of the animals "proceeded rather from the want of air than that the air was over-clogged by the steam of their bodies." He also showed that fishes also enjoyed the benefits of the air, for, said he, "there is wont to lurk in the water many little parcels of interspersed air, whereof it seems not impossible that fishes may make some use, either by separating it when they strain the matter thorow their gills, or by some other way."

His conclusion is "that the inspired and expired air may be sometimes very useful by condensing and cooling the blood;" but "I hold that the depuration of the blood in that passage is not only one of the ordinary but one of the principal uses of respiration." Thus, by the use of the air-pump, invented by Otto von Guericke about 1650, Boyle was able to make a contribution of fundamental importance to physiological science.

He also first clearly pointed out the real cause of the influx of air into the lungs. The older anatomists, from Galen downwards, held that the lungs dilated actively, and thus sucked in the air; and there was much controversy as to whether the chest, with the contained lungs, resembled a pair of bellows, which was filled because it was dilated, or whether the lungs resembled a bladder, which is dilated because it is filled. Boyle shows clearly that the cavity of the chest is actively dilated, and that the lungs are distended because the "spring" of the air is then less on their outer than on their inner surface. This simple explanation was not generally accepted, because the minds of Boyle's contemporaries were under the influence of an ancient idea that air existed in the cavity of the chest external to the lungs. This prevented them from seeing the simplicity and accuracy of Boyle's explanation, and to be constantly on the outlook for some mechanism by which the lungs could actively dilate. Such notions were held by Willis, Malpighi, and Erasmus Darwin. The opinion of Darwin is shown by the following passages in the "Zoonomia":—

"By the stimulus of the blood in the right chamber of the heart, the lungs are induced to expand themselves, and the pectoral and intercostal muscles and the diaphragm act at the same time by their associations with them." And, again, "to those increased actions of the air-cells are superadded those of the intercostal muscles and diaphragm, by irritative association."

Boyle's observations were published in 1660, and in 1685 we

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[1] Address to the British Medical Association at its annual meeting at Glasgow. Delivered on August 10 in the Natural Philosophy class-room University of Glasgow, by John Gray McKendrick, M.D., LL.D., F.R.SS.L. and E., F.R.C.P.E., Professor of the Institutes of Medicine in the University of Glasgow.

find Borelli (1608–79), in the second portion of his great work "De Motu Animalium," giving expression to very clear notions regarding respiration. Thus in the eighty-second proposition he shows that the lungs are not the effective causes of respiration, but are passively concerned in the movements; and in the eighty-third proposition he states that the efficient cause of inspiration is the muscular force by which the cavity of the chest is increased and permits the lungs to be filled by the elastic force of the air. Borelli was also the first, as shown in the eighty-first proposition of his work, to make an estimate of the quantity of air expelled by a single expiration. At the same time he attributed calm expiration to the elastic resiliency of the ribs, and he pointed out that the deepest expiration could not entirely empty the lungs of air (Propositions 92, 93, and 94). Whilst Borelli thus recognized the air as necessary to animal life, he naturally failed in explaining why this was so, being unacquainted with the composition of the air and of the so-called "fuligineous vapours" (carbonic acid, aqueous vapour, &c.) which were supposed to exist in expired air.

I find, in a work by Swammerdam (1637–80), dated 1667, and entitled "Tractatus Physico-Anatomico-Medicus de Respiratione usuque Pulmonum," at pp. 20, 21, a description of an experiment in which he immersed in a vessel of water a dog having a long tube inserted in the trachea, and he observed the rise and fall of the level of the water during respiration. This was practically the method followed by Borelli, but I am unable to say which experiment was first performed.

Here I may also refer to the curious experiments of Sanctorius, Professor of Medicine in Padua, who flourished from 1561 to 1636, as being probably the first quantitative estimate of substances escaping from the body. Sanctorius constructed a balance by which he weighed himself repeatedly, and observed what he gained by food and what he lost by excretion. The results appeared in his work "Ars de Staticâ Medicinâ," published in 1614, and he states the amount of matter separated by pulmonary exhalation at about half a pound in twenty-four hours. It is not easy to say precisely what these figures represent, and therefore we find the amount, on the authority of Sanctorius, differently stated by writers during the next century. His observations are of interest, however, as being a distinct step in physiological investigation.

Among the contemporaries of Boyle, Pascal, Spinosa, Barrow, Newton, and Leibnitz—all men of the first intellectual rank—was Dr. Robert Hooke, one of the most versatile and able of scientific thinkers. Hooke was born in 1635, and died in 1703. One of the founders of the Royal Society, its early Proceedings show that there was scarcely any department of science at the time to which he did not make important contributions. In particular, he showed a remarkable experiment, in October 1667, to the Royal Society. This experiment, as detailed in Lowthorp's "Abstract of the Philosophical Transactions," vol. iii. p. 67, showed that it was the fresh air, and not any alteration in the capacity of the lungs, which caused the renewal of the heart's beat. It has been said that a similar experiment was performed by Vesalius, but with this difference, that, whilst Vesalius observed the fact, he failed in giving a rational explanation. He supposed that the movements of the lungs affected the movements of the heart, but he did not see, as Hooke did, that the heart moved because it was supplied with blood containing fresh air. Hooke's experiment is one also of great practical importance as being the basis of the modern practice of using artificial respiration in cases of impending asphyxia.

