(*Phrynosoma cornutum*) from Texas, presented by Mr. Ernest E. Sabel; a Sulphur-breasted Toucan (*Ramphastos carinatus*) three Black-necked Stilt Plovers (*Himantopus nigricollis*), two Cayenne Lapwings (*Vanellus cayennensis*) from South America, a Slow Loris (*Nycticebus tardigradus*) from Malacca, a Radiated Tortoise (*Testudo radiata*) from Madagascar, two Electric Silurus (*Malapterurus beninensis*) from West Africa, purchased; a Squirrel-like Phalanger (*Belideus sciurea*), born in the Gardens.

ON RADIANT MATTER[1]

II.

Radiant Matter exerts strong Mechanical Action where it Strikes

WE have seen, from the sharpness of the molecular shadows, that radiant matter is arrested by solid matter placed in its path.

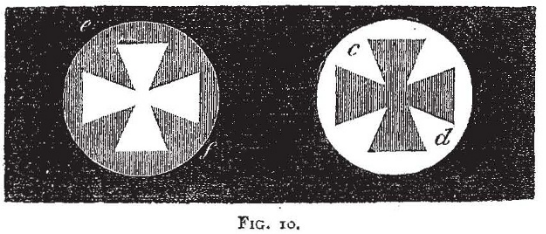

FIG. 10.

If this solid body is easily moved the impact of the molecules will reveal itself in strong mechanical action. Mr. Gimingham has constructed for me an ingenious piece of apparatus which when placed in the electric lantern will render this mechanical action visible to all present. It consists of a highly-exhausted glass tube (Fig. 11), having a little glass railway running along it from one end to the other. The axle of a small wheel revolves on the rails, the spokes of the wheel carrying wide mica paddles. At each end of the tube, and rather above the centre, is an aluminium pole, so that whichever pole is made negative the stream of radiant matter darts from it along the tube, and striking the upper vanes of the little paddle-wheel, causes it to turn round and travel along the railway. By reversing the poles I can arrest the wheel and send it the reverse way, and if I gently incline the tube the force of impact is observed to be sufficient even to drive the wheel up-hill.

This experiment therefore shows that the molecular stream

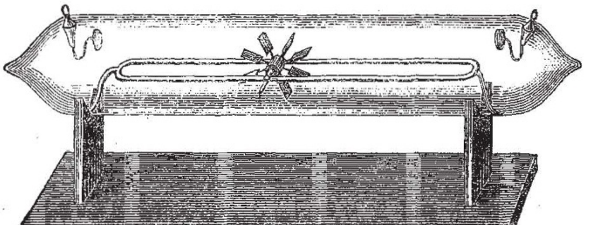

FIG. 11.

from the negative pole is able to move any light object in front of it.

The molecules being driven violently from the pole there should be a recoil of the pole from the molecules, and by arranging an apparatus so as to have the negative pole movable and the body receiving the impact of the radiant matter fixed, this recoil can be rendered sensible. In appearance the apparatus (Fig. 12) is not unlike an ordinary radiometer with aluminium disks for vanes, each disk coated on one side with a film of mica. The fly is supported by a hard steel instead of glass cup, and the needle-point on which it works is connected by means of a wire with a platinum terminal sealed into the glass. At the top of the radiometer bulb a second terminal is sealed in. The radiometer therefore can be connected with an induction-coil, the movable fly being made the negative pole.

For these mechanical effects the exhaustion need not be so high as when phosphorescence is produced. The best pressure for this electrical radiometer is a little beyond that at which the dark space round the negative pole extends to the sides of the glass bulb. When the pressure is only a few millims. of mercury, on passing the induction current a halo of velvety violet light forms on the metallic side of the vanes, the mica side remaining dark. As the pressure diminishes, a dark space is seen to separate the violet halo from the metal. At a pressure of half a millim. this dark space extends to the glass, and rotation commences. On continuing the exhaustion the dark space further widens out and appears to flatten itself against the glass, when the rotation becomes very rapid.

