pounds of carbon in the meteorite which require a higher temperature to bring them out, but which come out when that higher temperature is employed. The carbonaceous structure of some meteorites has already been determined on other grounds.

If we carry the heating a little further still, and instead of leaving the particles relatively cold and dark while the current is passing we apply a higher temperature outside the tube by means of the Bunsen burner, then we get the luminous vapours of some constituents of the meteorite added to the spectra of hydrogen and carbon.

What luminous vapours do we get first, and which last? The experiment is a very interesting one, and may certainly be carried on in a tube such as that described until a pretty considerable development of the spectrum is obtained. The first substance which makes itself visible obviously after the hydrogen and carbon when particles of a meteorite are treated in this way is magnesium derived from the olivine, that substance which exists in the greatest quantity in the stones, and in the schreibersite, which exists in the irons.

From such a method of research as this we can pass to one in which, by means of the oxy-coal-gas flame, we can determine the spectrum of any vapour given off, provided any vapour is given off, at a still higher temperature. That work has been done, and the main result is that in the case of an "iron," the first substance to make its appearance is manganese, and the next substance to make itself obvious is iron.

Here a very important remark must be made. The substance which will give us the predominant spectrum at lowest temperature must be that substance the volatility of which at that temperature is greatest. If, however complicated the chemical constitution of one of these meteorites may be, there is one substance which volatilizes out of it more readily than another at a low temperature, that substance will be the first to give us its characteristic spectrum at that temperature—and in fact we may get the spectrum of that substance alone, although its percentage in the meteorite may be extremely small. It is therefore an important result to find that in meteorites in which the quantity of iron is very considerable it is always the manganese that makes itself visible first, because its volatility is greater than that of iron. The point to bear in mind is that when we pass to the temperature of the oxy-coal-gas flame we get predominant evidence of the existence of manganese, and afterwards of iron.

Many diagrams of observations made in this way have been constructed of the oxy-coal-gas flame of meteorites and of olivine, and not only the flame but the "glow,"—glow being the name given to the luminosity produced in the tube under the conditions stated. There are some points of similarity, and other points of difference. One of the results which is most constant is a line at 500 on the wave-length scale which appears to run through all the observations until we come to deal with such meteorites as the Limerick and Nejed. On the other hand some lines and flutings do not make their appearance generally.

If we wish to extend our inquiry into the function of a still higher temperature we can use the electric arc; that also has been done. For this purpose specimens of iron meteorites have been cut into poles, the spectra of which have been observed and photographed, so that the vapours produced have been the vapours of the pure iron meteorites; that is to say, a small portion of a meteorite has *not* been placed in an impure carbon pole, so that the impurities of the carbon would be observed and photographed with the pure vapours of the meteorites. In addition to this method—in the case of the stony meteorites—the lower pole after its spectrum has been well studied has been utilized in this way: the upper pole remaining constant as an iron pole, pretty big particles of various stony meteorites have been inserted into the lower pole, and the added result has been recorded. Further, composite photographs of the spectra of many meteorites have been obtained. Half a dozen different stony meteorites have been rendered incandescent by their insertion into the lower pole during the exposure of a single photographic plate.

It is pretty obvious that if we can get detailed information on such points as these, and provided there are meteorites in space at the temperatures at which we are able to determine their spectra in the laboratory, such data should be of extreme value, for at present we know of no reason why the spectra should differ according to locality.

J. NORMAN LOCKYER.

(*To be continued.*)

MOLECULAR PHYSICS: AN ATTEMPT AT A COMPREHENSIVE DYNAMICAL TREATMENT OF PHYSICAL AND CHEMICAL FORCES.[1]

II.

