II. *Experimental Researches in Electricity.—Twenty-fifth Series.* By MICHAEL FARADAY, *Esq., D.C.L., F.R.S., Fullerian Prof. Chem. Royal Institution, Foreign Associate of the Acad. Sciences, Paris, Ord. Boruss. Pour le Mérite, Eq., Memb. Royal and Imp. Acadd. of Sciences, Petersburgh, Florence, Copenhagen, Berlin, Göttingen, Modena, Stockholm, Munich, Bruxelles, Vienna, Bologna, &c. &c.*

Received August 15,—Read November 28, 1850.

§ 31. *On the magnetic and diamagnetic condition of bodies.*

¶ i. *Non-expansion of gaseous bodies by magnetic force.* ¶ ii. *Differential magnetic action.* ¶ iii. *Magnetic characters of Oxygen, Nitrogen and Space.*

¶ i. *Non-expansion of gaseous bodies by magnetic force.*

2718. THERE can be no doubt that the magnetic force, the diamagnetic force, and the magneoptic or magnecrystallic force, will, when thoroughly understood, be found to unite or exist under one form of power, and be essentially the same. Hence the great interest which exists in the development of any one of these modes of action; for differing so greatly as they do in very peculiar points, it is hardly possible that any one of them should be advanced in its illustration or comprehension, without a corresponding advance in the knowledge of the others. Stimulated by such a feeling, I have been engaged with PLÜCKER, WEBER, REISCH and others, in endeavouring to make out, with some degree of precision, the mode of action of diamagnetic as well as magnecrystallic bodies; and the recent investigation (2640, &c.) and endeavour to confirm the idea of polarity in bismuth and diamagnetic bodies, the reverse of that in a magnet or in iron bodies, was one of the results of that conviction and desire.

2719. Having failed however to establish the existence of such an antipolarity, and having shown, as I think, that the phenomena which were supposed to be due to it are in fact dependent upon other conditions and causes, I was induced, in the search after something precise as to the nature of diamagnetic bodies, to examine another idea which had arisen in consequence of the development of magnetic and diamagnetic phenomena amongst gaseous substances: this thought, with some of the results which have grown out of it during its experimental examination, I purpose making the subject of the present paper.

2720. BANCALARI first showed that flame was diamagnetic*. The effect, as I proved, was due chiefly to the heated state of gaseous portions of the flame†; but besides that, it appeared that at common temperatures diamagnetic phenomena could

* Philosophical Magazine, 1847, vol. xxxi. pp. 401, 421. † Ibid. pp. 404, 406.

be exhibited by gases; and also that in their production the gases differed very much one from another*; so that, taking common air, for instance, as a standard, nitrogen, and many other gases, were strongly diamagnetic in relation to it, whilst oxygen took on the appearance of a magnetic body; for *they* were repelled from, while it was attracted to, the place of maximum force in the magnetic field.

2721. Recalling the general law given respecting the action of magnetic and diamagnetic bodies (2267, 2418), namely, that the former tended to go from weaker to stronger places, and the latter from stronger to weaker places of magnetic power, and applying it to such bodies as the gases, which are at the same time both highly elastic and easily changed in bulk by the superaddition of very small degrees of force, it would seem to follow, that if the particles of a diamagnetic gas tended to go from strong to weak places of action, in consequence of the direct and immediate effect of the magnetic power on them, then such a gas should tend to become enlarged or expanded in the magnetic field. For the amount of power by which the particles would tend to recede from the axis of the magnetic field, would be added to the expansive force by which they before resisted the pressure of the atmosphere; that pressure would therefore be in part sustained by the new force, and expansion would of necessity be the result. On the other hand, if a gas were magnetic (as for instance oxygen), then the force cast upon the particles, by such a direct and immediate action of the magnetic power upon them, would urge them *towards* the axis of the magnetic field, and so coinciding with, and being superadded to the pressure of the atmosphere, would tend to cause contraction and diminution of bulk.

2722. If such supposititious cases were to prove true, we should then be able to arrive at the knowledge of the real zero-point (2416, 2432, 2440)†, not amongst gases only, but amongst all bodies, and should be able to tell whether such a gas as oxygen were a magnetic or a diamagnetic body, and also able to range individual gases and other substances in their proper places. And though I had originally endeavoured to ascertain whether there was any change in the bulk of air in the magnetic field, and found none, still PLÜCKER's statement that he has obtained such an effect‡, and the great enlargement of knowledge respecting the gases which since then we have acquired relating to their diamagnetic relations, and especially of the great difference which exists between them, encouraged me to proceed.

2723. I first endeavoured to determine whether there was any affection of the layer of air (or other gas) immediately in contact with the magnetic pole, which, either by the consequent expansion or contraction of that layer, could render it able to affect the course of a ray of light and thus make manifest the changes occurring within. A metal screen, with a pin-hole in it, was set up before the flame of a bright lamp in a dark room, and thus an artificial star or small definite luminous object was formed.

* Philosophical Magazine, 1847, vol. xxxi. p. 409. † Ibid. p. 420.

‡ Annales de Chimie, 1850, xxix. p. 134.

Forty-six feet from it was placed the great horseshoe magnet (2247.), ready to be excited by twenty pairs of GROVE's plates; the poles were in a line, so that the ray from the lamp passed for 4 inches close to the surface of the first pole, then through 6 inches of air, and then, for 4 inches, close to the surface of the second pole. A very fine refracting telescope, belonging to Sir JAMES SOUTH, having an aperture of 3 inches and 46 inches focal length, received the ray. The telescope was furnished with a perfect micrometer, so that the smallest change in the place of the luminous image could be observed on the threads. The axis of the telescope was just above the level of the magnetic poles. Not the smallest change in either the character or place of the luminous image could be observed, either on the making or the breaking of the contact between the voltaic battery and the magnetic wire.

2724. As the chief part of the light which came to the telescope consisted of rays which passed at some distance above the magnetic poles, these were cut off by a screen, which rising only one-eighth of an inch above the level of the poles, allowed no ray to pass that was not within that distance. The intensity of the light was of course diminished, and the image was distorted by inflection; still its place was well marked by the micrometer. Not the slightest change in that or any other character occurred in the supervention or the withdrawal of the magnetic force.

2725. The terminals of the magnetic poles were then varied, so that the ray sometimes passed parallel and close to a long right-angled edge, or parallel to and between two right-angled edges, a little above or below them, or over the line joining two hemispherical poles, placed close together (and also in many other ways), but in no case did the magnetic action produce any effect upon the course of the ray.

2726. In another form of the experiment the telescope was dismissed, and a simple card, with a pin-hole $\frac{1}{50}$th or $\frac{1}{100}$th of an inch in diameter, employed in its place. The image of the star of light could be seen through the pin-hole in the dark room, and yet every ray tending to its formation passed within $\frac{1}{50}$th of an inch of the surface of the magnetic pole; still no effect due to the magnetic force could be observed.

2727. By another arrangement of the polar terminations, analogous to one I had formerly employed when experimenting on the diamagnetic relations of the gases*, I was able to surround them with other gaseous substances than air, and subject the ray for 2 inches of its course to these gases whilst under the influence of the magnet. Though the glass of the enclosing vessel disturbed the image of the object, *i. e.* the point of light, yet it was easy to perceive that no additional effect occurred when the magnetism was superinduced.