Here is another piece of apparatus (Fig. 13) which illustrates

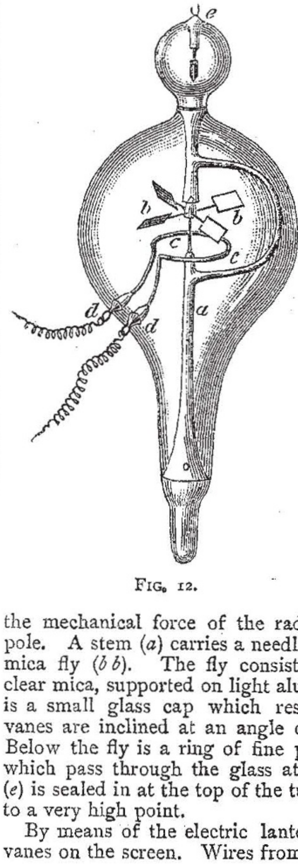

FIG. 12.

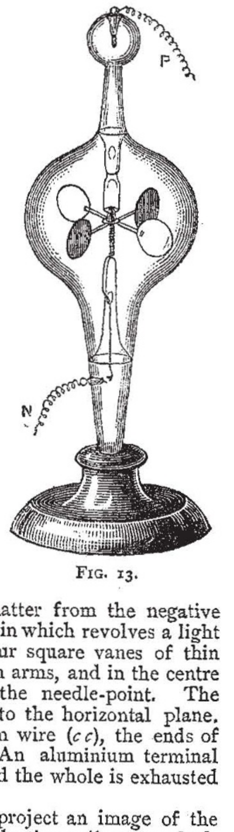

FIG. 13.

the mechanical force of the radiant matter from the negative pole. A stem (*a*) carries a needle-point in which revolves a light mica fly (*b b*). The fly consists of four square vanes of thin clear mica, supported on light aluminium arms, and in the centre is a small glass cap which rests on the needle-point. The vanes are inclined at an angle of 45° to the horizontal plane. Below the fly is a ring of fine platinum wire (*c c*), the ends of which pass through the glass at *d d*. An aluminium terminal (*e*) is sealed in at the top of the tube, and the whole is exhausted to a very high point.

By means of the electric lantern I project an image of the vanes on the screen. Wires from the induction-coil are attached,

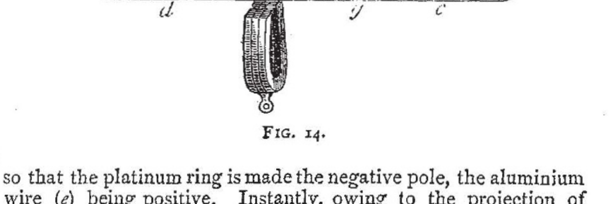

FIG. 14.

so that the platinum ring is made the negative pole, the aluminium wire (*e*) being positive. Instantly, owing to the projection of radiant matter from the platinum ring, the vanes rotate with extreme velocity. Thus far the apparatus has shown nothing more than the previous experiments have prepared us to expect; but observe what now happens. I disconnect the induction-coil altogether, and connect the two ends of the platinum wire with a small galvanic battery; this makes the ring *c c* red-hot, and under this influence you see that the vanes spin as fast as they did when the induction-coil was at work.

Here, then, is another most important fact. Radiant matter in these high vacua is not only excited by the negative pole of an induction-coil, but a hot wire will set it in motion with force sufficient to drive round the sloping vanes.

[1] A lecture delivered to the British Association for the Advancement of Science, at Sheffield, Friday, August 22, 1879, by William Crookes, F.R.S. Continued from p. 423.

Radiant Matter is deflected by a Magnet

I now pass to another property of radiant matter. This long glass tube (Fig. 14), is very highly exhausted; it has a negative pole at one end (*a*) and a long phosphorescent screen (*b, c*) down the centre of the tube. In front of the negative pole is a plate of mica (*b, d*) with a hole (*e*) in it, and the result is, when I turn on the current, a line of phosphorescent light (*e, f*) is projected along the whole length of the tube. I now place beneath the tube a powerful horse-shoe magnet: observe how the line of light (*e, g*) becomes curved under the magnetic influence waving about like a flexible wand as I move the magnet to and fro.

