was alluded to. The "Voyage of the *Fox* in the Arctic Seas" had been published late in 1859.

Passing to sectional details, it is incumbent to recall two papers read at Oxford at this time, respectively by Dr. Daubeny and Prof. Draper, of New York. Darwin's "Origin of Species" had appeared in 1859, of which by 1860 no fewer than eleven editions had been issued. These communications offered but cautious approbation of Darwin's researches. In itself, Draper's paper embodied an attempt to show that the advance of man in civilisation does not occur accidentally or in a fortuitous manner, but is determined by immutable law. From his work on physiology, published in 1856, he gave his views in support of the doctrine of the transmutation of species, the transitional forms of the animal and also the human type, the production of new ethnical elements or nations, and the laws of their origin, duration, and death. We must go outside the official Report of the Association for the year to piece together the records of the controversy and storm of words which waxed and raged round these communications; in a sense they were but stalking-horses, in any event traps for the unwary. Yet, looking back upon this mixed chapter of scientific and clerical polemics, the happenings all seemed inevitable. The stage was set, the disputants in place. Prof. Buckman sent a further report on experimental plots in the botanical garden of the Royal Agricultural College, Cirencester, while Lawes and Gilbert again entered the domain of classic inquiries with a paper on the "Composition of the Ash of Wheat grown under various circumstances." Capt. Maury, of the U.S. Navy, had written to the president urging attention to Antarctic exploration, concluding cheerily with the words, "So trusting and hoping that you will join with me in the cry 'Ho for the South Pole!'" William Fairbairn reported experiments to determine the effect of vibratory action and long-continued changes of load upon wrought-iron girders.

In 1894 the Association again chose Oxford, after what Lord Salisbury, the president, and Chancellor of the University, termed "a long and dreary interval of separation of thirty-four years." Consequently a new generation participated in the proceedings of the reunion. The gathering was a great success, 2321 persons taking up membership, while no fewer than 77 foreign members attended, including Prof. Mittag-Leffler, Prof. Ludwig Boltzmann, Dr. S. P. Langley, M. Cornu, Prof. E. Van Beneden and Prof. Strasburger. One is painfully conscious in looking over the roll that time has brought about the removal of many eminent personalities in science since Oxford last received the Association.

Certainly the most notable occurrence at the meeting was the announcement by Lord Rayleigh and Prof. William Ramsay of the discovery of a new gas in the

atmosphere—argon. It fell to Sir Henry Roscoe to propose a vote of congratulation.

The president's address was prefaced by the open confession that he was, after all, only a layman, and "all the skill of all the chemists the Association contains will not transmute a layman into any more precious kind of metal." Nevertheless, the discourse provided a distinctive summary of advances, and comments thereon. In Lord Kelvin's view there was throughout "the spirit of the student, the spirit of the man of science." Prof. Huxley seconded a vote of thanks. It was reserved for an eminent mathematician and publicist to write later: "We find nothing in it which shows either the student or man of science; it teems with fallacious conclusions; and whatever may have been intended by the author, it can only serve as an appeal to the gallery, which is occupied by the reconstructed theological party."

In one of the sections Hiram Maxim gave a description of his experiments on flying by means of aeroplanes. Mr. Henry Balfour, in a paper on the evolution of the bow as a musical instrument, gave the aboriginal races of Africa and India the credit of providing the prototype of many of our best stringed instruments. Mr. Preece discoursed on signalling through space. Sir Andrew Noble told of his methods for measuring pressures in the bores of guns; that the earliest attempt, by direct experiment, to ascertain pressures developed by fired gunpowder, was that made by Count Rumford; but Sir Andrew pointed out assumptions and erroneous determinations. Lord Salisbury attended Prof. Rücker's address in the mathematical section; afterwards an adjournment was made to the Clarendon Laboratory to hear Lord Kelvin describe experiments on the electrification of the air. Prof. H. B. Dixon, president of the section of chemical science, took as his subject "An Oxford School of Chemistry." "If it be a true saying," he remarked, "that men here imbibe a liberal education from the very air breathed by Locke and Berkeley, surely we also may draw scientific inspiration from this air, not only breathed, but first explained, by Boyle, and Hooke, and Mayow."

