

This view of the condition of intensely inflamed parts is exactly that to which I was led some years ago by a microscopic investigation, the results of which were detailed in a paper* that received the honour of a place in the *Philosophical Transactions*. It was there shown, as I think I may venture to say, that the tissues generally are capable of being reduced under the action of irritants to a state quite distinct from death, but in which they are nevertheless temporarily deprived of all vital power, and that inflammatory congestion is due to the blood-corpuscles acquiring adhesiveness such as they have outside the body, in consequence of the irritated tissues acting towards them like ordinary solids.

I cannot avoid expressing my satisfaction that this inquiry into the coagulation of the blood has furnished independent confirmation of my previous conclusions regarding the nature of inflammation.

June 18, 1863.

Major-General SABINE, President, in the Chair.

E. W. Cooke, Esq., James Fergusson, Esq., The Rev. R. Harley, W. Pengelly, Esq., and H. E. Roscoe, Esq., were admitted into the Society.

Pursuant to notice given at the last Meeting, Professor Ernst Edward Kummer, of Berlin, and Professor Johannes Japetus Smith Steenstrup, of Copenhagen, were balloted for and elected Foreign Members of the Society.

The following communications were read :—

- I. "On the Molecular Mobility of Gases." By THOMAS GRAHAM, F.R.S., Master of the Mint. Received May 7, 1863.

(Abstract).

The molecular mobility of gases is here considered in reference chiefly to the passage of gases, under pressure, through a thin porous plate or septum, and to the partial separation of mixed gases which can be effected, as will be shown, by such means. The investigation

* "On the Early Stages of Inflammation," *Phil. Trans.* for 1858.

arose out of a renewed and somewhat protracted inquiry regarding the diffusion of gases (depending upon the same molecular mobility), and has afforded certain new results which may prove to be of interest in a theoretical as well as in a practical point of view.

In the diffusiometer, as first constructed, a plain cylindrical glass tube, rather less than an inch in diameter and about ten inches in length, was simply closed at one end by a porous plate of plaster of paris, about one-third of an inch in thickness, and thus converted into a gas receiver*. A superior material for the porous plate is now found in the artificially compressed graphite of Mr. Brockedon, of the quality used for making writing-pencils. This material is sold in London in small cubic masses about 2 inches square. A cube may easily be cut into slices of a millimetre or two in thickness by means of a saw of steel spring. By rubbing the surface of the slice without wetting it upon a flat sand-stone, the thickness may be further reduced to about one-half of a millimetre. A circular disk of this graphite, which is like a wafer in thickness but possesses considerable tenacity, is attached by resinous cement to one end of the glass tube above described, so as to close it and form a diffusiometer. The tube is filled with hydrogen gas over a mercurial trough, the porosity of the graphite plate being counteracted for the time by covering it tightly with a thin sheet of gutta percha. On afterwards removing the latter, gaseous diffusion immediately takes place through the pores of the graphite. The whole hydrogen will leave the tube in forty minutes or an hour, and is replaced by a much smaller proportion of atmospheric air (about one fourth), as is to be expected from the law of the diffusion of gases. During the process, the mercury will rise in the tube, if allowed, forming a column of several inches in height—a fact which illustrates strikingly the intensity of the force with which the interpenetration of different gases is effected. The native or mineral graphite is of a lamellar structure, and appears to have little or no porosity. It cannot be substituted for the artificial graphite as a diffusion-septum. Unglazed earthenware comes next in value to graphite for this purpose.

The pores of artificial graphite appear to be really so minute, that

* "On the Law of the Diffusion of Gases," Transactions of the Royal Society of Edinburgh, vol. xii. p. 222; or Philosophical Magazine, 1834, vol. ii. pp. 175, 269, 351.

a gas *in mass* cannot penetrate the plate at all. It seems to be molecules only which can pass; and these may be supposed to pass wholly unimpeded by friction, for the smallest pores that can be imagined to exist in the graphite must be tunnels in magnitude to the ultimate atoms of a gaseous body. The sole motive agency appears to be that intestine movement of molecules which is now generally recognized as an essential property of the gaseous condition of matter.