We thus see that the necessity of a continual supply of fresh air was recognized as being essential to life. It was further surmised that the air imparted something to the blood, and received something in return; but no further advance was made in this direction until the researches of Mayow, a name now famous in the early history of chemistry and of physiology. John Mayow was born in 1645, and died at the early age of thirty-four. His principal work was published in Oxford in 1674. In it, by many ingenious experiments, he showed that combustion diminishes the volume of the air and alters its qualities; that respiration also affects the quality of the air; that an animal will die if kept in a confined space full of air—a fact to be explained, according to Mayow, by saying that the animal had used the respirable portion of the air, and that the residue was unfit for life; and, finally, he showed that an animal suffers if placed in an atmosphere the qualities of which have been injured by combustion. Further, he gave the name of "nitro-aërial spiritus" to the "principle" in the air which, he said, had to do with life, muscular action, and combustion. Thus he no doubt came near the discovery of oxygen, made by Priestley nearly a century later. It would be difficult to estimate the enormous influence on theories of combustion and of respiration exerted by the researches of Boyle, Hooke, and Mayow. They prepared the way in physiological science for the next great step—namely, the identification of the gaseous elements contained in respiration. The dependence of progress in physiology on the state of scientific opinion regarding chemical and physical questions could not be better illustrated than in the history of physiological ideas regarding respiration. Thus the researches of Boyle with the air-pump did much to explain the mere mechanism of breathing. Hooke made this even more apparent, and Mayow gave greater precision to the idea that in respiration the blood lost something and gained something. It is difficult to determine precisely, after the lapse of time, the contributions made by each of these distinguished observers, who were contemporaries; but I would venture to say that the germ of the ideas that bore fruit in the minds of Hooke, and more especially of Mayow, may be found in the writings of Robert Boyle.

The researches of Mayow, indicating the existence in the air of a "nitro-aërial spiritus" necessary to life, and the presence in expired air of something deleterious to life, did not immediately produce the fruits one would have expected. At first, his writings attracted considerable attention; they passed through two or three editions, and were translated for Continental readers; but from the beginning of the eighteenth century, nearly twenty years after Mayow's death, they passed almost into oblivion. Thus Hales vaguely refers to him in only two instances, and, as stated by Bostock, "in the discourse delivered by Sir John Pringle before the Royal Society, upon the assignment of Sir Godfrey Copley's medal to Dr. Priestley, which commences with a sketch of the discoveries that had been made in the science of aërology, previous to the period when this philosopher entered upon his experiments, the name of Mayow is not mentioned."

Mayow's writings were first again brought into notice in this country by Reinhold Forster, who gave a summary of Mayow's views in an introduction to his translation of Scheele's essay on "Air and Fire."

As another example of how Mayow's observations were neglected, it may be pointed out that Boerhaave (1668–1738), one of the most learned men of his time, states that he cannot explain the change which the air experiences by respiration; and even Haller, in his great work "Elementa Physiologiæ Corporis Humani," published in 1766, sums up his knowledge regarding expired air by stating that it is combined with a quantity of water and a noxious vapour, and has its elasticity diminished.

The next step in the physiology of respiration was the discovery, in 1754, of carbonic acid, by Joseph Black, then Professor of Medicine and Chemistry in this University. About this time there was much discussion in the medical world as to the use of lime-water in cases of stone and gravel. It was supposed that the lime-water dissolved calculi, and assisted in expelling them from the body. A discussion arose as to the virtues of lime-water produced from different substances. Two Professors in the University of Edinburgh—Alston and Whytt—specially investigated the subject, and Whytt asserted that the lime-water of oyster-shell lime had more power as a solvent than the lime-water of common stone lime. This led Black to examine the question. "I therefore," says he, "conceived hopes that, by trying a greater variety of the alkaline earths, some kinds might be found still more different by their qualities from the common kind, and perhaps yielding a lime-water still more powerful than that of oyster-shell lime."

This led Black to his celebrated investigation on magnesia. He showed that in the case of magnesia alba (carbonate of magnesia) the disappearance of the effervescence on treatment with an acid after heating was accompanied by a loss of weight. The substance thus given off he called "fixed air," or what we now term carbonic acid. This led to an examination of the salts of lime, and in 1757 he made two important physiological discoveries, namely: (1) that the fixed air was injurious to animal life; and (2) that fixed air was produced by the action of respiration. These important observations are thus described in his own words:—"In the same year, however, in which my first account of these experiments was published—namely, 1757—I had discovered that this particular kind of air, attracted by alkaline substances, is deadly to all animals that breathe it by the mouth and nostrils together; but that if the nostrils were kept shut, I was led to think that it might be breathed with safety. I found, for example, that when sparrows died in it in ten or eleven seconds, they would live in it for three or four minutes, when the nostrils were shut by melted suet. And I convinced myself that the change produced on wholesome air by breathing it, consisted chiefly, if not solely, in the conversion of part of it into 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 solutions made the air last longer for the purposes of life."

Fifteen years afterwards—namely, in 1772—Joseph Priestley examined the chemical effects produced by the burning of candles and the respiration of animals upon ordinary air; and he made the important discovery that, after air had lost its power of supporting combustion, as by the burning of candles, this property might be restored by the agency of plants. Pushing his experiments still further, he found that air, deteriorated by the breathing of animals, might again become suitable for respiration by the action of plants. In these experiments he employed mice for ascertaining how far an air was impure or unfit for respiration. In 1774, Priestley obtained oxygen by heating red precipitate by means of the sun's rays concentrated by a burning-glass. This led to an investigation of the constitution of the atmosphere, and it was shown that it was not a homogeneous elementary body, but consisted of two gases, and that its constitution was remarkably uniform. Priestley showed that by fermentation, combustion, the calcination of metals, and respiration, the air lost a portion of one of its constituents, oxygen.

Thus the chemical researches of Black and Priestley proved that in respiration oxygen was consumed and carbonic acid produced, although the latter fact, owing to the theoretical views of Priestley as to phlogiston, was not fully appreciated by him.