2728. Oxygen, nitrogen, hydrogen and coal-gas were thus employed; but whether any one of these, or whether air itself was submitted to examination, when in contact with the active pole of a very powerful magnet, it did not appear to be either expanded or condensed to such a degree as to cause any sensible change in its refractive force.

* Philosophical Magazine, 1847, vol. xxxi. pp. 414, 415.

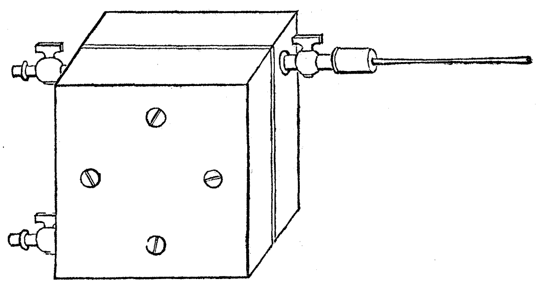
2729. In order to compare the expected result with the real result due to change of volume, I took a bar of iron 7 inches long, and placed it so that the ray from the luminous object in passing to the eye should proceed by the side of the bar at not more than $\frac{1}{50}$th of an inch from it, and then raised the temperature of the bar gradually, until by expanding the air in contact with it, the course of the ray of light was sensibly affected; to do this it required to be exalted many degrees. When the air of the place was at 60° and the iron raised to 100° FAHR., the effect was not distinct. Hence it seemed, that observation of the expected change of volume of the air would be rendered far more sensible by some arrangement, measuring that change directly, than by such means as those referred to above, dependent on refractive force; for it is certain that the change of volume, in a very small quantity of air, raised from 60° to 100°, would be very evident by the former method. On the other hand, it was just possible that if the air or gas was affected by the magnet, it might only be in that film immediately contiguous to the pole; and also that great differences in the degree of change might exist along the *edge* of a solid angle, and along the *sides* of the planes forming that angle. Hence the assumed necessity for examining those parts by a ray of light; and every precaution was taken, by inclining the course of the ray a little more or less to the sides or edges of the poles, and by making the sides or edges very slightly convex, to include every variation of the experiment, that might help to make any magnetic or diamagnetic effect, whether special or local, or general, manifest; but without effect.

2730. I proceeded, as these attempts had failed, to endeavour to determine and compare the *volume* of air subjected to the magnetic force, before and after its subjection; and there seemed to be the greater hope of obtaining some results in this way, provided any such change was a consequence of the action of magnetic power, because air and gases, at a considerable distance from the surface of the magnet, are known to be strongly affected diamagnetically, and because PLÜCKER had already said he had obtained such change of volume (2722.).

2731. The first instrument constructed for this purpose was of the following kind. Two blocks of soft iron, each 1 inch thick and 3 inches square, having filed and flattened surfaces, were prepared; and also a sheet of copper, $\frac{1}{60}$th of an inch in thickness and 3 inches square, having its middle part cut away to within 0·3 of an inch of the edge all round. This plate or frame was then placed between the iron blocks, and the whole held together very tightly by copper screws, so as to make an air-chamber $\frac{1}{60}$th of an inch wide and 2·4 inches square, having the faces of the blocks, which were to become the magnetic poles, for its sides. Three apertures and corresponding passages gave access to the interior of this chamber; small stop-cocks were attached to each. By two of these, any gas, after it had been properly dried, could be sent into the chamber, or swept out of it, by any other entering gas;

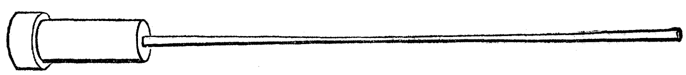
and to the third was attached a gauge (2732.) for the purpose of indicating and measuring any change of volume which might occur. The edges of the central copper plate and the heads of the countersunk screws, were touched with white hard varnish, and the chamber thus rendered perfectly tight, under every condition to which it had to be subjected (fig. 1).

Fig. 1.



2732. The gauges were formed of small capillary tubes from 1·5 to 3 inches in length, the diameter in the middle of their length being less than one-half of that at either termination. These were fixed at one end into a small socket, which screwed on to the third, or gauge-cock mentioned above (2731.). A minute portion of spirit, coloured by cochineal, being put into the external end of this gauge, from a slip of wood or glass, immediately advanced to the middle or narrowest part, forming, as it always should do, a single portion of fluid. By shutting the cock, this little cylinder could be easily retained in its place undisturbed during the filling of the air-chamber with gas, and the adjustment of its pressure to equality with that of the atmosphere. On shutting the other cocks and opening the gauge-cock, the gauge was then ready to show any change of volume which the supervention of the magnetic force might cause; but to give it the highest degree of sensibility, it was necessary previously to make the liquid cylinder travel right and left of its place of rest, that the tube might be moistened on each side of the indicating fluid; an effect easily obtained by inclining the chamber to and fro, the gravity of the fluid making it pass one way or the other. But this and many other necessary precautions as to position, temperature, &c., can only be learned from experience.

Fig. 2.



2733. When this box was in its place, it stood between the poles of the great electro-magnet, with the plane of the gas-chamber in the equatorial position; then square blocks of soft iron, resting on the magnet poles, were made to abut and bear against the sides of the box, so that in fact the inner faces of the air-chamber were the virtual magnetic poles, and being 3 inches square were only $\frac{1}{60}$th of an inch apart. Hence, whatever air or gas was within the chamber, would be subjected to a very powerful magnetic action, and could have very small changes in its bulk measured; but it is perhaps necessary to observe, that it would be contained in a field having everywhere lines of equal magnetic power (2463. 2465.).

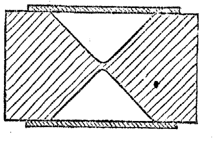
2734. *Air* was introduced into the box, and when all was properly arranged, the place of the indicating fluid was observed by a microscope. Then the magnet was rendered powerfully active, and there appeared a very slight motion of the fluid, as if the air were a little expanded; on taking off the magnetic force the fluid returned to its first place. The same effect recurred again and again. The amount of this change was very small, and there was reason to refer it to the pressure exercised by the magnet, when in action, upon the sides of the iron box; for afterwards, when the box was placed in a vice and squeezed, the same motion in the fluid occurred; and further, when the square blocks of soft iron (2733.) were kept apart by an under block of wood, so as not absolutely to touch and press the box, the effect was reduced to almost nothing.

2735. Oxygen, nitrogen, carbonic acid and nitrous oxide gases, were then introduced successively into the iron box, and with exactly the same result as with air. No difference appeared between oxygen and the other gases, greatly as they differ in magnetic and diamagnetic force and relations. Hydrogen and coal-gas were also subjected to experiment; but when these gases were in the box there was a gradual recession of the indicating fluid, due, as I found, to the absorption of the gases, probably either by the varnish or cement or cork used at the gauge, or at the joints of the box. The delicacy of the gauge was thus made manifest; but when the effect was taken into account, it was found that these gases were equally unaffected in bulk as the other gases by the magnetic influence.