This action of the magnet is very curious, and if carefully followed up will elucidate other properties of radiant matter. Here (Fig. 15) is an exactly similar tube, but having at one end a small potash tube, which if heated will slightly injure the vacuum. I turn on the induction current, and you see the ray of radiant matter tracing its trajectory in a curved line along the screen, under the influence of the horse-shoe magnet beneath. Observe the shape of the curve. The molecules shot from the negative pole may be likened to a discharge of iron bullets from a mitrailleuse, and the magnet beneath will represent the earth curving the trajectory of the shot by gravitation. Here on this luminous screen you see the curved trajectory of the shot accurately traced. Now suppose the deflecting force to remain constant, the curve traced by the projectile varies with the velocity. If I put more powder in the gun the velocity will be greater and the trajectory flatter, and if I interpose a denser resisting medium between the gun and the target, I diminish the velocity of the shot, and thereby cause it to move in a greater curve and come to the ground sooner. I cannot well increase before you the velocity of my stream of radiant molecules by putting more

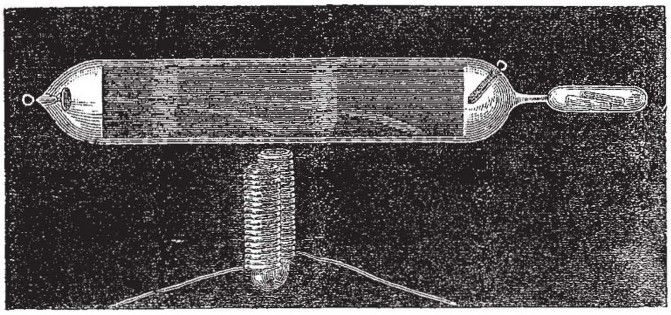

FIG. 15.

powder in my battery, but I will try and make them suffer greater resistance in their flight from one end of the tube to the other. I heat the caustic potash with a spirit-lamp and so throw in a trace more gas. Instantly the stream of radiant matter responds. Its velocity is impeded, the magnetism has longer time on which to act on the individual molecules, the trajectory gets more and more curved, until, instead of shooting nearly to the end of the tube, my molecular bullets fall to the bottom before they have got more than half-way.

It is of great interest to ascertain whether the law governing the magnetic deflection of the trajectory of radiant matter is the same as has been found to hold good at a lower vacuum. The experiments I have just shown you were with a very high vacuum. Here is a tube with a low vacuum (Fig. 16). When I turn on the induction spark, it passes as a narrow line of violet light

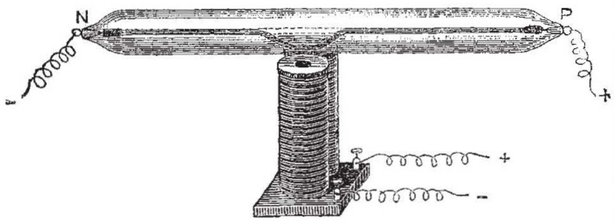

FIG. 16.

joining the two poles. Underneath I have a powerful electro-magnet. I make contact with the magnet, and the line of light dips in the centre towards the magnet. I reverse the poles, and the line is driven up to the top of the tube. Notice the difference between the two phenomena. Here the action is temporary. The dip takes place under the magnetic influence; the line of discharge then rises and pursues its path to the positive pole. In the high exhaustion, however, after the stream of radiant matter had dipped to the magnet, it did not recover itself, but continued its path in the altered direction.

By means of this little wheel, skilfully constructed by Mr. Gimingham, I am able to show the magnetic deflection in the electric lantern. The apparatus is shown in this diagram (Fig. 17). The negative pole (*a, b*) is in the form of a very shallow cup. In front of the cup is a mica screen (*c, d*), wide enough to intercept the radiant matter coming from the negative pole. Behind this screen is a mica wheel (*e, f*) with a series of vanes, making a sort of paddle-wheel. So arranged, the molecular rays from the pole *a b* will be cut off from the wheel, and will not produce any movement. I now put a magnet, *g*, over the tube, so as to deflect the stream over or under the obstacle *c, d*, and the result will be rapid motion in one or the other direction, according to the way the magnet is turned. I throw the image of the apparatus on the screen. The spiral lines painted on the wheel show which way it turns. I arrange the magnet to draw the molecular stream so as to beat against the upper vanes, and the wheel revolves rapidly as if it were an over-shot water-wheel. I turn the magnet so as to drive the radiant