§ 6. *Double Refraction.*

ACCORDING to the theories both of Fresnel and of Neumann, double refraction is explained on the assumption that the elasticity of the ether in crystals which exhibit this phenomenon is different in different directions. The elasticity is proportional to the square of the velocity of propagation, and if a, b, c are the ratios of the elasticities, parallel to the principal axes of the crystal, of the ether within it to its density, the velocity in any direction α, β, γ will be given by the equation—

$$v^2 = a^2 \cos^2 \alpha + b^2 \cos^2 \beta + c^2 \cos^2 \gamma \quad . \quad . \quad . \quad (18)$$

According to the author's theory, the elasticity of the ether is the same in every direction, so that any difference in the velocities of propagation in different directions must be due to the mutual action between the ether and the molecules of the crystal being a function of the direction, and therefore the values of the quantities c_i for the molecules of the crystal, and hence also the value of μ, must depend on the direction.

Assuming, for simplicity, that the molecules have a single shell only, it follows from (8) and (9) that—

$$\mu^2 = \frac{1}{v^2} = \frac{\rho}{l} - \frac{c_1 T^2}{l} \left\{ 1 + \frac{c_1}{\dfrac{m_1}{T^2} - c_1 - c_2} \right\}$$

$$= \frac{1}{l} \left\{ \rho - c_1 T^2 \left[1 + c_1 \frac{T^2}{m_1} \frac{\kappa_1^2 R_1}{\kappa_1^2 - T^2} \right] \right\} \quad . \quad . \quad (19)$$

where $\kappa_1^2 = m_1/(c_1 + c_2)$ and $R_1 = m_1/\kappa_1^2(c_1 + c_2)$.

Let the values of c_i and μ for a second direction be c_i^1 and μ^1, then

$$\mu^{1^2} = \frac{\rho}{l} - \frac{c_1^1 T^2}{l} - \frac{c_1^{1^2} T^4}{(c_1^1 + c_2^1) \left(\dfrac{m_1}{c_1^1 + c_2^1} - T^2 \right)} \quad . \quad . \quad (20)$$

Now, as Thomson has pointed out, the dispersion accompanying double refraction is of very small amount, so that the difference $\mu^2 - \mu^{1^2}$ must be sensibly independent of T.

If T were less than κ, $\mu^2 - \mu^{1^2}$ would, from (12), be proportional to T^2. It must therefore be assumed that the critical period is at the extreme blue end of the spectrum, which will give T greater than κ_1 for all the rays. Then from (12a)—

$$\mu^2 - \mu^{1^2} = \frac{c_1^2 m_1}{l(c_1 + c_2)^2} - \frac{c_1^{1^2} m_1}{l(c_1^1 + c_2^1)^2}$$

$$- \left(c_1 - c_1^1 - \frac{c_1^2}{c_1 + c_2} + \frac{c_1^{1^2}}{c_1^1 + c_2^1} \right) \frac{T^2}{l}$$

$$+ \left(\frac{c_1^2}{(c_1 + c_2)^3} - \frac{c_1^{1^2}}{(c_1^1 + c_2^1)^3} \right) \frac{m_1^2}{l T^2} + \quad . \quad . \quad . \quad (21)$$

In order that the coefficient of T^2 may be small, c_1 and c_1^1 must be small and nearly equal. The other terms of the series will then be also very small, especially if T is large in comparison with m_1, and the series may, to a first approximation, be replaced by its constant term.

Now let it be assumed that the manner in which c_1 and c_2 depend on the direction α, β, γ, is determined by an equation of the form—

$$\left(\frac{c_1}{c_1 + c_2} \right)^2 = C_1 \cos^2 \alpha + C_2 \cos^2 \beta + C_3 \cos^2 \gamma \quad . \quad . \quad (22)$$

Then from (19) and (12a)—

$$v^2 = \frac{1}{\mu^2} = \left(\frac{l}{\rho} - \frac{m_1}{\rho} C_1 \right) \cos^2 \alpha + \left(\frac{l}{\rho} - \frac{m_1}{\rho} C_2 \right) \cos^2 \beta$$
$$+ \left(\frac{l}{\rho} - \frac{m_1}{\rho} C_3 \right) \cos^2 \gamma,$$

an equation of the same form as (18), and which therefore gives a wave-surface identical with Fresnel's. It must, of course, be

[1] A Paper read before the Physico-Economic Society of Königsberg, by Prof. F. Lindemann, on April 5, 1888. Continued from p. 407.

assumed that the axes of the molecules in the crystal are all parallel.