2736. The diameter of the gauge, at the place where the fluid was placed, was rather less than $\frac{1}{100}$th of an inch. An amount of motion equal to $\frac{1}{100}$th of an inch was easily discerned. Comparing these numbers with the capacity of the gas-chamber, it would appear that if the gas in the latter had expanded or contracted to the extent of $\frac{1}{100,000}$th part, the result would have been visible; or any *difference* approaching to this amount, between oxygen and nitrogen or the other gases, would have become sensible, *but no such effects or differences appeared.*

2737. As the establishment of either the *occurrence* or the *absence* of change of volume in gases, when under the magnetic influence, appeared to me to be of great and almost equal importance, I was led to consider whether, in the experiment just described, the circumstance of the gases having been subjected to the magnetic power in a field of equal force (2733.) might not have interfered with the production of the effect sought for; for such a field is that where the diamagnetic phenomena, of solid and liquid bodies, occur in the most unfavourable manner, and where indeed they almost entirely disappear. I therefore constructed another apparatus so that this condition was removed, and in which, if the particles of the diamagnetic gas, by any unknown disposition of the powers in action, tended only to pass from strong to weaker places of force, and being thus incapable of enlargement in the axial direction, would only show that effect equatorially, the opportunity for their doing so should be present.

Fig. 3.



2738. A cylinder of soft iron had the central parts removed in a lathe, until it had assumed the form of an hour-glass, or that represented in fig. 3, which is to a scale of one-third. When placed between the poles of the magnet instead of the former box, it was expected that the continuation of the iron throughout would prevent any diminution of its length, from the pressure of the poles (2734.), and that the diamagnetic phenomena would be abundantly produced in the parts from whence the iron had been removed. The latter was found to be the fact, for flame, smoke, bismuth and other diamagnetic matter, when placed there, passed equatorially very freely.

2739. A copper tube, 2·5 inches long, made of metal 0·1 of an inch thick, was fitted to the iron, so that when in its place it should occupy the position represented (fig. 3), and could easily be made perfectly gas-tight by a little soft cement. In this way it formed an annular air-chamber round the iron, which, when measured, was found to have a capacity of rather more than 2 cubic inches, and included the most intense part of the magnetic field. Three stopcocks were fitted into this copper jacket, by two of which gas was passed into and out of the chamber, and the third was appropriated to the pressure-gauge as before. Whilst naked, this apparatus could not be used, because of its ever-varying temperature, and the consequent disturbance and ejectment of the fluid in the gauge; but when clothed in three thicknesses of flannel its temperature was perfectly steady; and by the further use of wooden keys to turn the cocks the apparatus became unexceptionable.

2740. Before proceeding to employ this apparatus with different gases, and in order to obtain some idea of what might be expected by comparing one gas with another, I made a preliminary experiment, dependent on the relative specific gravities of air and hydrogen, of the following nature. It is easy to diffuse a trace of ammonia through the air of a jar, by putting a little paper wetted with a strong solution into it*; and it is equally easy to send a jet of hydrogen, containing the smallest portion of muriatic acid gas, by a horizontal tube into the ammoniated air. When this is done, the course of the light hydrogen in the heavy air is rendered very distinctly visible; and it is seen, on leaving the horizontal tube, to turn at once upwards and to ascend rapidly, becoming wire-drawn in its course, in consequence of its small specific gravity compared to air.

2741. Two hemispherical iron pole terminations, associated with the great magnet, were then placed in contact with each other, so that they might be surrounded either by air or oxygen†, and the jet of hydrogen, delivering at the rate of 6 cubic inches per minute, was placed exactly beneath the axial line, in the centre of the magnetic field. When there was no magnetic force employed the hydrogen rose vertically, breaking against the points where the hemispherical poles touched; but when the magnetic power was on, the stream of hydrogen divided into two parts, moving right and left, and ascended in two streams at a distance from the point of contact. Now this division took place at a certain distance *below* the axial line; and at that point, notwithstanding the ascensive power of hydrogen in air or oxygen, it was constrained to go horizontally by the apparently repulsive power of the magnetic force, and did not in its further course approach nearer to the axial line, but formed a curve concentric

* Philosophical Magazine, 1847, vol. xxxi. p. 415.

† Ibid. pp. 413, 414.

with it, or nearly so, so that the compound streams of gas assumed exactly the shape of a tuning-fork.

2742. When air occupied the magnetic field, the division of the stream of hydrogen was 0·3 or 0·32 of an inch below the axial line. When oxygen was about the poles, then the division of the hydrogen took place as far off as 0·55 of an inch below the axial line. Hence at these distances the power which tended to make the hydrogen pass from the axial line, equatorially in the direction of the radius, was equal to the difference of the specific gravity of hydrogen compared with that of air and oxygen respectively. At lesser distances the power would be much greater; and indeed, if in any experiment the hydrogen was delivered nearer to the axial line, it was blown downwards and away with much force. Calculating with these data, and still assuming that the diamagnetic gases receded from the axial line, in consequence of the direct action of the magnet and that only, causing them to pass from stronger to weaker places of action, I found, as I thought, reason to believe that the more diamagnetic gases, occupying the space within the copper box (2739.), might probably be expanded at least $\frac{1}{60,000}$th part of their volume by the magnetic force. Now the gauges that I employed were sensible when the fluid in them moved the $\frac{1}{100}$th of an inch (2736.), yet that space is only the $\frac{1}{2,500,000}$th part of the capacity of the chamber, and therefore such an expansion as that above would have made it move through 0·4 of an inch; a quantity abundantly sufficient to render the result sensible if the fundamental assumption were correct.

2743. *Air* was first submitted to the power of the great horseshoe magnet, urged by twenty pairs of Grove's plates in this apparatus (2739.). The fluid moved very slightly outwards, as if a little expansion occurred on putting on the magnetic force, and returned when the force was taken off. This small effect was found afterwards to be due to compression, occasioned by the tendency of the magnetic poles to approximate (2734.).

2744. *Oxygen* presented exactly the same appearances as common air and to the same amount, so that no effect, due to magnetic or diamagnetic action, was here evident, but only that of the compression observed in the case of air (2743.).

2745. *Nitrogen* gave exactly the same results as oxygen and air. Now nitrogen is probably more diamagnetic than hydrogen, and should therefore have given a striking contrast with oxygen, if any positive results were to be obtained.

2746. *Carbonic acid* and nitrous oxide gases yielded the same negative results, and, as I believe, when the apparatus was in an unexceptionable condition.

2747. There is at the Pharmaceutical Society an excellent electro-magnet, of the horseshoe form, similar in arrangement to our own (2247.), but far more powerful, and this through Mr. Redwood I was favoured with the use of, for the repetition of the foregoing experiments at the house of the Society. The iron, which is very soft and good in quality, is a square bar, 5 inches in thickness, and the medium line is 50 inches in length. It has 1500 feet of copper wire, 0·175 of an inch in thickness, coiled round it, and arranged (when I used it) in one continuous length. The moveable terminal pieces for the poles are massive in proportion to the magnet. Eighty pairs of GROVE's plates were used to excite this magnet, and as it was found, by preliminary trials, that these were most powerful when arranged as four twenties, with their similar ends connected, they were so used, constituting a battery of twenty pairs of plates, in which each platinum plate was 4×9 inches in the immersed part, and therefore presented 72 square inches of surface towards the active zinc.

2748. On repeating the former experiments (2743.) the effect of pressure was again evident, and it was manifest that the magnet itself, though 5 inches in thickness, was a little bent by the mutual attraction of its poles. The effect was very small, because of the unity of the iron core passing through the centre of the experimental gas-chamber (2738.). It was the only effect indicated by the gauge, and was the same for all the gases; and when allowance was made for it, nothing remained to indicate any change in volume of the gas itself.