Within a year after Priestley's discovery, a paper on respiration was written by Lavoisier (1743–94), in which he showed that Priestley was correct in stating that the air lost oxygen in breathing, but Lavoisier specially pointed out that it had gained carbonic acid. No doubt Lavoisier was well acquainted with Black's researches, as is shown by the correspondence between these distinguished men. Lavoisier was the first, however, to make a quantitative examination of the changes produced in the air by breathing. In 1780, he performed a remarkable experiment, in which a guinea-pig was confined over mercury in a jar containing 248 cubic inches of gas consisting principally of oxygen. In an hour and a quarter the animal breathed with much difficulty, and, being removed from the apparatus, the state of the air was examined. Its bulk was found to be diminished by 8 cubic inches, and of the remaining 240 inches, 40 were absorbed by caustic potash, and consequently consisted of carbonic acid. Still later, he performed a more accurate experiment, giving quantitative results. During 1789 and 1790, by a special apparatus, Lavoisier and his friend Seguin attempted to measure the changes in the air produced by the breathing of man. These researches are not of value so much for the results they gave as for the method employed. Lavoisier constructed a still more elaborate apparatus, with which he began experiments. This research, however, he never finished, as, in 1794, he fell a victim to the blind fury of Robespierre. It is narrated that he earnestly requested a respite of a few days to give him time to prepare for publication the results of his investigations. This was denied, and thus perished one of the greatest scientific sons of France.

Stephen Hales (1677–1761) attempted to measure the amount of aqueous vapour given off by the lungs by breathing through a flask filled with wood-ashes, which absorbed the moisture, and he estimated the amount at about 20 ounces in twenty-four hours. Similar observations were afterwards made by Menzies and by the eminent surgeon, Mr. Abernethy. Lavoisier also attacked the problem by an indirect method. Thus he determined the quantity of oxygen consumed and of carbonic acid produced, and, assuming that the amount of oxygen was more than sufficient to form the carbonic acid, he came to the conclusion that the excess united with hydrogen in the lungs, and passed off as water. As may be supposed, this method gave widely different results.

Various other attempts were made to estimate the amount of the respiratory changes. In particular, Sir Humphry Davy, in March 1798, investigated the physiological action of nitrous oxide gas. In this research, published in 1800, he began by observations upon animals; and observations as to the effect of the gas on life, on muscular irritability, on the action of the heart, and on the colour of the blood are recorded with great precision. He then passed on to observations on the respiration of hydrogen, and this led him to a repetition of the experiments of Lavoisier and Goodwin. Next he subjected himself and friends to experiment, and recorded a number of interesting physiological and psychical phenomena. This research is of great historical interest as being the first leading to the discovery of a method of producing anæsthesia, or insensibility to pain, by breathing vapours or gases.

Another eminent man who contributed largely to the physiology of respiration was Lazarus Spallanzani, who was born in 1729 and died in 1799. He was educated under the direction of the Jesuits. When about sixteen years of age he went to Bologna, and studied at that University, specially under the tuition of his cousin, Laura Bassa, a woman celebrated in her day for eloquence and scientific knowledge, and who was then a Professor in the University. His biographer, Senebier, says:—"Under the direction of this enlightened guide he learned to prefer the study of Nature to that of her commentators, and to estimate their value by comparing them with the originals they professed to describe. The scholar at once perceived the wisdom of these counsels, and quickly experienced their happy effects. He evinced his gratitude to his instructress in a Latin dissertation published in 1765, which was dedicated to Laura Bassa, and in which he recounted the applauses she received at Modena when, entering the hall, where her pupil, on being appointed a Professor, was defending a thesis, 'De Lapidibus ab Aquâ Resilientibus,' she opposed it with the graces of an amiable woman and the wisdom of a profound philosopher."

Spallanzani became Professor of Logic, Mathematics, and Greek in Reggio in 1754, and about this date he published researches on Infusoria. In 1760, he became Professor in the University of Modena. In 1765, he showed that many microscopic animalcula were true animals, and in 1768 he published his celebrated researches on the reproduction of portions of the body removed from worms, snails, salamanders, and toads. He paid special attention to the great question of spontaneous generation, showing that infusions of animal and vegetable substances exposed to a high temperature and hermetically sealed, never produced living things. He also investigated respiration, more particularly in invertebrates. He proved that many such animals breathed by means of the skin as well as by the special breathing organs. He placed many animals, but more especially different species of worms, in atmospheres of hydrogen and nitrogen, and found that, even in these circumstances, carbonic acid was produced. He also showed the production of carbonic acid by the dead bodies of such animals, and reasoned from this that the carbonic acid was produced directly from the dead tissues and not from the action of the oxygen of the air. He contrasts the respiration of cold-blooded and warm-blooded animals, and shows the peculiarities of respiration in hibernating animals. Nor were these by any means superficial observations. They were usually quantitative, and by the use of the eudiometer, he analyzed the air before and after respiration. Probably the most important contribution made by Spallanzani to the subject was showing what he states in the following paragraph:—

"I inquire not here why the quantity of carbonic acid gas was greater in azotic and hydrogen gas than in common air. I shall only conclude, from these experiments, that it is clearly proved that the carbonic acid gas produced by the living and dead snails in common air resulted not from atmospheric oxygen, since an equal and even a greater quantity of it was obtained in azotic and hydrogen gas; consequently, in the oxygen gas destroyed by the presence of these animals, its base alone is absorbed by them either during life or after death."

But Spallanzani supposed that the carbonic acid thus produced was formed by digestion in the stomach, passed through the tissues, and was then exhaled. Thus he missed a great step in discovery—namely, that the carbonic acid is produced by the tissues themselves. It was, however, pointed out in 1823, by W. F. Edwards, in his work on the "Influence of Physical Agents on Life," that the amount of carbonic acid produced by animal breathing was too great to be accounted for by the amount of oxygen in their lungs at the beginning of the experiment, or by carbonic acid supposed to be in the stomach. The importance of this observation will be seen when we discuss the phenomena of the breathing of the tissues.

In 1809 the subject of aquatic breathing was investigated with great care by Provençal and Humboldt. They collected and analyzed the gases of water before and after fishes had lived in it for a certain time, and showed that oxygen was consumed and carbonic acid produced by these creatures.