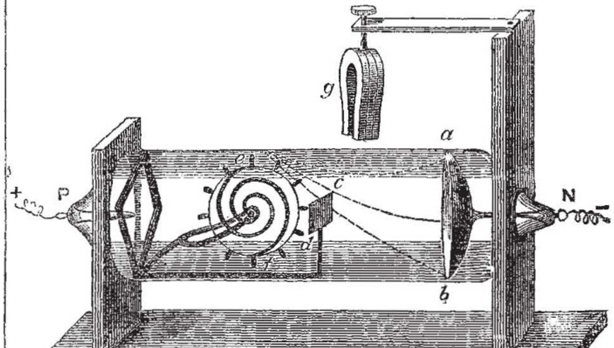

FIG. 17.

matter underneath; the wheel slackens speed, stops, and then begins to rotate the other way, like an under-shot water-wheel. This can be repeated as often as I reverse the position of the magnet.

I have mentioned that the molecules of the radiant matter discharged from the negative pole are negatively electrified. It is probable that their velocity is owing to the mutual repulsion between the similarly electrified pole and the molecules. In less high vacua, such as you saw a few minutes ago (Fig. 16), the discharge passes from one pole to another, carrying an electric current, as if it were a flexible wire. Now it is of great interest to ascertain if the stream of radiant matter from the negative pole also carries a current. Here (Fig. 18) is an apparatus which will decide the question at once. The tube contains two negative terminals (*a*, *b*) close together at one end, and one positive terminal (*c*) at the other. This enables me to send two streams of radiant matter side by side along the phosphorescent screen—or by disconnecting one negative pole, only one stream.

If the streams of radiant matter carry an electric current they will act like two parallel conducting wires and attract one

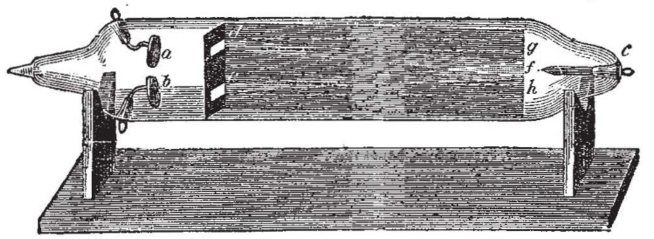

Fig. 18.

another; but if they are simply built up of negatively electrified molecules they will repel each other.

I will first connect the upper negative pole (*a*) with the coil, and you see the ray shooting along the line *d*, *f*. I now bring the lower negative pole (*b*) into play, and another line (*e*, *h*) darts along the screen. But notice the way the first line behaves; it jumps up from its first position, *d f*, to *d g*, showing that it is repelled, and if time permitted I could show you that the lower ray is also deflected from its normal direction: therefore the two parallel streams of radiant matter exert mutual repulsion, acting not like current carriers, but merely as similarly electrified bodies.

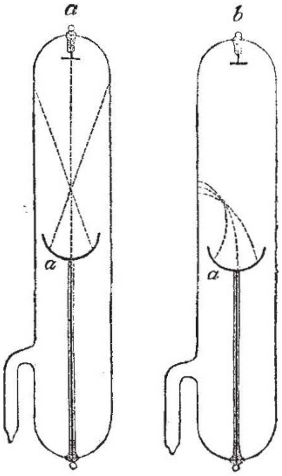

Fig. 19.

Radiant Matter produces Heat when its Motion is arrested

During these experiments another property of radiant matter has made itself evident, although I have not yet drawn attention