2749. *Air*, *oxygen*, *nitrogen*, *carbonic acid* and *nitrous oxide* were submitted, in varying order, to the effect of this very powerful magnet, but not the slightest trace of change of bulk in any of them appeared.

2750. I think that the experiments are in every respect sufficient to decide that these gases, whether they are considered as magnetic or diamagnetic bodies, or whether they include bodies of both classes (for oxygen is in striking contrast to the rest), are not affected in volume by the magnetic force, whether in fields of equal power (2737.), or in places where the power is rapidly diminishing. I think this decision very important in relation to the true nature of the magnetic force, either as existing in, or acting upon the particles of bodies; and as in the magnetic field the force exhibits itself, not as a central but as an axial power, so the further distinction of the phenomena, into such as are related to the axial direction (2733.), and such as are related to or include the equatorial direction (2737.), is not unimportant, for they show that the particles do not tend to separate either parallel to the lines of magnetic power, or in a direction perpendicular to these lines. Without the experiments, the mind might have considered it very possible that one of these modes of expansion might have occurred and not the other.

2751. No doubt it is true, that even yet changes in volume in these directions may occur, provided the change in one direction is expansion and in the other contraction, and that these are in amount equal to each other. It was partly in reference to such possible changes (which may be considered as molecular), that the experiments with the ray of light were made (2723. 2729.), and also that in these and other experiments instituted for the purpose, a polarized ray was employed as the examiner; but the results were always negative, when by repetition and care sources of error were removed.

2752. The great differences in the degree of diamagnetic susceptibility and condition which the gases employed in the foregoing experiments possess or can assume, are such as to make one ready to suppose, that if they show no tendency in any case to change in volume under the action of the magnet, so neither would any other gas or vapour do so, but that all the individuals belonging to this great class of bodies would be alike in that respect. In connection with this conclusion I may state, that I have on former occasions, and more lately, endeavoured to ascertain, by the use of very delicate apparatus and powerful electro-magnets, whether any change was produced in the volume of such fluids as water, alcohol and solution of sulphate of iron, but could observe no effect of the kind, and I do not believe in its existence. Still more recently, and in reference to the class of solid bodies, I have submitted iron as a magnetic metal, and bismuth as a diamagnetic body, to the same examination; the metals were employed both in the state of solid cylinders and of filings or fragments. The cylinders were put into glass tubes and the particles into glass bottles; gauges, like those described (2732.), were applied to them, and that part of the containing vessel which was not filled with metal, was occupied, in one set of experiments, by air, and in another by alcohol, yet in no case could the least change in the volume of the iron or bismuth be observed, however powerful the magnetic force to which they were submitted.

2753. One other result of a repulsive force seemed possible even in cases when, according to a former supposition (2751.), the tendency to expand equatorially might be compensated by an equal amount of tendency to contract in the axial direction, namely, that of the production of currents outwards or equatorially, *i. e.* in lines perpendicular to the magnetic axis, where pointed poles or the hour-glass core, already described, were used, and of other currents setting in towards that line along the inclined surfaces of the polar terminations; in some degree like those occurring so powerfully, and traced so readily when flame or hot air is observed in air, or when a stream of one gas is observed in another gas*.

2754. When however the gas occupying the whole of the magnetic field was uniform in nature and alike in temperature, not the slightest trace of such currents as these could be observed. It is not easy to devise unexceptionable tests of such motions, because visible bodies introduced into such a magnetic field to test the movements of the air there, are themselves diamagnetic; and if they form a little isolated cloud, are moved together and away as a diamagnetic body would be; but when the whole field was occupied pretty equally by very light particles of dust or lycopodium, and the magnet in powerful action, no signs of currents in the air were visible. Further, when a faint stream of diffuse cold smoke from a taper spark† was allowed to fall or rise a little on one side of the axial line, it was determined outwards and equatorially; but though it went outwards with the most force when equidistant from the two conical poles, or their representative parts in the double iron core (2738.), still when it was made to pass near to one side, it continued to go outwards and equatorially, even when, from its close vicinity to the iron surface, it had as it were to move

* Philosophical Magazine, 1847, vol. xxxi. pp. 402, 404, 409.

† Ibid, p. 403.

over it; showing that the tendency of the smoke was outwards in *every part* of the magnetic field occupied by air or gas, and that therefore its motion was due to the action of the magnet on it as a diamagnetic, and not to currents of the air, which, if existing, would be inwards in one place or direction, and outwards in another.

2755. When magnetic or diamagnetic fluids were subject to the magnetic force upon a plate of mica over the poles, according to the ingenious arrangement of Plücker, they quickly assumed the different forms correspondent to their nature, but after that there was no further motion or current in them. The cases are no doubt different to those where the whole of the magnetic field is occupied by the same medium; still, as far as it goes, it helps to confirm the conclusion that no currents are formed. On putting the same liquids between the poles in glass cells, no magnetic currents could be observed in them, though fine particles were introduced into the fluids, for the purpose of making such changes of place visible, if they occurred.

2756. So there is no evidence, either by the action on a ray of light (2727. 2729.), or by any expansion or contraction (2750.), or by the production of any currents (2754.), that the magnet exerts any direct power of attraction or repulsion on the particles of the different gases tried, or that they move in the magnetic field, as they are known to do, by any such immediate attraction or repulsion.

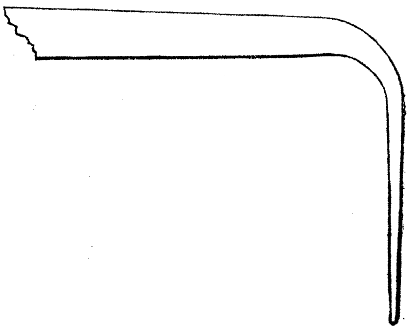
¶ ii. *Differential magnetic action.*

2757. Then what is the cause of the diamagnetic change of place? The effect is evidently a differential result, depending upon the *differences* of the two portions or masses of matter occupying the magnetic field, as the air and the streams of other gas in it*, or mercury and the tube of air in it (2407.), or water and the piece of bismuth in it (2301.); and though exhibited only in the action of masses, the latter must no doubt owe their differences to the qualities of the particles composing them. Yet it is to be observed, that no attempt to separate the perfectly mixed particles of very different substances has ever succeeded, though made with most powerful magnets. Oxygen and nitrogen differ exceedingly, yet no appearance of the least degree of separation occurred in very powerful magnetic fields†. In other experiments I have enclosed a dilute solution of sulphate of iron in a tube, and placed the lower end of the tube between the poles of a powerful horseshoe magnet for days together, in a place of perfectly uniform temperature, and yet without the least appearance of any concentration of the solution in that end which might indicate a tendency in the particles to separate.

2758. The diamagnetic phenomena of the gases, when considered as the differential result of the action of volumes of these bodies, may be produced and examined in a very useful manner by the employment of soap-bubbles, as follows:—A glass tube was fitted with a cap, stopcock and bladder, so that any given gas contained in the blad-

* Philosophical Magazine, 1847, vol. xxxi. p. 409. † Ibid. p. 416.

Fig. 4.



der might be sent through it, and also with a foot or stand so that it might be placed in any required position. The end of the tube was drawn down, bent at right angles, and cut off straight across at the extremity, being of the size and shape represented in fig 4.