We have now seen how gradually knowledge was arrived at as to the respiratory exchanges. At the beginning of the present century it was recognized that expired air had lost oxygen, gained carbonic acid and aqueous vapour, and had become hotter. Since then many researches have been carried on to determine with accuracy the quantities of these substances. In all of these, as shown in these diagrams,[1] the method followed has been to draw through a chamber containing the animal a steady constant stream of air, the quantity and composition of which is known. Thus, suppose a certain quantity of dry air, free from carbonic acid, and consisting only of oxygen and nitrogen, is passed through such a chamber. In the chamber some of the oxygen is consumed, and a certain amount of carbonic acid and of aqueous vapour is given up by the animal. The air is drawn onwards through bulbs or glass tubes containing substances such as baryta-water, to absorb the carbonic acid, and chloride of calcium or sulphuric acid, to absorb the aqueous vapour. It is evident that the increased weight of these bulbs and tubes, after the experiment has gone on for some time, will give the amounts of carbonic acid and aqueous vapour formed. Thus Andral and Gavarret in 1843, Vierordt in 1845, Regnault and Reiset in 1849, von Pettenkofer in 1860, and Angus Smith in 1862, determined the quantities both by experiments on animals and on human beings.

The results are—first, the expired air, at its own temperature, is saturated with aqueous vapour; secondly, the expired air is less in volume than the inspired air to the extent of about one-fortieth of the volume of the latter; thirdly, the expired air contains about 4 per cent. more carbonic acid and from 4 to 5 per cent. less oxygen than inspired air; fourthly, the total daily excretion of carbonic acid by an average man amounts to 800 grammes in weight, and 406 litres in bulk. This amount of carbonic acid represents 218·1 grammes of carbon and 581·9 grammes of oxygen. The amount of oxygen, however, actually consumed is about 700 grammes; so that nearly 120 grammes of oxygen absorbed are not returned by the lungs, but disappear in the body. It must be remembered, however, that carbonic acid escapes by the skin and other channels. These figures may be taken as averages, and are subject to wide variations depending on nutritional changes.

There is, however, another side to the problem of respiration —namely, a consideration of the chemical changes involved in the process.

According to Lavoisier, respiration was really a slow combustion of carbon and of hydrogen. The air supplied the oxygen, and the blood the combustible materials. The great French chemist, however, did not entirely commit himself to the opinion that the combustion occurred only in the lungs. He says that a portion of the carbonic acid may be formed immediately in the lung, or in the blood-vessels throughout the body, by combination of the oxygen of the air with the carbon of the blood. Lavoisier's opinions were understood correctly by only a few of his contemporaries, and a notion prevailed that, according to him, combustion occurred only in the lungs, and that the changes in these organs were the main sources of animal heat. Such a notion, however, was contrary to the opinion of the great mathematician Lagrange, announced in 1791, a few years after the first publication of Lavoisier's on respiration. Lagrange saw that, if heat were produced in the lungs alone, the temperature of these organs might become so high as to destroy them; and he therefore supposed that the oxygen is simply dissolved in the blood, and in that fluid combined with carbon and hydrogen, forming carbonic acid and aqueous vapour, which were then set free in the lungs. It will be observed that this opinion of Lagrange in 1791 was practically the same as that stated by Lavoisier in 1789.

Now, if the production of carbonic acid in a given time depended upon the amount of oxygen supplied in the same time, these views of Lavoisier and Lagrange would be correct; but Spallanzani had shown that certain animals confined in an atmosphere of nitrogen or of hydrogen exhaled carbonic acid to almost as great an extent as if they had breathed air. He was therefore obliged to say that carbonic acid previously existed in the body, and that its appearance could not be accounted for by the union of oxygen with the carbon of the blood. Spallanzani therefore thought that in the lung there was simply an exhalation of carbonic acid and an absorption of oxygen. These views were supported by the experiments of W. Edwards, published in 1824. Edwards showed that animals in an atmosphere of hydrogen produced an amount of carbonic acid not to be accounted for by any oxygen supposed to exist free in the body. In 1830, Collard de Martigny performed many similar experiments, and stated that carbonic acid was secreted in the capillaries and excreted by the lungs. This opinion was supported by Johannes Müller, who repeated the experiments of Spallanzani.

It might thus be said that two theories of respiration were before physiologists—the one, that combustion occurred in the lungs or venous blood, furnishing carbonic acid and aqueous vapour, which were exhaled by the lungs; the other, that there was no such combustion, but that oxygen was absorbed by the lungs and carried to the tissues, whilst in these carbonic acid was secreted, absorbed by the blood, carried to the lungs, and there exhaled. Some writers, soon after Lavoisier, misunderstood, as I have already stated, the opinions of that distinguished man, and taught that in the lungs themselves there was a separation of carbon, which united immediately with the oxygen to form carbonic acid. But this was really not Lavoisier's opinion; and we have to do, therefore, with two theories, which have been well named—the theory of combustion, and the theory of secretion.

The difficulty felt by the older physiologists in accepting the secretion theory was the absence of proof of the existence of free oxygen and carbonic acid in the blood. This difficulty also met those who rejected the notion of combustion occurring in the lungs, and substituted for it the idea that it really occurred in the blood throughout the body, because, if this were true, free gases ought to be found in the blood. Consequently, so long as physiologists had no definite knowledge regarding gases in the blood, the combustion theory, in the most limited sense, held its ground. This theory, although fruitful of many ideas regarding respiration and animal heat, was abandoned in consequence of the evidence afforded by two lines of inquiry—namely, researches regarding the gases of the blood, and researches as to the relative temperature of the blood in the right and left cavities of the heart.

Let me first direct your attention to the gradual development of our knowledge regarding the gases of the blood. The remarkable change in the colour of the blood when it is exposed to, or shaken up with, air was observed so long ago as in 1665 by Fracassati, and is also alluded to by Lower (1631-91), Mayow, Cigna (1773), and Hewson (1774); but Priestley was the first to show that the increased redness was due to the action of the oxygen of the air, and that the blood became purple when agitated with carbonic acid, hydrogen, and nitrogen. The presence of gas in the blood was first observed about 1672 by Mayow. I find in a paper of Leeuwenhoek (1632-1723), entitled "The Author's Experiments and Observations respecting the Quantity of Air contained in Water and other Fluids," published in 1674, a description of a method devised by this ingenious man for detecting the existence of air in certain fluids, and amongst them in the blood. It consisted of a kind of syringe, by which he was able to produce a partial vacuum. He then observed bubbles of gas to escape, and he estimated, in the case of human blood, that the air in the blood amounted to 1/1000 or 2/1000 part of the volume of the blood. He argues, from this interesting observation, against one of the prevalent medical theories of the time, that various diseases were caused by fermentations in the blood. How, said he, was such a theory consistent with the existence of so small a quantity of gas? He made the mistake, from the inefficiency of his apparatus, of stating that blood, when it issues from the veins, contains no air.