Thomson arrived at a different result, which the author attributes to his having assumed the product of the denominators

$c_1 + c_2 - m_1/T^2$ and $c_1{}^1 + c_2{}^1 - \dfrac{m_1}{T^2}$ to be sensibly a constant,

and therefore considered only the manner in which T enters into the numerators.

It is easy to see that similar results will be obtained for molecules consisting of any number of shells.

§ 7. *Spectra of Chemical Compounds.*

In considering chemical compounds it is necessary to make a clear distinction between atoms and molecules, and henceforward the author uses the term atom to denote a system of shells such as is described in § 1, and employs the term molecule only for a combination of two or more atoms having their external shells close together. The author restricts his investigations to diatomic molecules.

A molecule will then be capable of executing stationary vibrations without disturbing the ether, similar to those of an atom, and will therefore also have its critical periods ; but their values, in the case of the molecule, will depend on the direction of the disturbance. A diatomic molecule may be considered approximately as consisting of a series of concentric prolate spheroidal shells having their longer axes coincident with the lines joining the centres of the spheres.

There will be two principal series of critical periods, corresponding respectively to disturbances propagated in the direction of the longest axis or of any of the shortest axes. If the direction of propagation of a disturbance differs slightly from one of these axes, the corresponding lines of the spectrum will only be slightly displaced, and in this way well-defined bright lines will be replaced by bright bands sharply defined on one side and indistinctly on the other. If two of these bands overlap on their indistinct sides, a band may be produced of equal brightness throughout, and having both its sides sharply defined.

This gives an explanation of the well-known experimental fact that the spectra of chemical compounds usually consist of bright fluted bands, sometimes accompanied by distinct bright lines, and not of bright lines only. Conversely, if the spectrum of a gas contains bright bands, it will be natural to infer that it is a chemical compound. This would lead us to suppose that oxygen, sulphur, nitrogen, phosphorus, carbon, and silicon are really compound bodies—a conclusion which receives independent confirmation from other points of view.

The theory does not lead to any simple law, such as has often been sought after, for determining the spectrum of a compound from the spectra of its constituents, but it throws a good deal of light on the subject generally.

The differential equations to determine the motions of the shells within an atom differ from equations (1) only in virtue of the core itself being supposed to be in motion, so that the last of these equations will become—

$$\frac{m_j}{4\pi^2}\frac{d^2 x_j}{dt^2} = c_j(x_{j-1} - x_j) - c_{j+1}(x_j - x_{j+1}) \quad . \quad (23)$$

the difference consisting only in the presence of x_{j+1}, which was supposed equal to zero in equations (1).

If we discard the assumption that the mass of the core is so great relatively to that of the shells in an atom that the centre of gravity of the system may be identified with that of the core, the condition $x_{j+1} = 0$ will be replaced by the more general one—

$$m_1 x_1 + m_2 x_2 + \ldots + m_{j+1} x_{j+1} = 0 \quad . \quad . \quad (24)$$

which determines the value of $d^2 x_{j+1}/dt^2$, which is wanting in the system (23).

From (2), (3), and (23) we obtain the system—

$$
\begin{aligned}
- c_1\xi &= a_1 x_1 + c_2 x_2 \\
- c_2 x_1 &= a_2 x_2 + c_3 x_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad (25) \\
&\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\
c_j x_{j-1} &= a_j x_j + c_{j+1} x_{j+1} ;
\end{aligned}
$$

where, as before, $a_i = m_i/T^2 - c_i - c_{i+1}$.