Two evening lectures were delivered (1) by Dr. J. W. Gregory, on "Experiences and Prospects of African Exploration"; (2) by Prof. J. S. Nicholson, on "Historical Progress and Ideal Socialism"; the lecture to the operative classes was by Prof. Sollas, on "Geologies and Delugies."

There was an overflowing attendance at the Sheldonian Theatre to hear Lord Salisbury's presidential address. It seems that numbers of volunteer helpers were swept aside, through the determined inrush of visitors, and thus were unable to perform their functions. An experience such as this will doubtless be borne in mind on the occasion of the meeting to be held next year.

T. E. JAMES.

Recent Developments in the Theory of Magnetism.¹

By Prof. C. G. DARWIN, F.R.S.

THERE have been several important discoveries made in the theory of magnetism in the course of the last two or three years, and we shall discuss some of these; but in order to appreciate them it will be well to begin with a description of the general magnetic

properties of matter. All magnets can be typified by the ordinary bar magnet, which has a north pole at one end and an equally strong south pole at the other. If such a magnet is cut in half, the north half grows a south pole at the section and vice versa. In consequence of this we do not take the magnetic pole as the working

¹ Discourse delivered at the Royal Institution on Friday, May 15.

unit, but the magnetic dipole. We imagine that each molecule of the bar has north and south poles, and that they are ranged end to end, so that all the middle ones cancel out and leave a free north pole at one end and a free south at the other. The measure of a magnet is then taken, not as the pole strength, but as the *magnetic moment*, which is the product of the pole strength into the length. The moment of the whole bar is the sum of the moments of its molecules.

There are two chief ways in which magnetic effects exhibit themselves. The first is that shown by a compass when it twists round so as to point along the direction of the earth's field. There is another effect which is very important, and to be distinguished from it, which arises when the field is not uniform. Then one end of the magnet will be pulled more than the other is pushed, and so the magnet will experience a force moving it bodily—this may be either an attraction or a repulsion. The first effect is usually easier to exhibit, but we shall be more concerned with the second.

Under the influence of a magnet all bodies become themselves magnetic, but there are three quite distinct types of behaviour. A piece of iron becomes strongly magnetic with a south pole next the north pole of the inducing magnet. Iron, nickel, and one or two other substances have this property to a high degree, but there are many others, for example aluminium, which show it feebly. For all these it is about a hundred-millionth less, and so a different name is used. Iron, etc., are said to be *ferro-magnetic*, the rest are called *para-magnetic*. If a paramagnetic rod is put between the poles of an electro-magnet, it becomes itself a feeble magnet with north pole next to the south pole of the inducing magnet. There exist many other substances, for example copper, having the opposite property. Facing the north pole of the electro-magnet there appears a feeble north pole. This property is called *diamagnetism*. The measure of the two properties is called *susceptibility*, and is positive for paramagnetic and negative for diamagnetic substances. It is found by making experiments in non-uniform fields. A paramagnetic substance tends to move into the strong field, a diamagnetic out of it. So a bar hung between pointed pole pieces will twist round towards the points in the first case and away from them in the second.

Magnetic action is exhibited by electric currents, as is typified by the galvanometer and every ordinary electrical measuring instrument. Now, in science one cannot admit that two radically different things can produce identical effects, so we are forced to conclude that either the current is really a magnet, or the magnet is really a current, and the second is certainly the correct alternative. In each iron atom there is a current circulating, and this current gives rise to its magnetic moment. We shall see now how this explains dia- and para-magnetism, taking for simplicity the supposition that we are dealing with a gas.