According to the physical hypothesis now generally received*, a gas is represented as consisting of solid and perfectly elastic spherical particles or atoms, which move in all directions, and are animated with different degrees of velocity in different gases. Confined in a vessel, the moving particles are constantly impinging against its sides and occasionally against each other, and such collisions take place without any loss of motion, owing to the perfect elasticity of the particles. Now if the containing vessel be porous, like a diffusimeter, then gas is projected through the open channels, by the atomic motion described, and escapes. Simultaneously the external air or gas, whatever it may be, is carried inwards in the same manner, and takes the place of the gas which leaves the vessel. To the same atomic or molecular movement is due the elastic force, with the power to resist compression, possessed by gases. The molecular movement is accelerated by heat and retarded by cold, the tension of the gas being increased in the first instance and diminished in the second. Even when the same gas is present both within and without the vessel, and is therefore in contact with both sides of the porous plate, the movement is sustained without abatement—molecules continuing to enter and leave in equal number, although nothing of the kind is indicated by change of volume or otherwise. If the gases in communication be different but possess sensibly the same specific gravity and molecular velocity, as nitrogen and carbonic oxide do, an interchange of molecules also takes place without any change in volume. With gases opposed of unequal density and molecular velocity, the amount of penetration ceases of course to be equal in both directions.

* D. Bernoulli, J. Herapath, Joule, Krönig, Clausius, Clerk Maxwell, and Cazin. The merit of reviving this hypothesis and first applying it to the facts of gaseous diffusion, is fairly due to Mr. Herapath. See 'Mathematical Physics,' in two volumes, by John Herapath, Esq. (1847).

These observations are preliminary to the consideration of the passage through a graphite plate, in one direction only, of gas under pressure, or under the influence of its own elastic force. It is to be supposed that a vacuum is maintained on one side of the porous septum, and that air or some other gas, under a constant pressure, is in contact with the other side. Now a gas may pass into a vacuum in three different modes, or in two modes besides that immediately before us.

1. The gas may enter the vacuum by passing through a minute aperture in a thin plate, such as a puncture in platinum foil made by a fine steel point. The rate of passage of different gases is then regulated by their specific gravities, according to a pneumatic law which was deduced by Professor John Robison from Torricelli's well-known theorem of the velocity of efflux of fluids. A gas rushes into a vacuum with the velocity which a heavy body would acquire by falling from the height of an atmosphere composed of the gas in question, and supposed to be of uniform density throughout. The height of the uniform atmosphere will be inversely as the specific gravity of the gas, the atmosphere of hydrogen, for instance, sixteen times higher than that of oxygen. But as the velocity acquired by a heavy body in falling is not directly as the height, but as the square root of the height, the rate of flow of different gases into a vacuum will be inversely as the square root of their respective densities. The velocity of oxygen being 1, that of hydrogen will be 4, the square root of 16. This law has been experimentally verified*. The times of the effusion of gases, as I have spoken of it, are similar to those of the law of molecular diffusion; but it is important to observe that the phenomena of effusion and diffusion are distinct and essentially different in their nature. The effusion movement affects masses of gas, the diffusion movement affects molecules; and a gas is usually carried by the former kind of impulse with a velocity many thousand times greater than by the latter. The effusion velocity of air is the same as the velocity of sound.

2. If the aperture of efflux be in a plate of increased thickness, and so becomes a tube, the effusion-rates of gases are disturbed. The rates of flow of different gases, however, assume again a constant ratio to each other when the capillary tube is considerably

* "On the Motion of Gases," Phil. Trans. 1846, p. 573

elongated, when the length exceeds the diameter at least 4000 times. These new proportions of efflux are the rates of the "Capillary Transpiration of Gases"*. The rates were found to be the same in a capillary tube composed of copper as they are in a tube of glass, and appear to be independent of the material of the capillary. A film of gas no doubt adheres to the inner surface of the tube, and the friction is really that of gas upon gas, and is consequently unaffected by the nature of the tube-substance. The rates of transpiration are not governed by specific gravity, and are indeed singularly unlike the rates of effusion.

