



XXXVIII. The existence of the luminiferous ether

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To cite this article: Ernest H. Cook B.Sc. A.R.C.S. (1879) XXXVIII. The existence of the luminiferous ether , Philosophical Magazine Series 5, 7:43, 225-239, DOI: [10.1080/14786447908639599](https://doi.org/10.1080/14786447908639599)

To link to this article: <http://dx.doi.org/10.1080/14786447908639599>



Published online: 13 May 2009.



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THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1879.

XXXVIII. *The Existence of the Luminiferous Ether.* By
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THE enormous velocity with which the motion producing light is propagated through space induced the authors of the undulatory theory to seek about for some medium capable of transmitting the vibratory movement. Applying the known laws of the propagation of sound, which is also a vibratory movement, this medium must possess enormously high elasticity and extremely small density. Such a medium is the luminiferous ether. This substance fills *all* space, and is imprisoned between the atoms of *all* bodies. The vibrations of the atoms of luminous bodies are communicated to the ether, and by it transmitted in all directions. Each particle of the ether makes a small movement to and fro; but the whole mass is thrown into wave-like motions. The elasticity or density of the ether in free space is different from that of the same ether when imprisoned by the molecules of material bodies. Thus in a refracting body like glass, the elasticity of the ether is less (or its density is greater) than in air, and the elasticity in air is less than in a vacuum. We therefore find that the velocity of light in glass is less than it is in air, and is less in air than it is in a vacuum. Moreover in most crystalline substances the elasticity of the ether is different in different planes; and we find that light traverses such substances with different velocities in different directions. The explanation

* Communicated by the Author.

Phil. Mag. S. 5. Vol. 7. No. 43. April 1879.

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given of this is that the different grouping of the molecules along certain lines in the crystal determines a different arrangement of the ether particles along these lines also. The existence of this ether was, and is, considered of such importance by the supporters of the undulatory theory, that we find attempts being made to determine experimentally some of its properties. Thus Fizeau has arrived at the conclusion that a moving body drags part of the ether along with it in its motion. Stokes accounts for aberration by attributing to the ether the properties of an elastic solid. In fact, all our philosophers accept without reservation the material existence of the luminiferous ether. It is impossible to fail to note the analogy between some of the propositions of this theory and those of the two-fluid theories of Magnetism and Electricity. These fluids also are imponderable, invisible, yet all-pervading. They interpose themselves between the molecules of bodies, and are rendered evident to us only by the effects they produce when treated in certain ways. If we accept all these theories, we must assume that between the molecules of every unfortunate body we have five distinct fluids—two magnetic, two electric, and the ether. Why do we not discard the four and retain the ether? and attribute to it some other properties which would enable it to perform the functions of the magnetic and electric fluids? We should then only have to imagine the existence of one hypothetical medium. But as an effort of the imagination, the invention of five hypothetical fluids is as easy as the invention of one.

In order, then, to obtain for light the enormous velocity which experiment has shown it to possess, the supporters of the undulatory theory have boldly filled all space with a substance which, conforming to the equation $v = \sqrt{\frac{e}{d}}$, possesses very great elasticity and very little density. The velocity with which light travels through air we may take to be 185,000 miles per second. Sound, let us suppose, travels at 1100 feet per second. Light therefore travels 888,000 times as fast through air as sound does. To find what proportion exists between the density and elasticity of the air and ether, let us suppose the velocity of sound through air to be equal to 1000 feet per second (in this calculation the correct velocity is, of course, 916 feet per second). Then we have

elast. of air : elast. of ether :: 1000^2 : $(185,000 \times 5280)^2$,
 assuming the density to remain constant. This gives us 954,138,240,000 as the number of times that the elasticity of the ether is greater than that of the air, assuming the density