These, together with (24), form a set of $j + 1$ linear equations, which are sufficient to determine the $j + 1$ unknown quantities $x_1, x_2, \ldots x_{j+1}$ in terms of the given quantities ξ and T^2.

Replacing ξ, m, x, c, j by η, n, y, e, κ respectively, we obtain a similar set of equations to determine the vibrations of the second atom. If the outer shells of these two atoms are in contact, x_1 must be equal to y_1, unless the disturbance is such as to effect a separation, x_i and y_i being corresponding displacements from the common centre of gravity. Writing x for the common displacement of the shells in contact, equations (25) assume the form—

$$
\begin{aligned}
- e_1\eta &= b_1 x + e_2 y_2 \\
- e_2 x &= b_2 y_2 + e_3 y_3 \\
&\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\
- e_\kappa y_{\kappa-1} &= b_\kappa y_\kappa + e_{\kappa+1} y_{\kappa+1}.
\end{aligned}
$$

The condition that the common centre of gravity of the two atoms may remain at rest will therefore be—

$$(m_1 + n_1)x + m_2 x_2 + m_3 x_3 + \ldots + m_{j+1} x_{j+1}$$
$$+ n_2 y_2 + \ldots + n_{\kappa+1} y_{\kappa+1} = 0 \quad . \quad . \quad . \quad (27)$$

(25), (26), and (27) form a system of $j + \kappa + 1$ equations to determine the same number of unknowns, x, x_2, $\ldots x_{j+1}$, $\eta_2 \ldots \eta_{\kappa+1}$, in terms of the known quantities ξ, η, and T^2. ξ is determined as before by equation (2), and gives the vibration of the ether at the point where the ray impinges on the first atom. The axis of a molecule may be at any angle with the impinging ray, and η will give the ether vibration at the point where a ray parallel to the first strikes the second atom. For a given period and wave-length, ξ and η will therefore in general be in different phases.

In the case of vibrations parallel to the axis of the molecule we shall have $\xi = \eta$, supposing all the parallel rays impinging on the molecule to be in the same phase. The ratio x/ξ, required for the determination of μ^2 will then be the quotient of the second and first minors (viz. the coefficients of u_1 and u) of the determinant of order $j + \kappa + 2$ given below, in which the first row is completed by arbitrary quantities.

u	u_1	u_2	u_3	$u_4 \ldots$	u_{j+1}	v_2	v_3	$v_4 \ldots$	$v_{\kappa+1}$
o	$m_1 + n_1$	m_2	m_3	$m_4 \ldots$	m_{j+1}	n_3	n_3	$n_4 \ldots$	$n_{\kappa+1}$
c_1	a_1	c_2	o	o $\ldots$	o	o	o	o $\ldots$	o
o	c_2	a_2	c_3	o $\ldots$	o	o	o	o $\ldots$	o
o	o	c_3	a_3	$c_4 \ldots$	o	o	o	o $\ldots$	o
.	.	.	.	.	.	.	.	.	.
o	o	o	o	o $\ldots$	c_{j+1}	o	o	o $\ldots$	o
e_1	b_1	o	o	o $\ldots$	o	e_2	o	o $\ldots$	o
o	e_2	o	o	o $\ldots$	o	b_2	e_3	o $\ldots$	o
o	o	o	o	o $\ldots$	o	e_3	b_3	$e_4 \ldots$	o
.	.	.	.	.	.	.	.	.	.
o	o	o	o	o $\ldots$	o	o	o	o $\ldots$	$c_{\kappa+1}$

This will always be the case applicable to the determination of the light emitted by a molecule.

The equation $\xi = 0$, which determines the critical periods of the molecule, will then be obtained by equating the coefficient of u to zero, and as a_i and b_i are linear functions of T^{-2}, the resulting equation will be of the order $j + \kappa$. Therefore, for vibrations parallel to the axis, the number of critical periods of a diatomic molecule is equal to the sum of the numbers of critical periods of its constituent atoms. This number may be diminished if $x = 0$ while x/ξ and u_2 remain finite.