The transpiration-velocity of oxygen being 1, that of chlorine is 1.5, that of hydrogen 2.26, of ether vapour at low temperatures the same or nearly the same number as hydrogen, of nitrogen and carbonic oxide half the velocity of hydrogen, of olefiant gas, ammonia, and cyanogen 2 (double or nearly double that of oxygen), of carbonic acid 1.376, and of the gas of marshes 1.815. In the same gas the transpirability of equal volumes increases with density, whether occasioned by cold or pressure. The transpiration-ratios of gases appear to be in constant relation with no other known property of the same gases, and they form a class of phenomena remarkably isolated from all else at present known of gases.

There is one property of transpiration immediately bearing upon the penetration of the graphite plate by gases. The capillary offers to the passage of gas a resistance analogous to that of friction, proportional to the surface, and consequently increasing as the tube or tubes are multiplied in number and diminished in diameter, with the area of discharge preserved constant. The resistance to the passage of a liquid through a capillary was observed by Poiseuille to be nearly as the fourth power of the diameter of the tube. In gases the resistance also rapidly increases; but in what ratio, has not been observed. The consequence, however, is certain, that as the diameter of the capillaries may be diminished beyond any assignable limit, so the flow may be retarded indefinitely, and caused at last to become too small to be sensible. We may therefore have a mass of capillaries of which the passages form a large aggregate, but which are individually too small to permit a sensible flow of gas under pressure. A porous solid mass may possess the same reduced penetrability as

* Phil. Trans. 1846, p. 591, and 1849, p. 349.

the congeries of capillary tubes. Indeed the state of porosity described appears to be more or less closely approached by all loosely aggregated mineral masses, such as lime plaster, stucco, chalk, baked clay, non-crystalline earthy powders like hydrate of lime or magnesia compacted by pressure, and in the highest degree perhaps by artificial graphite.

3. A plate of artificial graphite, although it appears to be practically impenetrable to gas by either of the two modes of passage previously described, is readily penetrated by the agency of the molecular or diffusive movement of gases. This appears on comparing the time required for the passage of equal volumes of different gases under a constant pressure. Of the following three gases, oxygen, hydrogen, and carbonic acid, the time required for the passage of an equal volume of each through a capillary glass tube, in similar circumstances as to pressure and temperature, was formerly observed to be as follows :—

	Time of capillary transpiration.
Oxygen	1
Carbonic acid	0·72
Hydrogen	0·44

Through a plate of graphite, of half a millimetre in thickness, the same gases were now observed to pass, under a constant pressure of a column of mercury of 100 millimetres in height, in times which are as follows :—

	Time of molecular passage.		Square root of density (oxygen 1).
Oxygen	1	....	1
Hydrogen	0·2472	....	0·2502
Carbonic acid.....	1·1886	....	1·1760

It appears then that the times of passage through the graphite plate have no relation to the capillary transpiration-times of the same gases first quoted above. The new times in question, however, show a close relation to the square roots of the densities of the respective gases, as is seen in the last Table; and so far they agree with theoretical *times of diffusion* usually ascribed to the same gases.

The experiments were varied by causing the gases to pass into a Torricellian vacuum, and consequently under the full pressure of the

atmosphere. The times of penetration of equal volumes of gases were now—

	Times.		$\sqrt{\text{Density.}}$
Oxygen	1	....	1
Air	0·9501	....	0·9507
Carbonic acid	1·1860	....	1·1760
Hydrogen	0·2505	....	0·2502

This penetration of the graphite plate by gases appears to be entirely due to their own proper molecular motion, quite unaided by transpiration. It seems to offer the simplest possible exhibition of the molecular or diffusive movement. This pure result is to be ascribed to the wonderfully fine porosity of the graphite. The interstitial spaces, or channels, appear to be sufficiently small to extinguish transpiration, or the passage of masses, entirely. The graphite becomes a molecular sieve, allowing molecules only to pass through.

With a plate of stucco, the penetration of gases under pressure is very rapid, and the volumes of air and hydrogen passing in equal times are as 1 to 2·891, which is a number for hydrogen intermediate between its transpiration-volume 2·04 and diffusion-volume 3·8, showing that the passage through stucco is a mixed result.

With a plate of biscuitware, 2·2 millimetres in thickness, the volume of hydrogen rose to 3·754 (air=1), approaching closely to 3·8, the molecular ratio.