to remain constant. If we assume the elasticity to remain constant, we have that the density of the ether must be this number of times less than the density of the air. The necessity for the existence of the ether therefore is, that we require a body whose elasticity shall be this number of times greater, or whose density shall be this number of times less, than that of the air. It is hardly necessary to add that we know of no such body in nature; and since we cannot conceive of motion without having something moved, we invent the hypothetical substance ether, which shall be the vehicle of our wave-motion. But have we not been too eager to invent? have we thoroughly satisfied ourselves that matter itself (*i. e.* ordinary matter) is incapable of transmitting the vibratory movement? In attempting to answer these questions, we have first to show that the theory of the constitution of the luminiferous ether as at present held is untenable; and, secondly, we must endeavour to show that the particles of matter themselves are capable of taking up and transmitting the wave-motion.

Difficulties in the Conception of the Ether.

The difficulties which one meets with in the belief in the existence of this substance may be divided into two classes—those founded on theoretical considerations, and those founded on experimental evidence. We will first consider the former.

In the preceding portion we have stated that the ether must possess enormous elasticity and very little density. This is the view usually accepted: thus Tyndall says, “it is assumed to be of both extreme elasticity and of extreme tenuity.” Now, if this be the case, it of course follows that this ether will be distributed in space in the same way that matter is distributed; viz. it will accumulate around the celestial bodies, and the greater the mass of the body the greater the atmosphere (if we may use the term) of ether surrounding it. We ought, therefore, to find that a gradual increase of refractive power occurred as we approached a celestial body. In the comparatively few cases in which this can be tested it is found to be the case; but it is, I believe, universally attributed to the influence of the atmosphere. But we must consider this tenuity to be so great that it is impossible for us to recognize it by any of our balances. For if we carefully weigh a piece of a transparent substance, such as glass, and then grind it to powder (in which process we must liberate some of the ether which is held between the molecules), and weigh the powder, we obtain the same weight as before, showing that the ether we have lost had not sufficient weight to affect the balance. Some of the upholders of the undulatory theory, however, take

a different view : thus Sir John Herschel says, "though we suppose the ethereal molecules to possess inertia, we cannot suppose them affected by the force of gravitation." If this be the case, this hypothetical medium has no analogue in nature ; it is a substance of which we can form no notion, as it is impossible to conceive a body possessing moving force but no weight. Are we not inventing too much when we endow a hypothetical substance with impossible properties ? It is curious to observe how the same philosopher, in advancing arguments against the corpuscular theory, says, "This is one of the many weak points of the theory. It runs counter to the only analogy which the observation of nature furnishes"*. Yet eight pages further on he endows the ether with a property which causes it to be like no other substance in nature ! Again, if the ether has no density, it is not necessary for us to assume it to possess a high elasticity ; for any value given to the elasti-

city will fulfil the conditions of the equation $v = \sqrt{\frac{e}{d}}$. In fact, the equation has no meaning if v , e , or $d = 0$. We have thus arrived at these conclusions :—first, if we suppose the ether possesses weight, we ought to find an increase in refracting power near large masses ; and, secondly, if we suppose the ether to be unaffected by gravitation, then it is a body which bears no resemblance to any other body we know of.

Again, the ether is supposed to pervade all bodies, to interpose itself between the molecules, and, moreover, to be affected by the grouping of these molecules. When light passes from one body into another, it does so by throwing the ether contained in that body into vibration. Refraction occurs because the elasticity of the ether in the second body is different from the elasticity of the ether in the first. But why is this elasticity different ? We are told because the molecular arrangement is different in one body to what it is in another ; but are we to suppose that the proximity of the ether to different modes of molecular grouping causes that ether to be of different elasticity ? If this be so, we have to attribute to the ether a property which is peculiar to it, viz. that of having its elasticity altered by its proximity to different molecular groupings. If we, to avoid this conclusion, suppose that it is the density of the ether which undergoes change, then we again make a departure from all analogies. We know of no substance whose density is altered by the mere presence of another body.