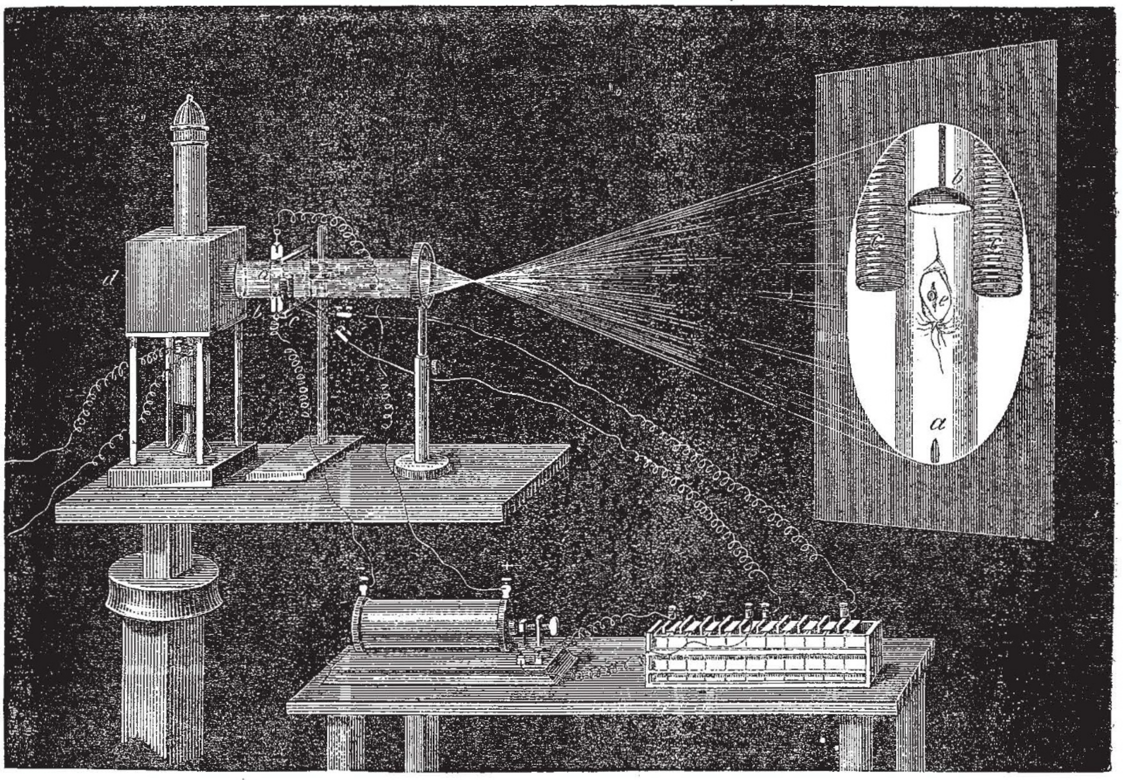

Fig. 20.

to it. The glass gets very warm where the green phosphorescence is strongest. The molecular focus on the tube, which we saw earlier in the evening (Fig. 8) is intensely hot, and I have prepared an apparatus by which this heat at the focus can be rendered apparent to all present.

I have here a small tube (Fig. 19, *a*) with a cup-shaped negative pole. This cup projects the rays to a focus in the middle of the tube. At the side of the tube is a small electro-magnet, which I can set in action by touching a key, and the focus is then drawn to the side of the glass tube (Fig. 19, *b*). To show the first action of the heat I have coated the tube with wax. I will put the apparatus in front of the electric lantern (Fig. 20, *d*), and throw a magnified image of the tube on the screen. The coil is now at work, and the focus of molecular rays is projected along the tube. I turn the magnetism on, and draw the focus to the side of the glass. The first thing you see is a small circular patch melted in the coating of wax. The glass soon begins to disintegrate, and cracks are shooting star-wise from the centre of heat. The glass is softening. Now the atmospheric pressure forces it in, and now it melts. A hole (*e*) is perforated in the middle, the air rushes in, and the experiment is at an end.

I can render this focal heat more evident if I allow it to play on a piece of metal. The bulb (Fig. 21) is furnished with a negative pole in the form of a cup (*a*). The rays will therefore be projected to a focus on a piece of iridio-platinum (*b*) supported in the centre of the bulb.

I first turn on the induction-coil slightly, so as not to bring out its full power. The focus is now playing on the metal, raising it to a white heat. I bring a small magnet near, and you see I can deflect the focus of heat just as I did the luminous focus in the other tube. By shifting the magnet I can drive the focus up and down, or draw it completely away from the metal, and leave it non-luminous. I withdraw the magnet, and let the molecules have full play again; the metal is now white hot. I increase

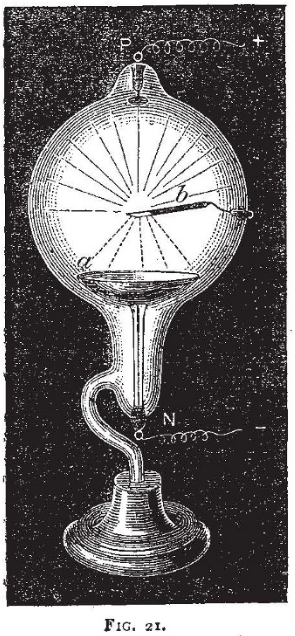

FIG. 21.

the intensity of the spark. The iridio-platinum glows with almost insupportable brilliancy, and at last melts.