Gas was also obtained from the blood in 1799 by Sir Humphry Davy, in 1814 by Vogel, in 1818 by Brand, in 1833 by Hoffmann, and in 1835 by Stevons. On the other hand, John Davy, Bergmann, Johannes Müller, Mitscherlich, Gmelin, and Tiedemann failed in obtaining any gas. The first group of observers, either by heating the blood, or by allowing it to flow into a vacuum, or by passing through it a stream of hydrogen, obtained small quantities of carbonic acid. Sir Humphry Davy was the first to collect a small quantity of oxygen from the blood. John Davy, by an erroneous method of investigation, was led, in 1828, to deny that the blood either absorbed oxygen or gave off carbonic acid. He was shown to be wrong, in 1830, by

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[1] Diagrams exhibited on wall.

Christison, who devised a simple method of demonstrating the fact.

So long as the evidence in favour of the existence of gases in the blood was so uncertain, the combustion theory of respiration held its own. At last, in 1836, appeared the researches of Heinrich Gustav Magnus, latterly Professor of Physics and Technology in the University of Berlin. He first attempted to drive off carbonic acid from the blood by a stream of hydrogen, and thus obtained as much as 34 cubic centimetres of carbonic acid from 62·9 cubic centimetres of blood. He then devised a mercurial air-pump, by which it was possible to exhaust a receiver to a much greater extent than could be done by the ordinary air-pump. When blood was introduced into such a vacuum, considerable quantities of carbonic acid, oxygen, and nitrogen were obtained. This research marks an epoch in physiological discovery, as it threw a new light on the function of respiration by demonstrating the existence of gases in the blood.

In order to appreciate the value of this evidence, and the method employed, let me direct your attention to the laws regulating the diffusion of gases. As a mass of gaseous matter has no independent form, like that of a solid body, nor a fixed volume like that of a liquid, but consists of an enormous number of molecules which, in consequence of their mutual repulsions, endeavour more and more to separate from each other, it is easy to see that if two masses of gas are brought into contact, they will mix—that is, their molecules will interpenetrate, until a mixture is formed containing an equal number of the molecules of each gas. The force by which the molecules repel each other, and by which they exercise pressure in all directions, is known as the pressure or tension of the gas. It is evident that the greater the number of gas molecules in a given space, the greater will be the tension of the gas, and from this it follows that the tension of a gas is in the inverse proportion to its volume (this is known as Boyle's law). Suppose now that two gases are separated by a porous partition; the two gases will mix, and the rapidity of the diffusion will vary according to the specific weight of the gases. Thus light gases, like hydrogen or coal-gas, will diffuse more quickly than air, or chlorine, or carbonic acid.

It is important also to note the laws regulating the absorption of gases by fluids. If we allow a little water to come into contact with ammonia gas above mercury, the gas is rapidly absorbed by the water (1 volume of water absorbs 730 volumes NH_3) all the gas above disappears, and in consequence of this the pressure of outer air drives up the mercury in the tube. The higher the temperature of the fluid the less gas it absorbs. At the boiling-point of the fluid its absorption is = 0, because at that temperature, the fluid itself changes into gas. The power of absorption of different fluids for the same gas, and the absorptive power of the same fluid for different gases fluctuates between wide limits. Bunsen defined the coefficient of absorption of a fluid for a gas as that number which represents the volume of gas (reduced to 0° and 760 mm. barometric pressure) which is taken up by 1 volume of the fluid. Thus 1 volume of distilled water takes up the following volumes:—

Temp. Cent.	N.	O.	CO_2.	Air.
0°	0·02	0·041	1·797	0·025
5	0·018	0·036	1·5	0·022
15	0·015	0·03	1·002	0·018
37	—	0·02	0·569	—

Again, 1 volume of distilled water at 0° C. absorbs 0·00193 volumes of hydrogen, while it can take up no less than 1180 volumes of ammonia; again, 1 volume of water at 0° C. absorbs only 0·2563 volumes of olefiant gas, but 1 volume of alcohol, at the same temperature, will take up as much as 3·595 volumes: The volume of gas absorbed is independent of the pressure, and the same volume of gas is always absorbed whatever the pressure may happen to be. But as according to Boyle's law the density of a gas, or in other words the number of molecules in a given space, is in proportion to the pressure, and as the weight is equal to the product of the volume and the density, so while the volume absorbed always remains the same, the quantity or weight of the absorbed gas rises and falls in proportion to the pressure (this is the law of Dalton and Henry). It therefore follows that a gas is to be considered as physically absorbed by a fluid, if it separates from it not in volumes but in quantities, the weights of which are in proportion to the fall of pressure.