Nor does it appear that we are better off if we assume the ether to be imprisoned between the molecules. For in this

* Familiar Lectures, p. 269.

case, although by the compression we do increase the density, yet we increase the elasticity in the same proportion, and consequently the velocity remains unchanged. Also, if we adopt this view, we must have the entire surface of a body composed of its own molecules: there must be no spaces; or the imprisoned ether would escape and assume the elasticity and density of the ether of the surrounding body. We thus arrive at the conclusion that, for refraction to be accounted for, we must assume that the elasticity of the ether is different in different bodies, and that this difference is due to the proximity of the ether particles to the different molecular arrangements of bodies. In this assumption, it is needless to state, we make a departure from all known facts. We know of no substance whose elasticity is altered by the proximity of another body. Slightly altering the words of Sir John Herschel, if we accept this explanation we are running counter to all the analogies which the observation of nature affords.

Again, although the ether in a certain sense is a most powerful substance, capable of entering into all bodies, and of vibrating with enormous velocity, yet chemically it is a most inert substance. In no way can we cause it to chemically combine with any other body. Although in intimate connexion with the molecules and atoms of all, it chemically affects none. In this property, also, our hypothetical medium is peculiar; no substance in nature refuses to combine with some one or more other substances.

The difficulties which one experiences in accepting the ether, owing to certain experiments, are varied and numerous. We will consider some of these. A common experiment in acoustics is to place an alarm under an exhausted receiver and to receive no sound when the air is withdrawn. This simple experiment is difficult to explain; for we must remember that, although the air is withdrawn, the ether remains. Why does this ether not take up the vibrations of the sounding body and transmit them? It cannot be because the vibrations producing sound are too slow; for an unlimited elastic medium is capable of vibrating in any way. The water of the ocean transmits a long rolling wave as readily as the minutest ripple, and the minutest ripple as easily as the shortest sound-wave. It will not suffice to say that the ether does take up the vibration and carry it on to the sides of the receiver, but that here it is unable to throw the molecules of the glass into vibration, and hence the sound cannot reach the external air, because according to theory the ether is contained in the glass. There is, in fact, no break in the line of communication of the ether particles outside with those in the inside of the receiver. What prevents the vibrations being taken up and transmitted?

Another experiment which seems difficult of explanation is that it is impossible to cause the electric discharge to occur in a perfect vacuum. Ether is present in this case also; yet this ether is unable to transmit the electricity. Whatever this electricity may be, it is certainly something which is much like light and heat, it is therefore probably molecular motion of some kind. If molecular motion, our ether ought to be able to transmit it; as it does not do so we are left to choose between two alternatives—either to say electricity is not due to molecular motion, or that no substance of the nature of ether is present. Evidence seems to be accumulating to show that electricity *is* due to molecular motion; and we must therefore conclude that no ether is present.

Thirdly, let us consider Faraday's experiment with the "heavy glass." When a polarized ray is passed along the axis of a prism of a transparent substance which under ordinary conditions is optically inactive, and the prism placed in the magnetic field, then the substance becomes able to turn the plane of polarization. Thus, if a polarized ray is sent through a prism of this glass which is placed between the poles of an electromagnet, the plane of polarization is immediately turned. The reason assigned for this peculiar action by Faraday is that the magnet has caused a temporary difference in the molecular constitution of the substance; and he finds that any cause which impedes the development of this power of rotation also impedes molecular displacement. But Faraday does not commit himself to the statement that this alteration of molecular grouping causes an alteration in the constitution of the ether of such a character as to cause it to vibrate in a particular plane. He simply states that a molecular rearrangement has produced the effect, and evidently considers this a sufficient explanation.