If a single ray only is considered, as at the limits of illumination, η may be taken equal to zero for any given value of ξ; it is only necessary to put $e_1 = 0$ in the first column of the determinant. This will, however, not affect the equation $\xi = 0$.

If the impinging ray is parallel to the axis of the molecule, in which case the vibrations will be perpendicular to it, the two atoms will be differently affected by the vibrations of the ether, for, in the case of the first atom, ξ is again determined by (2), or more generally by the equation—

$$\xi = a \cos\left(\frac{2\pi t}{T} - \frac{X}{\lambda}\right),$$

where X is the abscissa of the atom ; and if r and s are the radii of the two atoms we shall have for the second atom—

$$\eta = a \cos\left(\frac{2\pi t}{T} - \frac{X + r + s}{\lambda}\right).$$

Now the radii of the atoms are supposed to be very small in

comparison with the wave-length λ, so that ξ and η will be nearly equal, and therefore we may write—

$$\eta = \xi \left\{ 1 + \frac{r + s}{\lambda} \tan\left(\frac{2\pi t}{T} - \frac{X}{\lambda}\right) \right\}.$$

As a first approximation we may take ξ = η, and then the vibrations will be the same as those parallel to the axis. Since, however, the centre of gravity remains fixed, the vibration must be a pendulous one about this centre, which introduces a fresh set of considerations. The proper vibrations of the molecule would still be given by ξ = o and η = o, but, owing to the pendulous vibration, these would not completely determine the motion. The difference in the action of light in different directions, and the corresponding fluted nature of the spectrum, would appear to depend essentially on considerations of this kind.[1]

In the case of a triatomic molecule, we obtain three sets of linear equations of the same form as (25) and (26), together with one of the form (27); it is, however, unnecessary to pursue this further.

§ 8. *Production of Chemical Compounds by the Effect of Light and Heat.*

When an atom of any gas strikes in its course against an atom of some other gas, the question which presents itself is whether the two will unite to form a single molecule or not. The internal equilibrium of each atom will be disturbed by the impact, so that the resultant of the internal forces of the system formed by the two atoms will in general have a value different from zero. Let this resultant be transferred parallel to itself until it passes through the centre of gravity, as is allowable from a theorem of dynamics, then it will increase its velocity of translation. The total energy of the system must, however, remain constant, so that the energy of the internal atomic vibrations must be diminished by exactly the same amount as that by which the energy of the motion of the centre of gravity is increased. After the impact the internal vibrations will at first be of a very irregular character; but under the action of the light rays they will ultimately attain a condition of stationary equilibrium, supposing such to be possible with the diminished energy. When it is possible its stability will be greater, the greater the diminution in the internal energy.

Consider, for example, the formation of hydric chloride gas by the action of light on a mixture of chlorine and hydrogen, accompanied as it is by a measurable development of heat. Both these gases exhibit strong bright lines in the blue portion of the spectrum, and, in the case of hydrogen, also in the ultra-violet. Vibrations of corresponding critical periods will therefore easily be excited, which will greatly increase the internal energy of the atoms. When an atom of chlorine now impinges upon one of hydrogen, they will remain in contact for a finite, though exceedingly short interval. During this interval the mechanical theorem relative to the motion about the centre of gravity is applicable, since there will be no external forces acting on the pair of atoms during their common rectilinear motion. Let it be assumed further that the energy of the molecule formed by the union of the two atoms is, under the existing conditions, less than the sum of their separate energies, viz. that the critical vibrations of the molecule are less sensitive to the action of light than those of the separate atoms, then the spherical atomic shells will tend to execute resultant vibrations proper to the molecule according to § 7, so that the chlorine and hydrogen will unite to form hydric chloride. No energy can of course be lost, so that the difference between the internal energy of the molecules and that of the separate atoms will be added to that of the translatory motion, and will therefore become sensible in the form of heat.