The rate of passage of a gas through graphite appeared also to be closely proportional to the pressure.

Further, hydrogen was found to penetrate through a graphite plate into a vacuum, with sensibly the same absolute velocity as it diffused into air, establishing the important fact that the impelling force is the same in both movements. The molecular mobility may therefore be spoken of as the diffusive movement of gases; the passage of gas through a porous plate into vacuum, as diffusion in one direction or single diffusion; and ordinary diffusion, or the passage of two gases in opposite directions, as double, compound, or reciprocal diffusion.

Atmolysis.—A partial separation of mixed gases and vapours of unequal diffusibility can be effected by allowing the mixture to permeate through a graphite plate into a vacuum, as was to be expected from the preceding views. As this method of analysis has a practical character and admits of wide application, it may be convenient to

distinguish it by a peculiar name. The amount of the separation is in proportion to the pressure, and attains its maximum when the gases pass into a nearly perfect vacuum. A variety of experiments were made on this subject, of which perhaps the most interesting were those upon the concentration of the oxygen in atmospheric air. When a portion of air confined in a jar is allowed to penetrate into a vacuum through graphite or unglazed earthenware, the nitrogen should pass more rapidly than the oxygen in the proportion of 1.0668 to 1, and the proportion of oxygen be proportionally increased in the air left behind in the jar. The increase in the oxygen actually observed when the air in the jar was reduced from 1 volume

To 0.5	volume,	was 0.48	per cent.
0.25	„	0.98	„
0.125	„	1.54	„
0.0625	„	2.02	„

Or, the oxygen increased from 21 to 23.02 per cent. in the last sixteenth part of air left behind in the jar.

The most remarkable effects of separation are produced by means of the *tube atmolyser*. This is simply a narrow tube of unglazed earthenware, such as a tobacco-pipe stem two feet in length, which is placed within a shorter tube of glass and secured in its position by corks, so as to appear like a Liebig's condenser. The glass tube is placed in communication with an air-pump, and the annular space between the two tubes is maintained as nearly vacuous as possible. Air or any other mixed gas is then allowed to flow in a stream along the clay tube, and collected as it issues. The gas so atmolysed is of course reduced in volume, much gas penetrating through the pores of the clay tube into the air-pump vacuum; and the slower the gas is collected the greater the proportional loss. In the gas collected, the denser constituent of the mixture is thus concentrated in an arithmetical ratio, while the volume of the gas is reduced in a geometrical ratio. In one experiment the proportion of oxygen in the air after traversing the atmolyser was increased to 24.5 per cent., or 16.7 upon 100 oxygen originally present in the air. With gases differing so much in density and diffusibility as oxygen and hydrogen, the separation is of course much more considerable. The explosive mixture of two volumes of hydrogen and one volume of oxygen, gave oxygen con-

taining only 9·3 per cent. of hydrogen, in which a taper burned without explosion; and with equal volumes of oxygen and hydrogen, the proportion of the latter was easily reduced from 50 to 5 per cent.

Interdiffusion of Gases—double diffusion.—The diffusimeter was much improved in construction by Prof. Bunsen, from the application of a lever arrangement to raise and depress the tube in the mercurial trough. But the mass of stucco forming the porous plate in his instrument was too voluminous, in my opinion, and, from being dried by heat, had probably detached itself from the walls of the glass tube. The result obtained of 3·4 for hydrogen, air being 1, is, I understand, no longer insisted upon by that illustrious physicist. It is indeed curious that my old experiments generally rather exceeded than fell short of the theoretical number for hydrogen, $\sqrt{\frac{1}{0\cdot06926}} = 3\cdot7997$. With stucco as the