Suppose that we surround a cylinder of metal by a wire and then send a current through the wire. The current causes a magnetic field along the axis. At the moment of making, an eddy current will be induced in the cylinder in the opposite direction, but the frictional resistance to the flow of electricity will destroy this quickly. But if there were no friction (as is actually the case at very low temperatures) this

current would persist indefinitely, and would exert a magnetic field weakening the other. This is exactly what diamagnetism does. So we say that the atom is something like a frictionless conductor. When a field is put on it induces opposing currents in the atoms, and these persist and exert a field opposing the external field.

We must next explain paramagnetism. We believe that every atom has the induced current of diamagnetism, but that this is overridden by a second property. Each atom of a paramagnetic gas has a magnetic moment, even when there is no field. If we could suppose them to be little bar magnets, they would swing to and fro in the presence of an external field, and would be oftener pointing down the field than up it. This would give an extra magnetic moment down the field and would be paramagnetism. Unfortunately the matter is not so simple as this, because the moment must be caused by a revolving electron, and this behaves quite differently. It may be likened to a top, which has the property of always moving at right angles to the direction in which it is pulled. So our atom will not go towards the field at all but will precess round it, and there will be no gain of magnetic moment in the direction of the field. In order to get this gain we have to allow for collisions between the atoms, for then the axes of the tops will be able to change, and will, in fact, have the tendency to point oftener towards than away from the field. The amount of the effect may outweigh the diamagnetism which is always present. The phenomenon shows a clear sign that it depends on collisions, for whereas diamagnetism is constant, paramagnetism depends on the temperature. When the gas is hot, the violence of the collisions makes nearly as many molecules point away as towards the field, but when it is cold the gentle collisions allow them nearly all to settle down along the field.

There is a most difficult point in the argument which is rather too abstruse to explain in detail. It turns on the proper way of taking the averages of the moments of the atoms. This must be carried out with the greatest rigour from dynamical principles. In the past many writers tried to make short cuts and obtained a variety of results. Some proved there could be no paramagnetism, some no diamagnetism, and some even that there could be neither. The essential point of the argument is that the atom must have somewhere the property of a top, which goes on spinning at the same rate however its axis may be altered. It must, so to speak, be able to remember for an indefinite length of time how it behaved when the field was first put on. At least that is how the matter stands on the classical theory. But, as we shall see later, there is definite experimental evidence which shows that the atom is only allowed to exist in a certain very limited number of states, and this rather eases the difficulty; for it need no longer remember its past history, but instead must conform to a rule, unexplained it is true, but in general conformity with other unexplained properties of matter.

The question arises as to whether there would be any way of observing the magnetic moment directly. Such a way was suggested by Stern about three years ago, and the experiment which he carried out in conjunction with Gerlach is certainly one of the most remarkable

of the present century. In a vacuum an atom of gas will go in a perfectly straight line until it hits the wall. If a source of atoms is in line with two fine slits, they will all hit the opposite wall in a narrow line. The atoms were obtained by boiling silver in a small furnace. Those which get through the slits strike the wall and stick there. Even after four hours nothing is visible on the glass, but there exist chemical methods of development whereby the invisible trace of silver attracts more silver from the developer and becomes visible. Now suppose that in their path the atoms encounter a non-uniform magnetic field. In the gaseous form the atoms of silver have a magnetic moment, and so they will experience a deflecting force. If the atoms were pointing arbitrarily in all directions, the character of the field shows that the fine line of the image should be spread out into a lens-shaped figure. What is in fact observed is quite different; the lens is there but it is hollow. The atoms are all pointing straight towards or straight away from the magnetic field.