When two or more gases form an atmosphere above a fluid, the absorption takes place in proportion to the pressure which each of the constituents of the mixture would exercise if it were alone in the space occupied by the mixture of gases, because, according to Dalton's law, one gas does not exercise any pressure on another gas intermingled with it, but a space filled with one gas must be considered, so far as a second gas is concerned, as a space containing no gas, or in other words a vacuum. This pressure, which determines the absorption of the constituents of a gaseous mixture, is termed, according to Bunsen, the partial pressure of the gas. The partial pressure of each single gas in a mixture of gases depends, then, on the volume of the gas in question in the mixture. Suppose atmospheric air to be under a pressure of 760 mm. of mercury, then, as the air consists of 21 volumes per cent. of O and 79 volumes per cent. of N, $\frac{760 \times 21}{100} = 159{\cdot}6$ mm. of mercury, will be the partial pressure under which the oxygen gas is absorbed, while the absorption of nitrogen will take place under a pressure of $\frac{760 \times 79}{100} = 600$ mm. of mercury. Suppose, again, that above the fluid containing a gas, say carbonic acid, which has been absorbed, there is an atmosphere of another gas, say atmospheric air, then as carbonic acid exists in the air only in traces, its tension is equal to zero, and carbonic acid will escape from the fluid until the difference of tension between the carbonic acid in the water and the carbonic acid in the air above it has been balanced—that is, until the carbonic acid which has escaped into the air has reached a tension equal to that of the gas still absorbed by the fluid. By the phrase "tension of the gas in a fluid" is understood the partial pressure in millimetres of mercury which the gas in question has to exercise in the atmosphere, when no diffusion between the gas in the fluid and the gas in the atmosphere takes place.

The method followed by Magnus will now be understood. By allowing the blood to flow into an exhausted receiver surrounded by hot water, gases were set free. These were found to be oxygen, carbonic acid, and nitrogen. He further made the important observation that both arterial and venous blood contained the gases, the difference being that in arterial blood there was more oxygen and less carbonic acid than in venous blood. Magnus concluded that the gases were simply dissolved in the blood, and that respiration was a simple process of diffusion, carbonic acid passing out and oxygen passing in, according to the law of pressures I have just explained.

Let us apply the explanation of Magnus to what occurs in pulmonary respiration. Venous blood, containing a certain amount of carbonic acid at the temperature of the blood and under a certain pressure, is brought to the capillaries, which are distributed on the walls of the air-vesicles in the lungs. In these air-vesicles, we have an atmosphere at a certain temperature and subject to a certain pressure. Setting temperature aside, as it may be assumed to be the same in the blood and in the air-cells, let us consider the question of pressure. If the pressure of the carbonic acid in the blood be greater than that of the carbonic acid in the air-cells, carbonic acid will escape until an equilibrium is established between the pressure of the gas in the blood and the pressure of the gas in the air-cells. Again, if the pressure or tension of the oxygen in the air-cells be greater than that of the oxygen in the venous blood, oxygen will be absorbed until the tensions become equal. This theory has no doubt the merit of simplicity, but it will be observed that it depends entirely on the assumption that the gases are simply dissolved in the blood. It was pointed out by Liebig that, according to the experiments of Regnault and Reiset, animals used the same amount of oxygen when breathing an atmosphere composed of that gas alone as when they breathed ordinary air, and that the vital processes are not much affected by breathing the atmosphere of high altitudes where the amount of oxygen taken in is only about two-thirds of that existing at the sea level. It was also shown at a much later date, by Ludwig and W. Müller, that animals breathing in a confined space of air will use up the whole of the oxygen in the space, and it is clear that as the oxygen is used up the partial pressure of the oxygen remaining must be steadily falling. Liebig urged the view that the gases were not simply dissolved in the blood, but existed in a state of loose chemical combination which could be dissolved by the diminished pressure in the vacuum, or by the action of other gases. He also pointed out the necessity of accurately determining the coefficient of absorption of blood for the gases—that is, the amount absorbed under a pressure of 760 mm. of mercury