material, the cavities in the porous plate form about one-fourth of its bulk, and affect sensibly the ratio in question, according as they are or are not included in the capacity of the instrument. Beginning the diffusion always with these cavities filled with hydrogen, the numbers now obtained with a stucco plate of 12 millims. in thickness, dried without heat, were 3·783, 3·8, and 3·739 when the volume of the cavities of stucco is added to the air and hydrogen, and 3·931, 3·949, and 3·883 when such addition is not made to these volumes. The graphite plate, on the other hand, being thin, and the volume of its pores too minute to require to be taken into account, its action is not attended with the same uncertainty. With a graphite plate of 2 millims. in thickness, the number for hydrogen into air was 3·876, and of hydrogen into oxygen 4·124, instead of 4. With a graphite plate of 1 millim. in thickness, hydrogen gave 3·993 to air 1. With a graphite plate of 0·5 millim. in thickness, the proportional number for hydrogen to air rose to 3·984, 4·068, and 4·067. A similar departure from the theoretical number was observed when hydrogen was diffused into oxygen or carbonic acid, instead of air. All these experiments were made over mercury and with dried gases. It appears that the numbers are most in accordance with theory when the graphite plate is thick, and the diffusion slow in consequence. If the diffusion be very rapid, as it is with the thin plates, something like a current is possibly formed in the channels of the graphite,

taking the direction of the hydrogen and carrying back in mass a little air, or the slower gas, whatever it may be. I cannot account otherwise for the slight predominance which the lighter and faster gas appears always to acquire in diffusing through the porous septum.

Speculative ideas respecting the constitution of matter.

It is conceivable that the various kinds of matter, now recognized as different elementary substances, may possess one and the same ultimate or atomic molecule existing in different conditions of movement. The essential unity of matter is an hypothesis in harmony with the equal action of gravity upon all bodies. We know the anxiety with which this point was investigated by Newton, and the care he took to ascertain that every kind of substance, "metals, stones, woods, grain, salts, animal substances, &c.," are similarly accelerated in falling, and are therefore equally heavy.

In the condition of gas, matter is deprived of numerous and varying properties with which it appears invested when in the form of a liquid or solid. The gas exhibits only a few grand and simple features. These again may all be dependent upon atomic and molecular mobility. Let us imagine one kind of substance only to exist, ponderable matter; and further, that matter is divisible into ultimate atoms, uniform in size and weight. We shall have one substance and a common atom. With the atom at rest the uniformity of matter would be perfect. But the atom possesses always more or less motion, due, it must be assumed, to a primordial impulse. This motion gives rise to volume. The more rapid the movement the greater the space occupied by the atom, somewhat as the orbit of a planet widens with the degree of projectile velocity. Matter is thus made to differ only in being lighter or denser matter. The specific motion of an atom being inalienable, light matter is no longer convertible into heavy matter. In short, matter of different density forms different substances—different inconvertible elements as they have been considered.

What has already been said is not meant to apply to the gaseous volumes which we have occasion to measure and practically deal with, but to a lower order of molecules or atoms. The combining atoms hitherto spoken of are therefore not the molecules of which the movement is sensibly affected by heat, with gaseous expansion as

the result. The gaseous molecule must itself be viewed as composed of a group or system of the preceding inferior atoms, following as a unit laws similar to those which regulate its constituent atoms. We have indeed carried one step backward and applied to the lower order of atoms ideas suggested by the gaseous molecule, as views derived from the solar system are extended to the subordinate system of a planet and its satellites. The advance of science may further require an indefinite repetition of such steps of molecular division. The gaseous molecule is then a reproduction of the inferior atom on a higher scale. The molecule or system is reached which is affected by heat, the diffusive molecule, of which the movement is the subject of observation and measurement. The diffusive molecules are also to be supposed uniform in weight, but to vary in velocity of movement, in correspondence with their constituent atoms. Accordingly the molecular volumes of different elementary substances have the same relation to each other as the subordinate atomic volumes of the same substances.

But further, these more and less mobile or light and heavy forms of matter have a singular relation connected with equality of volume. Equal volumes of two of them can coalesce together, unite their movement, and form a new atomic group, retaining the whole, the half, or some simple proportion of the original movement and consequent volume. This is chemical combination. It is directly an affair of volume, and only indirectly connected with weight. Combining weights are different, because the densities, atomic and molecular, are different. The volume of combination is uniform, but the fluids measured vary in density. This fixed combining measure—the *metron* of simple substances—weighs 1 for hydrogen, 16 for oxygen, and so on with the other “elements.”