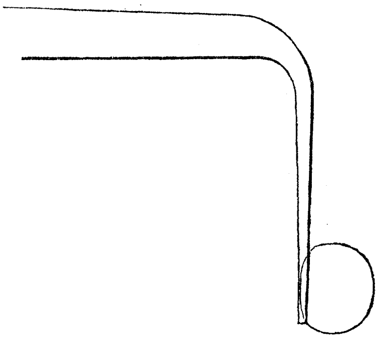
2759. It is easy to blow soap-bubbles at the end of such a tube, of any size up to an inch in diameter, and retain them for the time required by the action of the stopcock. The soapy water should be prepared, when wanted (and not beforehand), by putting a cutting or two of soap into a little cold distilled water, for then bubbles of the thinnest and most equable texture can be blown, which are more mobile than if thicker suds be used, and if a little care be taken, quite permanent enough for every useful experiment. The end of the pipe should be perfectly clean and free from heterogeneous matter (which is often destructive of the bubble), and should be wetted both inside and outside with the soap-water, and *left awhile in it before use.*

2760. If a bubble be blown with the end of the tube downwards, and be half an inch in diameter, it will usually have a little extra water at the bottom, and will hang from the slender extremity of the tube by an attachment so small as to allow it great freedom of motion. Hence it will swing to and fro like a pendulum; and according as there is more or less water at the bottom, it will vibrate more or less rapidly, will, as a whole, gravitate more or less powerfully, and therefore will retain its perpendicularly dependent position with more or less stability,—circumstances which are very useful in the employment of the bubble as a magnetic or diamagnetic indicator.

2761. The determination of the relative quantity of water which is in or upon the bubble is easily obtained within certain limits. If, after the pipe is dipped in the soap-water, the end be touched with a piece of wood or glass rod, which has also been kept in the soap-water, more or less of the liquid may be removed; and by observing the height at which the fluid stands by capillary action within the tube, which may be varied between $\frac{1}{20}$th and $\frac{1}{2}$ an inch, it is easy, after a few experimental trials, to observe how much is required to make a bubble charged with a certain amount of water, and how little to give a bubble without any dependent water below; and then it is just as easy, by arranging the amount of water beforehand, to blow a bubble of any required character. Even when no drop of water is left at the bottom, still a range of thickness or thinness in the film itself can be obtained.

2762. As the bubbles contain less and less of water, so are they rendered more sensitive in their action. They vibrate slower, and are more easily moved by forces applied laterally to them. The diamagnetic effect of the soap-water constituting them is less, and therefore that of the gas contained within them comparatively greater. If the bubble is very thin, the dependent position becomes a position of unstable equilibrium, for any inclination of the tube, or any lateral force, however small, then causes the bubble to pass to one side, and to run up and adhere to the side of the tube, fig. 5. The dependent position supplies, in inclosed spaces or atmospheres, an exceedingly delicate indicator; and even when the bubble is on the side of the tube it still forms a very valuable instrument, for it freely moves round the tube as axis; and as it possesses a certain degree of steadiness, it can be held in the magnetic field in any position, and by its motion to or from the axial line, shows very well the magnetic or diamagnetic condition of the gas contained in it in relation to the surrounding air.

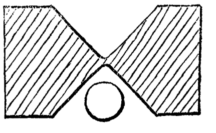
Fig. 5.



2763. If the mouth of the tube be turned upwards, bubbles of the thinnest texture can be blown; but they are then also very unstable in position, and run to the side of the tube; they can be used as indicators, as above (2762.). If the mouth of the tube be made broader, the bubbles, being thin, can be retained standing on the extremity; but as their attachment is larger, so they require more force to move them sideways, and they lose in delicacy of indication.

2764. It is convenient, in working with such bubbles, to make them nearly equal in size and thickness for the same set of comparative experiments. I usually employ them about half an inch in diameter. On blowing such a bubble with *air*, in the dependent position, placing it in the angle of the double pole on a level with the axial line (fig. 6), and then putting on the magnetic power, by the use of twenty pair of plates the bubble was deflected outwards from the axial line (or equatorially) with a certain amount of force, and returned to its first position on the interruption of the electric current. The deflection was not great, and being due to the water of the bubble, gave an indication of the amount of that effect, to be used as a correction in experiments with other gases.

Fig. 6.



2765. *Nitrogen in air.*—A bubble of nitrogen went outwards or equatorially in common air with a force much surpassing the outward tendency of a bubble of air (2764.), in a very striking and illustrative manner. It was often driven up from the end to the side of the tube; and when on the side, if presented inwards, it was driven to the outside of the tube, and however the tube was turned round, kept that position as long as the magnetic force was maintained. This effect is the more striking when it is considered that four-fifths of the air itself is nitrogen gas.

2766. *Oxygen in air.*—The effect was very impressive, the bubble being pulled inwards or towards the axial line sharply and suddenly, exactly as if the oxygen were highly magnetic. The result was expected, being in accordance with the phenomena presented by oxygen and nitrogen in a former investigation of the diamagnetic phenomena of the gases*.

2767. *Nitrous oxide and olefiant gases in air.*—The bubbles went outwards or diamagnetically with a force much greater than that due to the effect of the water of the bubble, proving the relation of these gases to air, and according with the results formerly obtained with streams of these substances†.

* Philosophical Magazine, 1847, vol. xxxi. pp. 410, 415.

† Ibid. p. 411.

2768. There is no difficulty in applying this method of observation to experiments with gases in atmospheres of other gases than air, provided they be such as do not destroy the bubble; but I do not consume time by detailing the results of such experiments, which accorded perfectly with those before obtained*. The description given is quite sufficient to illustrate the point stated, namely, that the motions of the gases, one in another, when in the magnetic field, is a differential result, and supply sufficient cases for reference hereafter.

2769. The same conclusion, that the effect is a differential result of the masses of matter present in the magnetic field, is also manifest from the consideration of the cases of gaseous, liquid, and solid diamagnetic bodies, advanced in a former part of these Researches (2405–14.); and a conclusion of the same kind, as regards magnetic bodies, may also be drawn from experiments then described (2361–68.).

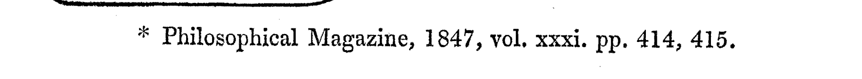
¶ iii. *Magnetic characters of Oxygen, Nitrogen and Space.*

2770. The differential action of two portions of gas, or of any two bodies, may, by a more elaborate method, be examined in a manner far more interesting and important than that just described. The mode of action referred to may even be made the basis of instruments, by which, probably, most important indications and measurements of both magnetic and diamagnetic actions may be obtained, leading to results which are not even as yet contemplated by the imagination.

2771. If two portions of matter, gaseous or liquid, are tied together and placed in a symmetric magnetic field, on opposite sides of the magnetic axis, they will be simultaneously affected. If both are diamagnetic, or less magnetic than the medium occupying the magnetic field, both will tend to go outwards or equatorially; equally if they are alike, but unequally if they differ. The consequence will be, that, if they are placed, in the first instance, equidistant from the magnetic axis, the supervention of the magnetic force will not alter their position, provided they be alike; but if they differ, then their position will be changed; for the most diamagnetic will move outwards equatorially, pulling the least diamagnetic inwards until the two are in such new positions that the forces acting on them are equipoised, and they will assume a position of stable equilibrium. Now the distance through which they will move may be used indirectly, or better still, the force required to restore them to their equidistant position may be employed directly to estimate the tendency each had to go from the magnetic axis; that is, to give their relative diamagnetic intensities.