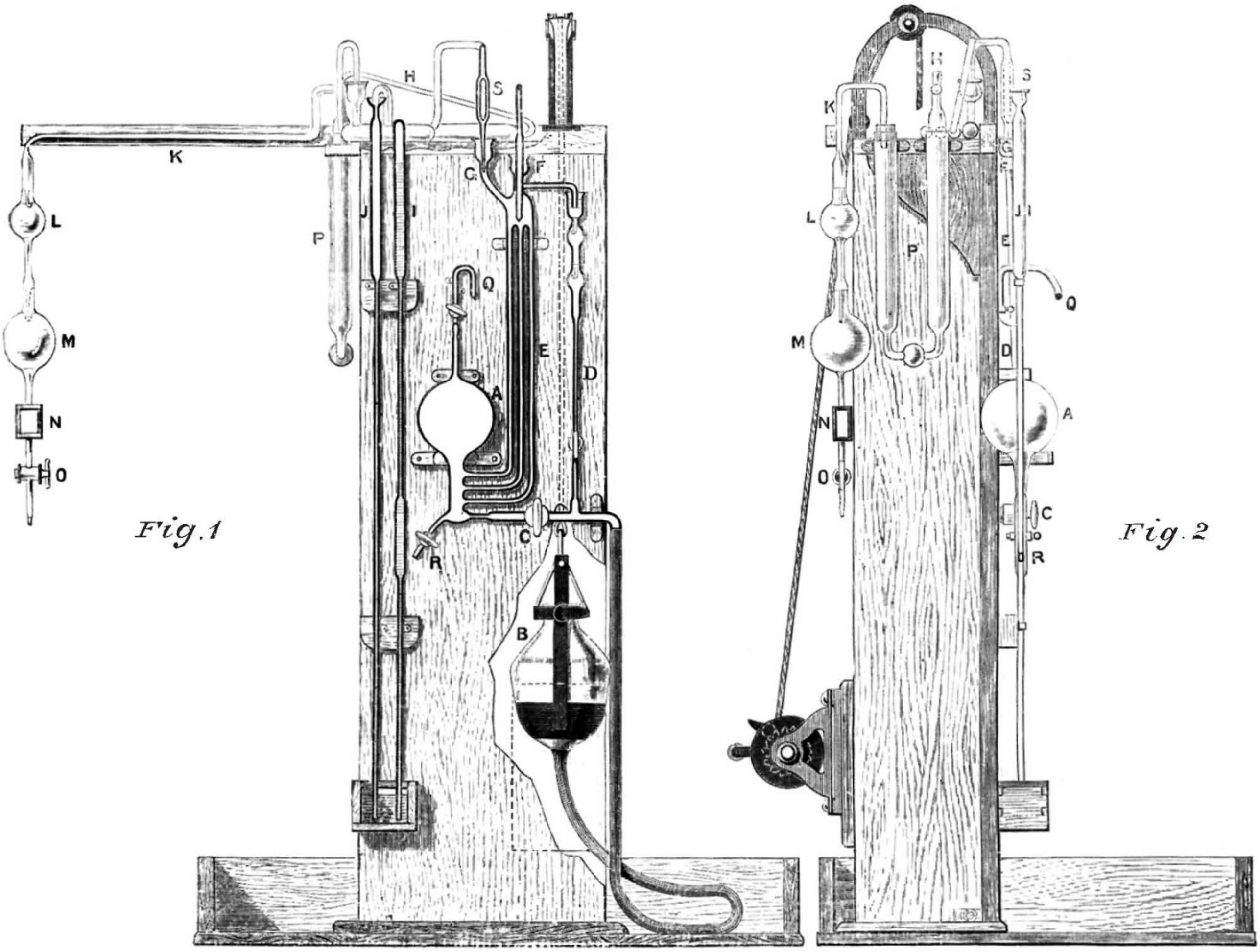

Fig. 1

Fig. 2

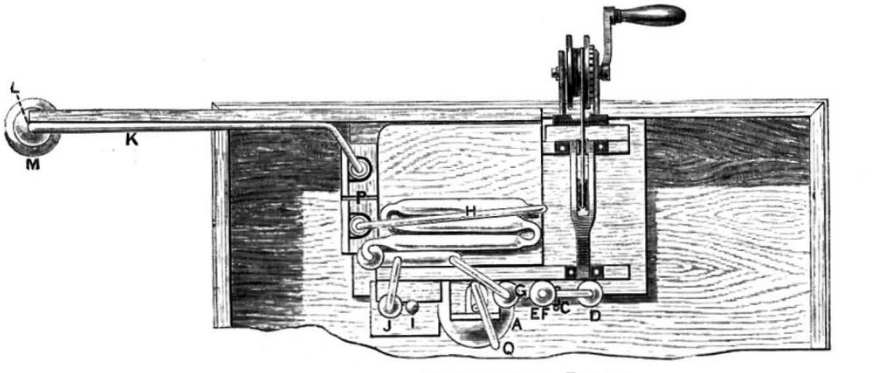

Fig. 3

DESCRIPTION OF FIGURES.

FIGS. 1, 2, and 3.—Views of a gas pump constructed for the purpose of extracting and collecting the gases of the blood and suitable for the physiological lecture table. These views have been correctly drawn on the scale of 1 to 10 by my friend the Rev. A. Hanns Geyer.[1] Fig. 1, front view: A, glass bulb connected by horizontal glass tube with bulb B; this tube guarded by stopcock C. By elevating B, A is filled with mercury, stopcock of delivery tube Q is closed, and B is lowered; A is thus exhausted and air is drawn into it by tubes E, connected by G with drying apparatus and blood chamber. I, permanent barometer; J, barometer gauge tube connected with part of instrument to be exhausted. Both I and J dip into mercury trough seen below; S, a glass float to prevent mercury from running into drying apparatus when B is raised. After A and the drying apparatus and the blood chamber have been well exhausted, B is raised and mercury may be allowed to pass up D, and then the apparatus acts as a Sprengel pump by the three tubes E. Fig. 2, side view of apparatus: same references. Fig. 3, drying apparatus, placed on a shelf at the top of the pump, consisting of H, tubes containing solid phosphoric acid, and U-tube P, seen in Fig. 2, containing sulphuric acid. The tube K passes to receiver. In the drawing it is seen to be connected with an apparatus suitable for projecting the spectrum of oxy-hæmoglobin by lime or electric light on screen; then exhausting the blood of oxygen and showing the spectrum of reduced hæmoglobin. L and M, froth chambers with traps; N, parallel-sided chamber for blood; O, stopcock. The whole pump is modelled on one I obtained about ten years ago from Messrs. Mawson and Swan, of Newcastle, but it has been much altered and added to so as to make it suitable for physiological demonstration. It is evident that the gases can be readily obtained for analysis by driving out of A by delivery tube Q. A rough demonstration of the gases can be made in from five to ten minutes.

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[1] The pump can be obtained from Mr. W. Potter, glass-blower, Physical and Physiological Laboratories, University of Glasgow, who will give information as to cost.

by one volume of the gas at the temperature of the observation. The next important observations were those of Fernet, published in 1855 and 1857. He expelled the greater part of the gas of the blood (dog) by passing through it a stream of hydrogen and then submitting it to the action of the air-pump. He then introduced into the apparatus the gas under a given pressure, the absorption coefficient of which he had to determine. He then estimated the amount of gas absorbed, under different pressures, and found in the case of oxygen that the amount absorbed with gradually decreasing increments of pressure was greater than what would have been the case had it been in accordance with Dalton's law of pressures. The oxygen was not then simply dissolved in the blood. Further, Fernet arrived at the conclusion that the greater portion of the oxygen was in a state of combination, whilst a small amount was simply dissolved according to Dalton's law.

It is evident, then, that while the amount of oxygen absorbed varies with the pressure, it does not do so according to Dalton's law. The amount decreases slowly with pressures below atmospheric pressure, and it increases very rapidly with pressures above it. It is when the pressure in the vacuum is as low as one-thirtieth of an atmosphere that the oxygen is given up, and this will be about the pressure of the aqueous vapour in the apparatus at the temperature of the room, when the experiment is made. The view that something in the blood is chemically united to the oxygen is strengthened by the fact that serum does not absorb much more oxygen than water can absorb, so that blood at a temperature of 30° C. would contain only about 2 volumes per cent. of oxygen gas were the latter simply dissolved in the fluid. It can also be shown that defibrinated blood takes up oxygen independently of the pressure, and that the quantity of oxygen taken up by defibrinated blood is about equal to the quantity absorbed by a solution of pure hæmoglobin containing as much of that substance as exists in the same volume of blood.