Two observations recently made are also difficult of explanation on the ethereal theory, viz. the increase of the electrical resistance of selenium by its exposure to light, and Dr. Kerr's experiments with the light reflected from the polished pole of a magnet (see Phil. Mag. May 1877 and March 1878). In the first of these we find that the vibratory movement of light affects the material particles of matter; for we believe that the particles of the body are alone concerned in the transmission of electricity. This difficulty may be overcome by assuming the ether to be the medium for the conduction of electricity as it is of light; but up to the present, I believe, this theory has not been propounded. Dr. Kerr finds that the light reflected from the polished pole of a magnet is polarized. We must therefore suppose that the ether is susceptible of magnetic influence. May I ask if it contains the two magnetic

fluids? If, however, we consider the particles of the air concerned in the propagation of light, we have to make no fresh assumption, as we already know nitrogen to be very feebly diamagnetic and oxygen paramagnetic. The particles of these gases are affected by contiguity to the pole of the magnet; and this kind of affection is such as to cause the molecules to vibrate in certain planes: hence the light is polarized.

Finally, let us look at the explanation offered by the ether theory to two of the chemical actions of light as representatives of most of the chemical effects of light. We will take the reduction of silver salts and the decomposition of CO_2 into its elements by the action of light on the chlorophyll of plants. Scheele discovered that when chloride of silver was exposed to light, a black powder, insoluble in nitric acid, was formed; and at the same time free hydrochloric acid was produced. The black powder he concluded to be metallic silver. He also made the important discovery that the violet rays were far more active in producing this reduction than the other rays. Here, then, we have three distinct results to account for, viz.:—1st, the production of the black powder; 2nd, the formation of hydrochloric acid; and, 3rd, the superior power of the violet rays. The ether theory says that the vibration of the ether shakes asunder the bond of chemical union; that is, the vibrations of the medium in which the molecules of the argentic chloride are imbedded causes the separation of the atoms of the molecules. This explanation seems at once insufficient and unnecessary. It is insufficient for this reason: it does not seem probable that the vibrations of an intermolecular medium should be able to cause an atomic separation. It is quite possible to conceive that the molecules are caused to vibrate by the vibrations of the surrounding ether; but that the individual atoms of these molecules are caused to vibrate, and *that with different velocities, or otherwise no separation can occur*, seems improbable. That this vibration of the atoms may occur it is necessary to assume that the ether is interatomic instead of intermolecular. If we make this additional assumption, we stretch to the point of breaking an already “elastic” theory, and we render much more difficult of explanation the combination of bodies produced by the action of light. The above explanation seems unnecessary, because we have only to assume that the atoms of bodies are capable of vibrating at a great velocity to account for these experiments in a simple and most satisfactory manner. The latter portion of this paper is devoted to the working-out of this assumption.

Continuing our investigation of this experiment further, we notice that colourless chloride of silver has been converted

into a black substance. A body is colourless because the power of the ether between its molecules to vibrate is the same as the power of the ether in the surrounding medium to vibrate. A body is black because its ether takes up and retains all the vibrations which fall upon it. Thus the vibration of the ether in the black substance must be more powerful than in the colourless. (This also follows because energy cannot be destroyed by the black substance.) Here, then, the vibration of the ether in the colourless chloride of silver has produced a substance containing ether particles vibrating with more energy. In other words, the energy of the vibration in the argentic chloride has been used up in first shaking the atom of silver from the atom of chlorine, and also in causing the ether in the silver and the ether in the chlorine to vibrate. According to the conservation of energy, these energies should be equal. But we find that there is more energy in the black silver than in the chloride; and consequently we have inequality.

The reason assigned for the superior energy of the violet rays is simple and satisfactory if we admit the previous assumptions. It is that in consequence of their more rapid vibration they are more energetic and thus capable of doing more work.

In the decomposition of carbonic anhydride effected by light in the presence of chlorophyll, we have another experiment which is difficult of explanation on the ether theory. The vibration of the ether of the carbonic anhydride is unable to effect the decomposition itself; but when brought *near* to the vibrating ether of the chlorophyll, the decomposition is effected. What is the nature of the action which here takes place? and what known action is analogous to it?

Stating briefly the difficulties in the conception of the ether, we have:—

- (α) The want of any direct evidence.
- (β) The fact that no ethereal condensation is observed around the celestial bodies.
- (γ) The interposition of this substance between the molecules of bodies.
- (δ) The nature of the action producing a difference of elasticity or density in this imprisoned ether.
- (ϵ) The chemical inertness of the ether.