To the preceding statements respecting atomic and molecular mobility, it remains to be added that the hypothesis admits of another expression. As in the theory of light we have the alternative hypotheses of emission and undulation, so in molecular mobility the motion may be assumed to reside either in separate atoms and molecules, or in a fluid medium caused to undulate. A special rate of vibration or pulsation originally imparted to a portion of the fluid medium enlivens that portion of matter with an individual existence, and constitutes it a distinct substance or element.

With respect to the different states of gas, liquid, and solid, it may be observed that there is no real incompatibility with each other in these physical conditions. They are often found together in the same substance. The liquid and the solid conditions supervene upon the gaseous condition rather than supersede it. Gay-Lussac made the remarkable observation that the vapours emitted by ice and water, both at 0° C., are of exactly equal tension. The passage from the liquid to the solid state is not made apparent in the volatility of water. The liquid and solid conditions do not appear as the extinction or suppression of the gaseous condition, but something *super-added* to that condition. The three conditions (or constitutions) probably always coexist in every liquid or solid substance, but one predominates over the others. In the general properties of matter we have, indeed, to include still further (1) the remarkable loss of elasticity in vapours under great pressure, which is distinguished by Mr. Faraday as the Caignard-Latour state, after the name of its discoverer, and is now undergoing an investigation by Dr. Andrews, which may be expected to throw much light upon its nature; (2) the colloidal condition or constitution, which intervenes between the liquid and crystalline states, extending into both and affecting probably all kinds of solid and liquid matter in a greater or less degree. The predominance of a certain physical state in a substance appears to be a distinction of a kind with those distinctions recognized in natural history as being produced by unequal development. Liquefaction or solidification may therefore not involve the suppression of either the atomic or the molecular movement, but only the restriction of its range. The hypothesis of atomic movement has been elsewhere assumed, irrespective of the gaseous condition, and is applied by Dr. Williamson to the elucidation of a remarkable class of chemical reactions which have their seat in a mixed liquid.

Lastly, molecular or diffusive mobility has an obvious bearing upon the communication of heat to gases by contact with liquid or solid surfaces. The impact of the gaseous molecule, upon a surface possessing a different temperature, appears to be the condition for the transference of heat, or the heat movement, from one to the other. The more rapid the molecular movement of the gas the more frequent the contact, with consequent communication of heat. Hence, probably, the great cooling power of hydrogen gas as compared with air

or oxygen. The gases named have the same specific heat for equal volumes; but a hot object placed in hydrogen is really *touched* 3·8 times more frequently than it would be if placed in air, and 4 times more frequently than it would be if placed in an atmosphere of oxygen gas. Dalton had already ascribed this peculiarity of hydrogen to the high “mobility” of that gas. The same molecular property of hydrogen recommends the application of that gas in the air-engine, where the object is to alternately heat and cool a confined volume of gas with rapidity.

II. “Results of the Magnetic Observations at the Kew Observatory, from 1858 to 1862 inclusive.”—No. I. By Major-General EDWARD SABINE, P.R.S. Received May 21, 1863.

(Abstract.)

The first three sections of this paper are occupied by a discussion of the Laws of the Disturbances of the Magnetic Declination at Kew, derived from the photographic records of the Kew Observatory between January 1, 1858, and December 31, 1862. In the first section a synoptical table is given, showing the direction and amount of the easterly and of the westerly deflections of the declination magnet at 24 equidistant epochs on each of 95 days of principal disturbance occurring in the years 1858 to 1862 inclusive. The deflections are measured from the normals of the same month and hour, computed from the undisturbed positions at the same epochs on the 1825 days comprised in the five years since the commencement of the photographic records. The phenomenal laws of the disturbances on the 95 days are then investigated, and are compared with the corresponding laws derived from a far larger number of observations in the same years, taken out by the well-known process employed by the author in the reduction of the observations of the colonial magnetic observatories. The result is shown to be that, so far as the laws of the disturbances are concerned, the two processes furnish mutual confirmation—the laws being approximately the same whether they are derived from the whole body of the hourly positions, or from that portion only which includes 95 days (or on an average 19 days in each year) which were specially affected by disturbance,—but that, for the purpose of eliminating the effects of the disturbances in the