2772. That I might submit gases to such a method of examination, I selected a piece of very thin and regular flint-glass tube, about $\frac{5}{16}$ths of an inch external diameter, and not more than $\frac{1}{60}$th of an inch in thickness, and drawing at the blowpipe lamp two equable portions of this tube into the shape and size represented, fig. 7, in which the barrel part is $1\frac{1}{2}$ inch long, I filled one with oxygen gas and the other

Fig. 7.



* Philosophical Magazine, 1847, vol. xxxi. pp. 414, 415.

with nitrogen gas, and then sealed them up hermetically. The end of the prolonged part of each was touched whilst warm with sealing-wax and a thread fastened to it, which thread was tied into a loop, also represented of full size. By these the tubes were to be suspended perpendicularly from a torsion balance, so that the middle of each should, when in place, be on a level with the magnetic axis.

2773. The torsion balance consisted of a bundle of sixty equally stretched cocoon silk fibres, made fast above to a vertical axis carrying a horizontal index and graduated plate, and below to a horizontal lever. A cross bar, about $1\frac{1}{2}$ inch long, was attached to one end of this lever, also in the horizontal plane; and on the extremities of this cross bar, and $8\frac{1}{2}$ inches from the centre of motion, were hung the two tubes of oxygen and nitrogen (2772.), counterbalanced by a weight on the other arm of the horizontal level. The whole was thus so placed and adjusted in relation to the electro-magnet, furnished at the time with the double cone core or keeper (2764.), that the middle part of each tube was level with the middle of the core, and equidistant on each side from it. Under these circumstances, if any motion was given to the balance, so as to make its arm vibrate, the vibrations were made with great slowness, in consequence of the weight of the whole moving arrangement, and the small amount of torsion force in the cocoon silk.

2774. The moment the magnetic force was thrown into action all things changed. The oxygen tube was immediately carried inwards towards the axis, and the nitrogen tube driven outwards on the contrary side. The balance swung beyond its new place of rest and then returned with considerable power, vibrating many times in the period, which before was filled by a single oscillation; and when it had come to its place of rest, or of stable equilibrium, the oxygen tube was about one-eighth of an inch from the iron of the core, and the nitrogen tube four-eighths distant. Ten revolutions of the torsion axis altered only in a slight degree these relative distances.

2775. The actions which determine the mutual self-adjustment of the oxygen and nitrogen, as regards their place in relation to the magnetic axis, are very simple and evident. In the first place, the *glass* of the tubes is more diamagnetic than the surrounding medium or air (2424.), and therefore each tends to move outwards; but being equal in nature and condition to each other, they tend to move with equal force when at equal distances, and at those distances compensate each other. If one be driven inwards, it is subjected to a greater exertion of force by coming into a more intense part of the magnetic field; and the other, being at the same time carried outwards, is for a corresponding reason in a place of less intense action; and therefore, as soon as the constraint is removed, the system returns to its position of stable equilibrium, in which the two bodies are equidistant from the magnetic axis.

2776. The *contents* also of the tubes are subject to the magnetic forces, and as the result shows (2774.), in very different degrees. Either the oxygen tends inwards much more forcibly than the nitrogen, or the nitrogen tends outwards more powerfully than the oxygen; and the difference must exist to a very great degree, for it is such as to carry the glass of the oxygen tube up to a position so near the axis that it could not by itself, or with mere air inside, retain it for a moment without the aid of considerable restraint. The power with which the tubes only would retain their equidistant position, combined with the extent to which they are displaced from this position, shows the great amount of force which this conjoint action of the oxygen and the nitrogen leaves free to be exerted in the one direction, namely, from the oxygen inwards or axially, for though the action be complicated the result is simple. By former experiments, the nitrogen is known to pass equatorially and the oxygen axially in air*, and the nitrogen tube will pass equatorially according to a certain differential force, depending on the flint-glass and the nitrogen on the one hand, and the bulk of air displaced by them on the other. The oxygen tube in like manner will tend to pass axially by a differential force, the amount of which will depend upon the tendency of the oxygen to go axially, of its tube to go equatorially, and of their joint relation to the air they displace. But both the tubes and their contents are by their joint relation to the air and their mechanical connexion so related to each other, that when a force (as of torsion) is employed to restore them to their equidistant position from the magnetic axis, all consideration of the matter of the tubes and of the air as a surrounding medium may be dismissed. The gases within them may be considered as in immediate relation with each other and the magnetic axis, and disembarrassed from all other actions: and the force which may be found needful to place them *equidistant*, is the measure of their magnetic or diamagnetic differences.

2777. Having thus explained the general principles of action, I will not at present go into their application in the construction of a measuring instrument or the results obtained with it, further than is required for the general elucidation of magnetic and diamagnetic bodies, and the determination of the true zero-point (2721. 2722.).

2778. The principles just described enabled me to return to a method of investigation which on a former occasion greatly excited my hopes (2433.), but which seemed then suddenly cut off by want of power. Various bodies, whether considered as magnetic or diamagnetic substances, admit of two modes of treatment, which promise to be exceedingly instructive as regards their properties and their destined purposes in natural operation. A gas may be *heated* or *cooled*, and the effect of temperature, which is known to be very influential†, may now be ascertained without any change in the bulk of the gas; or it may be *rarefied* and *condensed* through a very extensive range, and the effect of this kind of change upon it ascertained independent of temperature or the presence of any other substance. Solids and liquids do not admit of these methods of examination, and do not therefore assist in the determination of the zero-point and of the true distinction of magnetic and diamagnetic bodies in the same manner that the gases do.

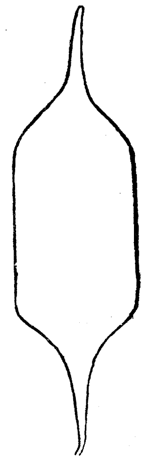
2779. It appeared to me that if a gaseous body were magnetic, then its magnetic properties ought to be diminished in proportion as it was rarefied, *i. e.* that equal volumes of such a gas at different pressures ought to be more magnetic, as they are denser; on the other hand, that if a gas were diamagnetic, rarefaction ought to

* Philosophical Magazine, 1847, vol. xxxi. p. 409.

† Ibid. pp. 406, 417.

diminish its diamagnetic character, until, when reduced to the condition of a vacuum, it should disappear. In other words, if two opposed portions of the same magnetic gas, one rarer than the other, were subjected at once to the magnetic force, the *denser* ought to approach the axial line, or be drawn into the place of most intense action; whereas if two similarly opposed portions of a diamagnetic gas were subjected to the magnetic action, the more expanded or *rarer* gas ought to go inwards to the place of strongest action.

Fig. 8.