In addition to these we have from experimental evidence the following:—

- (α) Inability of the ether to take up every species of vibration.
- (β) Inability to transmit electricity.

(γ) Inability to explain circular polarization produced by magnetic action.

(δ) Incompleteness of explanation offered of the chemical effects of light.

Probably a more exhaustive survey will reveal other and greater difficulties; but these will be sufficient to show that the acceptance of the theory is beset with difficulties and makes such great calls upon our imaginations that it behoves the least sceptical to "pause and consider."

Now let us proceed with the second portion of our subject, to endeavour to show that the particles of matter themselves are capable of taking up and transmitting the wave-motion. Dalton considered all bodies to be composed of atoms, which atoms are all of the same size but of different weights. This difference in weight is expressed in the atomic weight of the elements. Atoms in the free state combine with each other and form molecules. About the absolute size or density of these atoms we know nothing, save that they are very very small. Recent advances in scientific theory have but extended Dalton's hypothesis. Thus, a high authority, stating the theory at present held of the constitution of bodies, says:—

"All bodies consist of a finite number of small parts called molecules. Every molecule consists of a definite quantity of matter, which is exactly the same for all the molecules of the same substance. . . . A molecule may consist of several distinct portions of matter held together by chemical bonds, and may be set in vibration, rotation, or any other kind of relative motion. . . . The molecules of all bodies are in a state of continual agitation. The hotter a body is, the more violently are its molecules agitated"* . Here, then, heat is produced by the vibration of the molecules of bodies. If the particles of a body are capable of such rapid vibration in the production of heat, why may they not be capable of taking up this vibration and transmitting it? It is more than probable that heat is thus transmitted. Why may not light be also thus transmitted? We only have a difference in quantity between the two, heat being produced by the less rapid and light by the more rapid vibrations. Nor is the difference so great between the vibration producing heat and that producing light. The maximum heating effect of the spectrum occurs at a point where the rate of vibration is about 400 millions of millions of vibrations per second; the maximum chemical effect occurs where the rate is about 800 millions of millions per second. As an effort of the intellect, it is as easy to endow matter with the ability to vibrate at the latter rate as at the former; and if

* Maxwell, *Theory of Heat*, p. 306.

it can vibrate at this rate (which seems to be admitted) why cannot it transmit this vibration?

It cannot transmit it because its density is too great and its elasticity too small we should be told. But if we reduce the size of the atom we reduce the weight of it, and we reduce the amount of energy necessary to throw it into vibration. In fact, if we reduce the size 954,138,240,000 times, we should reduce the weight and endow the atom with power of vibrating. It appears, then, that the ability of a body to take up vibratory motion depends upon the size of the atom; and, given that the atoms and molecules of bodies are sufficiently small, they are capable of transmitting light and heat. In order to compare the velocity with which light travels with that which sound travels, let us take a few examples. In air we have already seen that light travels with 888,500 times the velocity of sound. In water we know that sound travels at about 5000 feet per second. The index of refraction of water is, according to Brewster and Wollaston, 1.336; if the velocity of light in air is 185,000 miles per second, the velocity in water is 138,500. Thus the velocity of light in water is 146,300 times that of sound. The greatest velocity of sound in any substance is through iron at 100° C., in which it is 17,500 feet per second. The substance with the greatest refractive index is chromate of lead=nearly 3. The velocity of light is therefore less in this body than in any. Let us compare these two, and we find that the velocity of light in chromate of lead is *only* 17,620 times as great as the velocity of sound through iron. Now we have no doubt that the sound is transmitted through the iron by the vibration of its molecules, why may not the light be transmitted through the chromate of lead by the vibration of its molecules? Here, again, it is merely a question of degree; the one is a more rapid motion than the other. There is another point which must not be overlooked in comparing sound and light; and that is, that the vibrations of the molecules composing a light-wave oscillate in planes perpendicular to the direction of propagation of the wave, while those composing a sound-wave oscillate in the direction of propagation. This difference, it seems reasonable to suppose, will exercise an important influence on the relative velocities even in a homogeneous medium. It is evident that it must do so in a medium whose elasticity is different in the two planes, *i. e.* the plane of propagation and the plane of vibration.