The Chemistry of Radiant Matter

As might be expected, the chemical distinctions between one kind of radiant matter and another at these high exhaustions are difficult to recognise. The physical properties I have been elucidating seem to be common to all matter at this low density. Whether the gas originally under experiment be hydrogen, carbonic acid, or atmospheric air, the phenomena of phosphorescence, shadows, magnetic deflection, &c., are identical, only they commence at different pressures. Other facts, however, show that at this low density the molecules retain their chemical characteristics. Thus by introducing into the tubes appropriate absorbents of residual gas, I can see that chemical attraction goes on long after the attenuation has reached the best stage for showing the phenomena now under illustration, and I am able by this means to carry the exhaustion to much higher degrees that I can get by mere pumping. Working with aqueous vapour I can use phosphoric anhydride as an absorbent; with carbonic acid, potash; with hydrogen, palladium; and with oxygen, carbon, and then potash. The highest vacuum I have yet succeeded in obtaining has been the 1-20,000,000th of an atmosphere, a degree which may be better understood if I say that it corresponds to about the hundredth of an inch in a barometric column three miles high.

It may be objected that it is hardly consistent to attach primary importance to the presence of *Matter*, when I have taken extraordinary pains to remove as much matter as possible from these bulbs and these tubes, and have succeeded so far as to leave only about the one-millionth of an atmosphere in them. At its ordinary pressure the atmosphere is not very dense, and its recognition as a constituent of the world of matter is quite a modern notion. It would seem that when divided by a million, so little matter will necessarily be left that we may justifiably neglect the trifling residue and apply the term *vacuum* to space from which the air has been so nearly removed. To do so, however, would be a great error, attributable to our limited faculties being unable to grasp high numbers. It is generally taken for granted that when a number is divided by a million the quotient must necessarily be small, whereas it may happen that the original number is so large that its division by a million seems to make little impression on it. According to the best authorities, a bulb of the size of the one before you (13·5 centimetres in diameter) contains more than 1,000,000,000,000,000,000,000,000 (a quadrillion) molecules. Now, when exhausted to a millionth of an atmosphere we shall still have a trillion molecules left in the bulb—a number quite sufficient to justify me in speaking of the residue as *matter*.

To suggest some idea of this vast number I take the exhausted bulb, and perforate it by a spark from the induction-coil. The spark produces a hole of microscopical fineness, yet sufficient to allow molecules to penetrate and to destroy the vacuum. The inrush of air impinges against the vanes, and sets them rotating after the manner of a windmill. Let us suppose the molecules to be of such a size that at every second of time a hundred millions could enter. How long, think you, would it take for this small vessel to get full of air? An hour? A day? A year? A century? Nay, almost an eternity! A time so enormous that imagination itself cannot grasp the reality. Supposing this exhausted glass bulb, indued with indestructibility, had been pierced at the birth of the solar system; supposing it to have been present when the earth was without form and void; supposing it to have borne witness to all the stupendous changes evolved during the full cycles of geologic time, to have seen the first living creature appear, and the last man disappear; supposing it to survive until the fulfilment of the mathematician's prediction that the sun, the source of energy, four million centuries from its formation, will ultimately become a burnt-out cinder;[1] supposing all this—at the rate of filling I have just described, 100 million molecules a second—this little bulb even then would scarcely have admitted its full quadrillion of molecules.[2]

But what will you say if I tell you that all these molecules, this quadrillion of molecules, will enter through the microscopic hole before you leave this room? The hole being unaltered in size, the number of molecules undiminished, this apparent paradox can only be explained by again supposing the size of the molecules to be diminished almost infinitely—so that instead of entering at the rate of 100 millions every second, they troop in at a rate of something like 300 trillions a second. I have done the sum, but figures when they mount so high cease to have any meaning, and such calculations are as futile as trying to count the drops in the ocean.

In studying this fourth state of matter we seem at length to have within our grasp and obedient to our control the little indivisible particles which with good warrant are supposed to constitute the physical basis of the universe. We have seen that in some of its properties radiant matter is as material as this table, whilst in other properties it almost assumes the character of radiant energy. We have actually touched the borderland where matter and force seem to merge into one another, the shadowy realm between Known and Unknown which for me has always

[1] The possible duration of the sun from formation to extinction has been variously estimated by different authorities, at from 18 million years to 400 million years. For the purpose of this illustration I have taken the highest estimate.