It will be noted that no special chemical affinity between chlorine and hydrogen has to be assumed, but two elements may be said to have a chemical affinity whenever the energy of the resultant molecular vibration is, under the given conditions, less than that of the separate atomic vibrations.[2]

[1] Bunsen's observations (*Poggendorff's Annalen*, vol. cxxviii.) on crystals of certain didymium salts show that there is actually a difference in the absorption of light in different directions.
[2] A chemical compound may therefore be regarded as produced in a manner similar to the variation of a species on the Darwinian theories of adaptation and natural selection. A species undergoes variation such as to increase its suitability to its environment. In exactly the same way two atoms will unite to form a molecule, when they thereby become less sensitive to the influence of their surroundings than they would be separately. Accidental conditions are of no more importance in determining the formation of chemical compounds, than the voluntary actions of individuals in determining the variation of a species.

The given conditions may depend on light, heat, or electro-motive force, though the consideration of the last-named may be eliminated (see § 16). An example of the action of heat is given by the formation of water from hydrogen and oxygen. The hydrogen burns with a blue flame. Both the elements give bright lines in the red portion of the spectrum, hydrogen at 6562, and oxygen at 6171,[1] so that their internal energy can easily be increased by the action of heat, so that combination will take place, and this is accompanied by a considerable development of heat. Water being a very stable compound with respect to the action of heat, we should expect it to give chiefly blue lines. This has not hitherto been proved by direct experiment, but it appears to be indicated by the blue colour and intense heat of the hydrogen flame.

Since the heat of combustion which is usually developed during the formation of oxides arises from a diminution in the internal energy of the atoms, we should infer that (1) the stability of an oxide will be greater the greater its heat of combustion ; (2) the spectrum of the oxide will not extend so far towards the red end of the spectrum as the spectra of the constituents.

The former inference is confirmed by the researches of Favre and Silbermann ; the latter is found to be justified for the oxides of aluminium, lead, carbon, copper, and strontium (the ultra-red portion of the spectrum in the case of strontium should be specially noted), but it cannot be expected to hold good so universally as the former.

§ 9 *Molecular Theory of Chemistry.*

In modern chemistry the term molecule is used to denote the smallest mass of a substance which can exist separately. This conception of a molecule is essentially different from that set forth in § 7 of this paper. The chemical molecule may be simply an atom, as in the cases of mercury and cadmium, but this is not the case for the molecules considered by the author. On the author's theory, each atom is supposed capable of separate existence, which agrees with chemical phenomena when the atoms are considered in the isolated, or so-called nascent condition, but appears to be in conflict with them in that Mariotte's (Boyle's) law, and the comparison of the weights of equal volumes of various elements in the gaseous state, appear to point to the conclusion that their chemical molecules consist of two or more atoms.

This only applies to elements in the gaseous state and under the ordinary conditions of pressure and temperature, and it is quite conceivable that in high vacua and at a high temperature, as for example in a Geissler tube, the atoms of diatomic molecules may exist separately, a dissociation taking place similar to that which is invariably found to occur in the case of chemical compounds under similar circumstances (see § 10). The ordinary hypothesis must therefore be regarded as simply expressing that under ordinary circumstances the atoms of diatomic molecules tend to unite in pairs to form chemical molecules.

According to § 8, it must therefore be assumed that the diatomic molecules of certain elements are less sensitive to the external influences of light and heat than the separate atoms, and that the internal energy of such a molecule is less than the sum of the internal energies of its two constituent atoms. Suppose that ξ is again determined by (2) and that $x_i = a_i \cos 2\pi t/T$, then the quantities a_i must be determined from the equations (25) and (24). The internal energy of an atom will therefore be

$$E = \tfrac{1}{2}(m_1 a_1{}^2 + m_2 a_2{}^2 + \ldots + m_{j+1} a_{j+1}{}^2).$$

The energy of a second atom of the same substance under identical external conditions will have the same value. If the two atoms are placed in contact, the new values of x_i must be determined from (25), (26), and (27). In this case, however, we have $y_i = x_i$, $a_i = b_i$, $c_i = e_i$, $m_i = n_i$, so that (26) and (27) become identical, and (27) reduces to (24), with the distinction, however, that the quantities x_i now represent the displacements relatively to the common centre of gravity, instead of relatively to the centre of gravity of the single atom. It therefore follows that, approximately, the critical vibration periods of a molecule consisting of two similar atoms will be identical with those of the separate atoms.