This result would have been astonishing twenty years ago, but as a matter of fact the experiment was tried with a fairly strong expectation that it would turn out as it did. The quantum theory has illuminated many branches of physics, but none more than spectroscopy, and in particular it describes with complete success the influence of magnetic fields on spectra. According to this theory the atom is a very definite structure, and the definiteness extends not merely to size and shape, but also to its direction in space. The theory goes further and indicates that an atom ought to have a definite magnetic moment, which is called the "Bohr magneton," or in some cases a simple multiple or fraction of this. In silver the deflexion corresponds exactly to one magneton. Several other substances have since been measured, and most of the effects explain themselves on the same principles. Modern physical theory has to face a great many difficulties, and one of the severest is to explain how it is that half the atoms can point away from the field. Each atom evaporates in the furnace right outside the magnetic field and pointing in an arbitrary direction. As it enters the field, if it is to point away, it must gain energy, and there is nowhere from which the energy can come. This would have been a severe difficulty a few years ago, but dynamical toleration has grown recently, and it is becoming recognised as a probability that energy is only conserved on the average and not exactly.

The older calculations of para- and dia-magnetism depend essentially on assuming that the atoms can

point in any direction, and they go wrong if this ceases to be true. We know it to be untrue in Gerlach's experiments, and the question arises as to whether it is true in other cases. This is the subject of some very remarkable recent experiments by Glaser. The susceptibility of gases is very small and hard to measure unless the gases are compressed. Glaser has perfected the arrangements of one method of experiment to such a high degree that he could measure the effect for very low pressures. The principle of his experiment can be described by analogy with the question of buoyancy. If a body is weighed in air and in water, the difference of the weights measures the weight of the displaced water. If a different liquid is used, a similar weighing will give its density in terms of water. Glaser takes a light rod of some substance, actually a slightly paramagnetic glass, and suspends it in a non-uniform field. In a vacuum the field twists the rod round by a definite amount. If it is surrounded by a gas which is also paramagnetic, it will not experience so great a twist, because it will, so to speak, be partly floated by the gas. Similarly, if the gas is diamagnetic, it will be more twisted than in a vacuum. The effect is very small and by no means easy to obtain, but by measuring the amount of twist a value can be found for the susceptibility. The diamagnetism stays constant down to a fairly low pressure, and then changes over to a larger value—actually three times as great. The work is very recent, and the theory is still more or less unknown. Superficially the phenomenon is rather like that of Gerlach, but a little deeper consideration shows that no very close analogy can be drawn between the two cases.

It is natural to suppose that the collisions between the molecules are somehow responsible for reducing the susceptibility at high pressures; but there is great difficulty in seeing how it comes about, for it must be remembered that even at high pressures a molecule is in collision for only a small fraction of the time it spends between collisions. Moreover, though it might be possible to explain in this way a change of susceptibility, there seems no chance of getting a factor so great as three to one. No doubt there will soon be more experiments to help us. For example, much could be deduced if we knew how the curves varied for different temperatures; and it would also be most interesting to know how other gases behave, in particular the strongly paramagnetic oxygen. Unlike the work of Stern and Gerlach, Glaser's experiments do not seem to fit in with the general scheme of things, and so we may perhaps hope that they will lead to some surprising new developments in physical theory.

Obituary.

MR. W. E. CUTLER.

WE regret to have to record the death, on August 30, of Mr. W. E. Cutler, the field palæontologist who was working in Tanganyika Territory for the British Museum on the Dinosaur-bearing beds near Lindi. Those who lead sheltered lives in Europe are sometimes apt to overlook the arduous character of the work on expeditions in tropical or arctic lands, where either endemic disease or extremes of temperature endanger human life, and we may venture to refer to an article in these columns on April 18, p. 573, of this

year, in which it was pointed out that the region in which these wonderful relics of an ancient fauna exist is pest-ridden to an unusual degree.

Mr. Cutler was a Londoner by birth, but emigrated to Canada with his parents at an early age. As a young man he became attracted by fossil collecting, and for some time it is believed worked in that wonderful natural museum which exists in Wyoming; later on he made some fine collections from the Cretaceous beds of Alberta and elsewhere. He served with the Canadian forces during the War, and then returned to