[2] According to Mr. Johnstone Stoney (*Phil. Mag.*, vol. 36, p. 141), 1 c.c. of air contains about 1,000,000,000,000,000,000,000 molecules. Therefore a bulb 13·5 centims. diameter contains $13{\cdot}5^3 \times 0{\cdot}5236 \times$ 1,000,000,000,000,000,000,000 or 1,288,252,350,000,000,000,000,000 molecules of air at the ordinary pressure. Therefore the bulb when exhausted to the millionth of an atmosphere, contains 1,288,252,350,000,000,000 molecules, leaving 1,288,251,061,747,650,000,000,000 molecules to enter through the perforation. At the rate of 100,000,000 molecules a second, the time required for them all to enter will be

12,882,510,617,476,500 seconds, or
214.708.510,291,275 minutes, or
3.578.475,171,521 hours, or
149,103.132,147 days, or
408,501,731 years.

had peculiar temptations. I venture to think that the greatest scientific problems of the future will find their solution in this Border Land, and even beyond; here, it seems to me, lie Ultimate Realities, subtle, far-reaching, wonderful.

"Yet all these were, when no Man did them know,
Yet have from wisest Ages hidden beene;
And later Times thinges more unknowne shall show.
Why then should witlesse Man so much misweene,
That nothing is, but that which he hath seene?"

THE BRITISH ASSOCIATION

GENERAL satisfaction is expressed with the Sheffield meeting. The people of the town and district did their best, amid many difficulties, to give the members of the Association a hearty reception, and they succeeded. The excursions on Thursday were well attended, and those who took part in them seem to have enjoyed themselves. At the meeting of the General Committee, Swansea was selected as next year's place of meeting, with Prof. A. R. Ramsay as president; the date of meeting is August 25. A letter was read from the Archbishop of York, warmly urging upon the Association to meet in the archiepiscopal City in 1881, when, for some unaccountable reason, the jubilee is to be celebrated, as we have already said, in the fifty-first year of the Association's existence. As the result of the important discussion in Section F on science teaching in schools, a committee was appointed for the purpose of reporting, in addition to other matters, whether it is important that her Majesty's inspectors of elementary schools should be appointed with reference to their ability for examining on scientific specific subjects of the code, the committee to consist of Mr. Mundella, M.P., Mr. Shaw, Mr. Bourne, Mr. Jas. Heywood, Mr. Wilkinson, and Dr. J. H. Gladstone.

REPORTS

Report of the Committee on Erratic Blocks, presented by the Rev. H. W. Crosskey, F.G.S. (Abstract.)

Several contributions of interest and importance have been received respecting the position and distribution of erratic blocks.

A granite boulder 3 × 2·5 × 2 feet has been found by Mr. Hall, in the village of Bickington, parish of Fremington. There is no similar rock nearer than Lundy Island, twenty-five miles west-north-west from the boulder and Dartmoor, twenty-five miles south by east. Its height above the sea is 80 feet.

Among the most remarkable erratic blocks yet described in the midland district, are those reported upon Frankley Hill, at a height of 650 feet above the sea. They were examined by the writer in company with Prof. T. G. Bonney, and the following is a summary of the observations made:—

A section of drift beds is exposed in a cutting of the new Hales Owen Railway passing through Frankley Hill. The section is as follows:—Permian clay, sand of clayey texture, yellowish sand, greyish sandy clay with brinter pebbly clay, somewhat sandy. The heights of the clays and sands are very irregular throughout the section which is in itself about 60 feet in depth.

Fragments of permian sandstone (which is exposed in a part of the section) are scattered through the sands and clays, but erratic blocks are rare. Indeed, one only—a green-stone—was noticed in the cutting itself, although others doubtless occur.

No part of this section can be called a "boulder clay"—if by "boulder clay" be meant either a clay formed beneath land ice, or a clay carried away by an iceberg and deposited on the sea-bottom, as the berg melted or stranded.