Now the energy of the molecule is just double that of either of the constituent atoms, so that the union of the atoms cannot be due to a decrease in the internal energy. It is easy to understand, however, that when two atoms have once combined they

[1] See B.A. Reports, 1884, 1885, and 1886.

will not separate again. except under special circumstances ; but so far the fact that different gases behave differently in this respect remains unexplained. If two spherical bodies collide, they will remain in contact only if perfectly inelastic, otherwise they will fly off in opposite directions.

In the latter case the elastic forces are due to the displacement of the molecules of the spheres from their positions of equilibrium. If the colliding bodies are two of Thomson's atoms, similar elastic forces will be called into play by a displacement of their outer shells. If the mass m_1 of each of the outer shells is very large compared with that of the inner ones, the outer shells will remain nearly at rest after the collision, while the inner ones will be thrown into violent vibration ; indeed it follows from (24) that x_1 will be very small. The atoms will therefore behave very nearly as if they were inelastic, and may remain long enough in contact to assume a new condition of equilibrium by uniting to form a single molecule. Exactly the reverse will happen if m_1 is small compared with the mass of the inner shells.

We must therefore assume that in diatomic chemical molecules the masses of the outer shells are very large compared to the sums of the masses of the interior shells, while in the monatomic molecules the masses of the outer shells are comparatively small.

We might now inquire why it is that in general more than two atoms do not unite in this manner. To which the answer is that the more complicated the structure of a molecule, the more easily will it be broken up by the impacts of other molecules. We must therefore assume that in the case of diatomic molecules the violence and frequency of the impacts, even under ordinary circumstances, are sufficient to break up any molecules which may be formed containing more than two atoms ; while in the case of other elements, such as arsenic and phosphorus, the impacts are unable to break up the tetratomic molecules, even at the high temperature of vaporization.

In virtue of these considerations it appears that the formation of a chemical compound, such as hydric chloride, is not such a simple process as it was supposed to be in § 7. The impacts will frequently produce diatomic molecules of hydrogen and of chlorine respectively. The final condition of equilibrium will, however, be arrived at on the same principle as before—namely, that the molecules of hydric chloride are the least sensitive to the action of light. Tetratomic molecules of hydric chloride, will not be permanently formed, as the impacts, increased in violence and frequency by the heat developed, will break them up. Similar considerations apply to the formation of water.

The formation of these simple compounds is, therefore, accompanied by, and due to the simultaneous breaking up of the original diatomic molecules of the elements present.

Double decompositions will take place in an exactly similar manner, and considerations of the same kind apply to solid and liquid bodies, in which, however, the impacts will be very much less frequent.

We also see that the broadening of the bands in the spectrum of a gas, especially when due to a lowering of temperature, does not necessarily show that the gas is a compound, as it may be due to the union of previously dissociated similar atoms into molecules.

§ 10. *Dissociative Action of Light and Heat.*

The fact that the same compounds which are formed by the action of heat are again broken up when the temperature is further increased, and, indeed, the dissociation of every chemical compound at a sufficiently high temperature, is in apparent contradiction to the conclusions of § 8. In the case of compounds formed by the action of light it is quite possible that the internal energy due to the action of heat may be greater than that of the atoms at the same temperature. In general, it may be that when the two constants c_i (§ 1) combine to form one, the corresponding critical vibrations are only produced at a much higher temperature, and may then give rise to dissociation. Since, however, all compounds are dissociated at sufficiently high temperatures, there must be some other causes at work. We may suppose that in gases at very high temperatures the molecules are broken up simply by the violence of the impacts, and this process would be facilitated by the molecules not being spherical in form.