2780. Several bulbs of oxygen (fig. 8), similar in arrangement to those already described (2772.), and very nearly alike in size, were prepared and hermetically sealed, after that the quantity of gas within them had been reduced to a certain degree by the air-pump. The first contained the gas at the pressure of one atmosphere; the second had the gas at half an atmosphere, or 15 inches of mercury; the third contained gas at the pressure of 10 inches of mercury; and the fourth, after being filled with oxygen, was reduced to as good a vacuum as an excellent air-pump could effect. When the first of these was compared with the other three, the effect was most striking; opposed to the half atmosphere, it went towards the axis, driving the expanded portion away; when in relation to the one-third atmosphere, it went inwards or axially with still more power; and when opposed to the oxygen vacuum, it took its place as close to the iron core as in the former case, when contrasted with nitrogen (2774.); and it was manifest that the diamagnetic power of the glass tube which inclosed it (2775.), was the only thing which prevented the oxygen from pressing against the iron core occupying the centre of the magnetic field.

2781. On experimenting with the other tubes exactly the same result was obtained. Thus the tube with one-third of an atmosphere, in association with the vacuum tube, went inwards, driving the other outwards, *i. e.* it was more magnetic than the vacuum; but in association with the one-half atmosphere tube it went outwards, whilst the denser gas passed inwards. Any one of the tubes, if associated with another having a rarer atmosphere, passed inwards or magnetically, whilst if associated with others having denser atmospheres it passed outwards, being driven off by the superior magnetic force of the denser gas. As far as I could ascertain in these preliminary forms of experiment, the tendency inwards or axially appeared to be in proportion to the density of the gas; but the exact measurement of these forces will be given hereafter.

2782. Thus oxygen appears to be a very magnetic substance, for it passes axially, or from weaker to stronger places of force, with considerable power; a conclusion in accordance with the result of former observations*. Moreover it passes more powerfully when dense than when rare, its tendency inwards being apparently in proportion to its density. Hence, as the oxygen is removed, the magnetic force disappears with it, until when a vacuum is obtained, little or no trace of attraction or inward force remains. No doubt it may be said that dense oxygen is less diamagnetic than

* Philosophical Magazine, 1847, vol. xxxi. pp. 410, 415.

rare oxygen, or a vacuum. This however would imply, that the acting force of a substance, as the oxygen, could increase in proportion as the quantity of the substance diminished, which is not, I think, a philosophical assumption; and besides that, other reasons will soon appear to show that the magnetic condition which disappears as the oxygen is removed, belongs to, and is dependent upon that substance, and that oxygen is therefore a truly magnetic body.

2783. *Nitrogen*, being the other and larger part of the atmosphere, was then subjected to experiment, and three tubes, one containing the gas at a pressure of 30 inches of mercury, another with the gas at the pressure of 15 inches, and the third reduced as nearly as it could be to a vacuum, were prepared (2780.). When these were compared one with another in the magnetic field, they were found to be so nearly alike as not to be distinguishable from each other, *i. e.* they remained equidistant from the magnetic axis. I do not mean to imply that nitrogen at these different pressures is absolutely the same bulk for bulk (an instrument now under construction will enable me hereafter to compare and measure with infinitely greater accuracy, and to ascertain these points); but as compared with oxygen, the great and extraordinary differences produced by rarefaction there, have no corresponding differences here. If there are any, they are insensible at present, and may, for the chief purpose of this paper and the determination of the zero-point between magnetics and diamagnetics, be taken as nothing.

2784. Nitrogen therefore appears to be neither magnetic nor diamagnetic; if it were either, it could not but fall in its specific condition as it was rarefied; as it is, it is equivalent to a vacuum. If a given space be considered as a vacuum, into which oxygen or nitrogen is to be gradually introduced, as oxygen is added the space becomes more and more magnetic, *i. e.* more competent to admit of the kind of action distinguished by that word; but the corresponding gradual addition of nitrogen to an empty space produces no effect of that kind, or the contrary, and the nitrogen is therefore neither magnetic nor diamagnetic, but like space itself.

2785. As yet I have found no gas, which, being on the diamagnetic side of zero, can at all compare with oxygen in the range of effect produced by rarefaction. For the present, I may mention olefiant gas and cyanogen as substances which appear to proceed inwards, or towards the axial line, as they are more rarefied. They are therefore not merely at zero, but are in opposition to oxygen and are diamagnetic bodies. But if we want a body that is strongly and undeniably diamagnetic, and which, being added to or introduced into space, will make it diamagnetic, as oxygen renders it magnetic, then flint glass or phosphorus presents us with such a substance. When these bodies are made into forms similar to the volumes of nitrogen, or the vacua in size and shape, and are compared with them on the torsion balance, they pass outwards with much force; and it is probably the great diamagnetic force of the glass of the tubes that prevents the effect of rarefaction from being more evident in olefiant and other gases.

2786. When a tube has been filled with a particular gas, then exhausted as much as possible, and sealed up hermetically, it may be considered as inclosing what is commonly called a vacuum. I have prepared many such vacua, and may be permitted to distinguish them by the name of the gas, traces of which still remain. In comparing these vacua in the magnetic field (2773.), they appeared to me to be in all respects alike; the oxygen vacuum was not more magnetic than the hydrogen, nitrogen, or olefiant vacuum. Their differences, if any, were far smaller than the differences which could be produced by the variations of size and other conditions of the glass bulbs, and can only be made manifest by the means hereafter to be used (2783.); and I am fully persuaded that they will ultimately be nearly alike, ranging close *up to and about a perfect* vacuum.

2787. Before determining the place of zero amongst magnetic and diamagnetic bodies, we have to consider the true character and relation of *space* free from any material substance. Though one cannot procure a space perfectly free from matter, one can make a close approximation to it in a carefully prepared Torricellian vacuum. Perhaps it is hardly necessary for me to state, that I find both iron and bismuth in such vacua perfectly obedient to the magnet. From such experiments, and also from general observations and knowledge, it seems manifest that the lines of magnetic force (2149.) can traverse pure space, just as gravitating force does, and as static electrical forces do (1616.); and therefore space has a magnetic relation of its own, and one that we shall probably find hereafter to be of the utmost importance in natural phenomena. But this character of space is not of the same kind as that which, in relation to matter, we endeavour to express by the terms magnetic and diamagnetic. To confuse them together would be to confound space with matter, and to trouble all the conceptions by which we endeavour to understand and work out a progressively clearer view of the mode of action and laws of natural forces. It would be as if, in gravitation or electric forces (1613.), one were to confound the particles acting on each other with the space across which they are acting, and would, I think, shut the door to advancement. Mere space cannot act as matter acts, even though the utmost latitude be allowed to the hypothesis of an ether; and admitting that hypothesis, it would be a large additional assumption to suppose that the lines of magnetic force are vibrations carried on by it (2591.); whilst as yet, we have no proof or indication that time is required for their propagation, or in what respect they may in general character assimilate to, or differ from, the respective lines of gravitating, luminiferous, or electric forces.

2788. Neither can space be supposed to have those circular currents round points diffused through it, which AMPÈRE's theory assumes to exist around the particles of ordinary magnetic matter, and which I had for a moment supposed might exist in the contrary direction round the particles of diamagnetic matter (2429. 2640. &c.). The imagination, restrained by philosophical considerations, fails to find anything in pure space about which the currents could circulate, or to which they could by any association be attached; and the difficulty, if already not immeasurable, would be still greater to those, if there be any, who, assuming that magnetic and diamagnetic bodies are alike in nature, must assume that there are like currents in both; for it does not seem possible to add (for instance) phosphorus having such a magnetic constitution to space, supposed to be of a similar constitution, and yet to have as a result a diminution of the magnetic powers of the space.