The various sands and gravels have all the appearance of being a "wash" from older beds, effected during the depression and subsequent upheaval of the present land surface. They are neither compactly crowded with erratics, nor are fragments of local rocks heaped irregularly together, and grooved and striated. The way in which the pieces of native rock are scattered through the beds, does not indicate any other force than that which would be exerted by the ordinary "wash" of the waters during the movements just mentioned.

The presence of a few erratics shows that the *wash* must have taken place beneath the waters of a glacial sea, over which icebergs floated.

These beds appear to have been formed in the earlier rather than the later part of the glacial epoch. In a field *on the summit of the section* a large number of erratics are to be seen which have been taken from a recent surface-drain. Twenty of these boulders are felsite, two are basalt, one is a piece of vein-quartz, and one is a Welsh diabase. They constitute a group of allied rocks, evidently from one district. Probably they belong to the great Arenig dispersion. Two of the felsites close to the group are of considerable size, the larger being about 6 × 4 × 2 feet. Similar blocks may be traced to the summit of the hill. One felsite boulder opposite the Yew Trees is about 4·5 × 3 × 2 feet, and is partly buried in the ground.

The height of the boulders above the sea is remarkable, their highest level being 650 feet.

This indicates a corresponding depression of the land, since no Welsh glacier could have travelled over hill and down dale to this summit-level. To render any such glacier work conceivable, the Welsh mountains must have stood at a height beyond any point for which there is the slightest evidence.

This group of boulders on Frankley Hill appears to have been dropped by an iceberg travelling from Wales upon the top of the clays and sands exposed in the railway cutting at a time when the land was depressed at least 700 feet. In the clays and sands upon which the summit group of erratics rests, we must have beds belonging to an earlier date than the *close* of the glacial epoch; and the erratics in the cutting must be discriminated from those left at the higher level.

Some remarkable boulders were described from the neighbourhood of Wolverhampton: (1) a striated boulder of felsite 11 × 3 × 3 feet; (2) one of slate, broken into two parts, but which, when whole, measured 11·25 × 6·25 × 3·5 feet; (3) one of granite about 4·75 feet in each dimension, and weighing about three tons.

Mr. D. Mackintosh traces the origin of the so-called "greenstone" boulders (more properly to be called diorites or dolerites) around the estuaries of the Mersey and the Dee.

The area in which they are very much concentrated is intensely striated, and nearly all the striæ point divergently to the south of Scotland, *i.e.*, between N. 15° W. and N. 45° W.

A large "greenstone" boulder has been found at Crosby, resting on a perfectly flat glaciated rock surface, with striæ pointing N. 40° W.

Additional presumptions in favour of the Scottish derivation of these boulders may be found (1) in the fact that nearly all these boulders consist of basic rocks similar to some found in the south of Scotland, and (2) in the extent to which they are locally concentrated on the peninsula of Wirral and the neighbouring part of Lancashire. Many fresh greenstone boulders have been lately exposed in the newest Bootle Dock excavation. The largest is 6 × 4·5 × 3 feet, and was found on the surface of the upper boulder clay. As a rule these boulders are excessively flattened and regularly grooved.

Mr. J. R. Dakyns describes the occurrence of Shap granite boulders on the Yorkshire coast. There are several at Long Nab on the north side of the Nab; one of these measures 3 cubic feet. Others are on the north side of Cromer Point; south of Cromer Point there are more till you come nearly to Filey. There is one measuring 3 × 2·5 × 2 feet on the top of the cliff about a mile from Filey. It is probably practically undisturbed, for the ground slopes inland from the cliff, and therefore, if it has been turned up in ploughing and moved, it cannot have been moved far, for no one would take the trouble to cart a huge boulder far up-hill.

There are several boulders of Shap granite on the shore along the north of Filey Bay, but none along the south till one reaches Flamborough Head. Several occur along the shore between Flamborough Head and Flamborough south landing; one of these measures 36 cubic feet. One may be seen rather more than a mile south of Bridlington Quay, and doubtless they have travelled still further south, since there is one built into a wall at Hornsea.

The destruction of erratic blocks is going on so rapidly that the Committee invite continued contributions of information concerning them.

Report of the "Geological Record" Committee, by W. Whitaker, B.A., F.G.S.—Since the last meeting of the Association the third volume of the "Geological Record" has been published. This gives an account of books, papers, &c., on geology, mineralogy, and palæontology published at home and abroad during the year 1876. The fourth volume (for 1877) is in the