By similar experiments made with carbonic acid, Fernet determined that the greater portion of it was in a state of loose chemical combination, whilst a small amount was simply dissolved according to the law of pressures. Experiments with blood serum showed similar results as regards carbonic acid, with the difference that the coefficient of absorption for oxygen was much less than with ordinary blood. He therefore concluded that nearly the whole of the carbonic acid was chemically retained in the fluid of the blood, whilst nearly the whole of the oxygen was combined with the red blood corpuscles. He then proceeded to investigate whether or not the three principal salts of the blood, carbonate of soda, phosphate of soda, and chloride of sodium, in any way influenced the absorption coefficient of carbonic acid. He found (1) that the addition of these salts to distilled water in the proportion in which they exist in the serum slightly diminishes the absorption coefficient; (2) that chloride of sodium has no influence on the absorption coefficient; and (3) that carbonic acid combines with the carbonate and phosphate of soda.

In the same year (1855) Lothar Meyer published the results of a series of researches of the same nature. Under the direction of Bunsen, the blood was diluted with ten times its bulk of water, and the gases were collected by boiling the liquid *in vacuo* at a very gentle heat; a certain amount of gas was thus obtained. He also found that blood absorbs a much larger quantity of carbonic acid than pure water at the same temperature, and stated that when blood was exposed to oxygen at various pressures the quantity of that gas taken up might be regarded as consisting of two portions, one following Dalton's law and the other independent of it.

Further researches of a similar kind have been carried out by Setschenow, Ludwig, Alexander Schmidt, Bert, Pflüger, and others, and ingenious methods of collecting and of analyzing the gases have been devised. To Prof. Pflüger and his pupils, in particular, are we indebted for the most complete series of gas analyses on record. The result has been to enable us to give the average composition of the gases of the blood as follows. From 100 volumes of dog's blood there may be obtained—

	Oxygen.	Carbonic Acid.	Nitrogen.
Arterial	18·4 to 22·6, mean 20	30 to 40	1·8 to 2
Venous	Mean 11·9	43 to 48	1·8 to 2

the gases being measured at 0° C. and 760 mm. pressure. The venous blood of many organs may contain less than 11·9 per cent. of carbonic acid, and the blood of asphyxia may contain as little as 1 volume per cent. It is clear, then, that the gases of the blood do not exist in a state of simple solution, but that they are largely combined with certain constituents of the blood. Take, for example, the case of oxygen. Berzelius showed long ago that 100 volumes of water will absorb, at a given temperature and pressure, 2·9 volumes of oxygen; while, in the same circumstances, 100 volumes of serum will absorb 3·1 volumes, and 100 volumes of blood will absorb 9·6 volumes. Something in the blood must have the power of taking up a large amount of oxygen.

(*To be continued.*)

THE BATH MEETING OF THE BRITISH ASSOCIATION.

THE arrangements for the Bath meeting of the British Association are now practically completed. The Reception Room, adjoining the Assembly Rooms, will be opened on Monday, September 3, at 1 p.m., and on each succeeding week-day till Thursday, September 13, at 8 a.m. precisely; on Sunday, September 9, from 8 to 10 a.m., and from 3 to 6 p.m. In this building will be the offices of the General and Local Secretaries and Treasurers, a post office, telegraph office, telephone, ticket office, lodgings, inquiry, excursion, and lost property offices, and offices for the supply of all official papers and programmes. There will also be lavatories, cloak-rooms, &c., &c. The Council of the Association will meet in the Guildhall.

In the Reception Room there will be offices for supplying information regarding the proceedings of the meeting. The tickets contain a map of Bath, and particulars as to the rooms appointed for the Sectional and other meetings. A list of lodgings, or apartments, with prices, &c., and also information concerning hotels, and other similar matters, will be furnished by the Lodgings Clerk between the hours of 9 a.m. and 6 p.m. daily, at No. 13 Old Bond Street, up to 1 p.m. on Monday, September 3, and after that time at the Reception Room between the same hours daily.

The places of meeting, &c., will be in the Assembly Rooms, the Drill Hall, and the Guildhall. The Secretaries of Sections will be lodged at the White Lion Hotel. The following are the Section Rooms:—A, Mathematics, St. James's Hall; B, Chemistry, Friends' Meeting House; C, Geology, Mineral Water Hospital; D, Biology, Mineral Water Hospital; E, Geography, Guildhall; F, Statistics, Christ Church Hall; G, Mechanics, Masonic Hall; H, Anthropology, Grammar School; Sub-Sections C and D, Blue-Coat School.

By the courtesy and liberality of the Directors of the Western Counties and South Wales Telephone Company, the whole of the Section Rooms will be telephonically connected with the Reception Room, and, through the Telephone Exchange, with all important places in the neighbourhood, free of any expense to the Local Executive Committee, or members and associates, for the meeting.

The first general meeting will be held on Wednesday, September 5, at 8 p.m. precisely, in the Drill Hall, when Sir H. E. Roscoe, M.P., F.R.S., will resign the chair, and Sir Frederick Bramwell, F.R.S., President-Elect, will assume the Presidency, and deliver an address. According to the *Times*, Sir Frederick is sure to deal pretty largely with progress in the department with which his name is so eminently connected. With regard to the addresses of the Presidents of Sections the *Times* makes the following statement:—In Section A (Mathematics and Physics), Prof. Fitzgerald is President, and the subject of his address will probably be connected with Clerk-Maxwell's theory that electric and magnetic forces are produced by the same medium that propagates light, and some recent experimental proofs of that theory. In Section B (Chemistry), Prof. W. A. Tilden, of Birmingham, is President, and his address will be concerned with the history of the teaching of chemistry practically, and will review the existing provision for efficient teaching of chemistry in this country. This will be followed by some discussion of the methods actually used or proposed for teaching chemistry either as a constituent part of a liberal education or for technical purposes, together with an endeavour to trace the causes of the unproductiveness of the English schools in respect to advanced studies, and especially in regard to the results of original research. Prof. Boyd Dawkins