2789. As space therefore comports itself independently of matter, and after another manner, the different varieties of matter must, in relation to their respective qualities, be considered amongst themselves. Those which produce no effect when added to space, appear to me to be neutral or to stand at zero. Those which bring with them an effect of one kind will be on the one side of zero, and those which produce an effect of the contrary kind will be on the other side of zero; by this division they constitute the two subdivisions of magnetic and diamagnetic bodies. The law which I formerly ventured to give (2267. 2418.), still expresses accurately their relations; for in an absolute vacuum or free space, a magnetic body tends from weaker to stronger places of magnetic action, and a diamagnetic body under similar conditions from stronger to weaker places of action.

2790. Now that the *true zero* is obtained, and the great variety of material substances satisfactorily divided into two general classes, it appears to me that we want another name for the magnetic class, that we may avoid confusion. The word *magnetic* ought to be general, and include *all* the phenomena and effects produced by the power. But then a word for the subdivision, opposed to the diamagnetic class, is necessary. As the language of this branch of science may soon require general and careful changes, I, assisted by a kind friend, have thought that a word not selected with particular care might be provisionally useful; and as the magnetism of iron, nickel and cobalt, when in the magnetic field, is like that of the earth as a whole, so that when rendered active they place themselves parallel to its axis or lines of magnetic force, I have supposed that they and their similars (including oxygen now) might be called paramagnetic bodies, giving the following division:—

$$\text{Magnetic}\begin{cases}\text{Paramagnetic.}\\ \text{Diamagnetic.}\end{cases}$$

If the attempt to facilitate expression be not accepted, I hope it will be excused.

2791. From the presence of oxygen in the air, the latter is, as a whole, a magnetic medium of no small power. Hence all the comparative experiments on the diamagnetic condition of other gases, made by passing streams of them through it and through each other*, require a correction, which occasionally may place some of these bodies on the paramagnetic side of zero. Even solid and fluid substances may be thus affected; and the preliminary list, which I formerly gave (2424.), will need alteration in this respect. I hope soon however to have the means of ascertaining,

* Philosophical Magazine, 1847, vol. xxxi. pp. 407, 420, &c. &c.

not only the place of bodies, but also their relative degrees of force, at the same and at different temperatures, with a degree of accuracy that will serve great purposes in the further development of this branch of science.

2792. Amongst the gases hitherto examined there is nothing that compares with oxygen. The following are comparatively indifferent by the side of it:—chlorine and bromine vapour, cyanogen, nitrogen, hydrogen, carbonic acid, carbonic oxide, olefiant gas, nitrous oxide, nitric oxide, nitrous acid vapour, muriatic acid, sulphurous acid, hydriodic acid, ammonia, sulphuretted hydrogen, coal-gas, ether vapour and sulphuret of carbon vapour; for though some, as olefiant and cyanogen gases, appear to be a little diamagnetic, and others, as nitrous oxide and nitric oxide, are magnetic, yet their effects disappear in comparison with the results produced by oxygen.

2793. I hope to give the correct expression of the paramagnetic force of oxygen (2783.) hereafter, in the meantime I am tempted to give one or two rough illustrations of its degree in this place, in addition to the former one (2774.). The capacity of the oxygen bulb, containing one atmosphere, is not quite 0·34 of a cubic inch, and the weight therefore of the oxygen within 0·117 of a grain. I endeavoured to compare this quantity in the first place with soft iron, and therefore attached a portion of that metal, having one-tenth of this weight or 0·012 of a grain, to a fine platina wire fixed into one end of a vessel, corresponding in size to that containing the oxygen, so as to bring the iron into the middle, and then the bulb was exhausted and hermetically sealed. Being now opposed to the oxygen tube in the magnetic field, it was found, as expected, far to surpass the oxygen in magnetic power. As it was inconvenient further to reduce the iron or to enlarge the oxygen, another magnetic substance was employed for the comparison.

2794. One hundred grains of clean, good, crystallized protosulphate of iron were dissolved in distilled water, and diluted until a glass bulb, of nearly the same size as the oxygen bulb when filled with the solution, was equal to the oxygen bulb in force, and stood equidistant from the axial line, as far as I could judge by the present modes of observation. When the solution had this strength, it occupied the bulk of $17\frac{1}{2}$ cubic inches. As the bulk of the oxygen is only 0·34 of a cubic inch (2793.), that volume of this solution would contain very nearly two grains of crystallized sulphate of iron, equivalent to 0·4 of a grain of metallic iron; so that, bulk for bulk, oxygen is equally magnetic with a solution of sulphate of iron in water containing seventeen times the weight of the oxygen in crystallized protosulphate of iron, or 3·4 times its weight of metallic iron in that state of combination.

2795. Again, the oxygen tubes, containing respectively one atmosphere and a vacuum (2780.), were adjusted about an inch apart, and placed on each side of the magnetic axis, and the force of the magnet developed. The oxygen of course approached the magnetic axis, and the vacuum passed equatorially. A slender glass filament, about 6 inches in length, had been drawn out at the lamp and fixed to a foot; and the end of this filament was then employed to press back the oxygen tube into its original place, and render it equidistant from the magnetic axis with the vacuum tube. In this position the two tubes would, as respects the glass, neutralize each other (2775.); and considering the vacuum as zero, the oxygen alone may be considered as active, and the force required to hold it out may be looked upon as the force with which the oxygen, at that distance of half an inch, tended to go to the magnetic axis. The deflection of the glass filament or spring, at the place where the oxygen tube was held by it, was rather more than 1 inch from its position when relieved from the pressure of the tube. Being taken away, it was set up in the horizontal position (after being turned 90° on its axis, so that the flexure might be in the same direction, relative to the filament, as before); and the position of the end being marked, weights were put on it at the place of former contact with the oxygen tube, until they produced the same amount of deflection as before. It required rather more than the tenth of a grain to produce this effect; and this, considering that the whole oxygen only weighed 0·117 of a grain, and that no part of it was nearer than half an inch, whilst the average distance of the mass was above an inch from the magnetic axis, gives a high expression for the magnetic power.

2796. It is hardly necessary for me to say here that this oxygen cannot exist in the atmosphere, exerting such a remarkable and high amount of magnetic force, without having a most important influence on the disposition of the magnetism of the earth as a planet, especially if it be remembered that its magnetic condition is greatly altered by variations in its density (2781.) and by variations in its temperature*. I think I see here the real cause of many of the variations of that force, which have been, and are now, so carefully watched on different parts of the surface of the globe. The daily variation and the annual variation both seem likely to come under it; also very many of the irregular continual variations which the photographic process of record renders so beautifully manifest. If such expectations be confirmed, and the influence of the atmosphere be found able to produce results like these, then we shall probably find a new relation between the aurora borealis and the magnetism of the earth, namely, a relation established, more or less, through the air itself in connexion with the space above it; and even magnetic relations and variations which are not as yet suspected, may be suggested and rendered manifest and measurable, in the further development of what I will venture to call *Atmospheric Magnetism* (2847. &c.). I may be over-sanguine in these expectations, but as yet I am sustained in them by the apparent reality, simplicity and sufficiency of the cause assumed, as it at present appears to my mind. As soon as I have sufficiently submitted these views to a close consideration and the test of accordance with observation, and where applicable with experiments also, I will do myself the honour to bring them before the Royal Society.

* Philosophical Magazine, 1847, vol. xxxi. p. 417.

Royal Institution, August 2, 1850.