The dissociative action of light observed in certain cases cannot of course have a similar general explanation, and must not be attributed to special chemical properties of light of certain wave-

lengths, but to the values of the internal constants of the molecules being of a kind specially favourable to such action. Thus, as the author points out, we are led to the point of view expressed by Lockyer,[1] as follows :—

" The causes which are given in the text-books, showing us the maxima of heat, light, and chemical action, are, I fancy, merely causes showing us, as it were, the absorption spectra of those substances by which the maxima have been determined— whether they be lamp-black, the coating of the retina, or salts of silver, and are really altogether independent of the nature of light."

§ 11. *Fluorescence.*

It has been pointed out in § 4 how critical vibrations may be excited in a molecule by external disturbances, causing the molecule to emit light of a certain wave-length. The disturbance was supposed to be due to the action of heat, but from what has gone before it is clear that they may be produced by ether vibrations if only the molecule or atom is very sensitive to light vibrations. For as soon as the impact of light waves of a certain (critical) vibration period has raised the internal energy of the molecule to its maximum value, the molecule itself—that is to say, its centre of gravity—will begin to execute vibrations ; the different molecules will strike against one another, and the result of these encounters will be to produce vibrations of the other critical periods of the molecule, which will be different from the vibration period of the impinging light.

The substance will therefore emit rays different from those which have fallen upon it. As a matter of fact some substances having such special sensitiveness have been observed,[2] and are known as fluorescent substances. The phenomena of fluorescence must therefore be attributed to the absorption of light, as was pointed out by Stokes.

A fluorescent body is to be regarded as one in which the molecular constants c_i have such values that the corresponding light vibrations can be easily excited by external impulses. Fluorescent substances must, in agreement with Stokes's conclusions, be regarded as being exceptionally sensitive.

The theory does not lead to the law which has usually been asserted, that the emitted light must necessarily be of longer wave-length than the impinging light, and therefore the theory is not inconsistent with Lömmel's observations on naphthalin red.

Fluor-spar exhibits the phenomena of fluorescence to an exceptional degree. It may be that fluorine itself is exceptionally sensitive to the action of light, and that the formation of the mineral has not altogether destroyed this sensitiveness. If this be so, it would explain the impossibility of preventing fluorine from entering into combination with any substance with which it is in contact.
G. W. DE TUNZELMANN.

(To be continued.)

THE FORESTRY SCHOOL IN SPAIN.

IN a Report to the Foreign Office which has just been published the British Ambassador at Madrid states that Mr. Gosling, First Secretary to the Embassy, has had the opportunity of studying the excellent School of Forestry established at the Escurial, and as great interest is now taken in forestal science in England, and as efforts are being made to establish a British National School of Forestry, he sends the information collected by Mr. Gosling at an institution which, he thinks, is well adapted as a type for a similar institution in England.

Forestal legislation in Spain dates as far back as the close of the fifteenth century—that is, in the reign of Ferdinand and Isabella—and there is reason to believe that reckless destruction of the rich forests was checked from time to time by Royal ordinances. At the close of the sixteenth century Madrid was surrounded by dense forests ; in fact, the city arms—a bear climbing up a green tree—bear out the old chroniclers when they speak of the forests which lay around the city, which must have existed in the time of Charles V. So far is this from being the case at present that for the most part the districts around Madrid are treeless and unproductive, and as a consequence exposed to the furious mountain storms, and unsheltered in the scorching summer, whence comes the extreme unhealthi-

---

[1] "Studies in Spectrum Analysis," p. 110.
[2] Thomson mentioned, "Lectures on Molecular Dynamics," p. 280, that his theory of absorption would account for the phenomena of fluorescence, but he did not follow up the subject.