And in thus assuming that the particles of matter themselves are capable of vibrating and propagating the undulatory movement of light, are we making too great a strain upon them? Certainly not. We can form no notion, even the most remote,

of the magnitude of these particles. The best microscopes will detect particles $\frac{1}{100,000}$ of an inch in diameter; yet "we are here dealing with infinitesimals, compared with which the test-objects of the microscope are literally immense"*. By means of the spectroscope we can detect $\frac{1}{200,000,000}$ of a grain of sodium; so that the atom of this metal must be smaller than this. Also, "the number of molecules in a cubic millimetre of atmospheric air is about a unit-eighteen (10^{18})"†—that is, one million billions! (A billion is a million times a million.) With a wave-length of $\frac{1}{5000}$ of a millimetre, we cease to have any luminous effect, but we still possess a faint photographic effect. We therefore see that the shortest waves in the spectrum are of immense length when compared with the size of the molecules of a body. With regard, then, to the size of the molecule, we can have no doubt that it is sufficiently minute to be fully able to oscillate and produce waves of the size of those of light. But can these molecules oscillate with sufficient rapidity? In an article on "Polarization Stress in Gases" (Phil. Mag. Dec. 1878), Mr. G. J. Stoney supplies data which will enable us to answer this question. At common temperatures the average velocity of the molecules of air may be taken as 500 metres per second. The molecules meet with so many encounters that the direction of the path of each is changed 10,000,000,000 times a second. We have, then, that in one movement the particle travels $\frac{1}{2,000,000}$ of a metre, or $\frac{1}{2000}$ of a millimetre; and it makes this movement in $\frac{1}{10,000,000,000}$ of a second. Now we have seen that the length of the wave of the extreme chemical ray is $\frac{1}{5000}$ of a millimetre; consequently we find that the molecule of air travels through a distance which is more than twice as long as the length of this particular wave in this fraction of a second. The time of one oscillation of the molecules composing the mean chemical rays may be taken as $\frac{1}{800,000,000,000}$ of a second. Thus, in 80 times as long as the time occupied by a molecule in one oscillation the molecule of air has travelled through a distance twice as long as that of the whole wave-length. The distance moved through by a wave would be underestimated at a million times the distance moved through by a molecule composing that wave; consequently we see that our air-particles move with a far higher velocity than that required by the shortest waves of the spectrum.

* Tyndall, 'Scientific Use of Imagination,' p. 25.

† Johnstone Stoney, Phil. Mag. December 1878.

With these considerations before us, what need is there to assume the existence of an all-pervading ether? The particles of ordinary matter are small enough, and can, nay do, vibrate at the requisite speed; why, then, are these particles not able to transmit the waves of light? Substituting for the luminiferous ether theory this molecular theory, let us now see if the explanation of some of the difficulties of the former theory are satisfactorily accounted for. Before doing so, however, I will endeavour to answer two objections which it seems to me may be made against this theory. First, it may be asked, If light travels through bodies by the vibrations of its molecules, why is not the velocity of light through the body the same as the velocity of sound? In answering this we must bear in mind the differences between sound and light. The shortest wave of sound would be produced by 38000 vibrations per second, and would have a wave-length of about 9 millimetres, or 11250 times as great as the length of the longest wave of light. We have also to remember that the particles of a sound-wave oscillate in the direction of propagation, whilst those in a light-wave oscillate in planes perpendicular to that of propagation. Is it unreasonable to suppose, then, that so vast a commotion as that produced by sound *in the direction of propagation* should be retarded more than the minute disturbance produced by light in planes at right angles to this direction? Another objection which may be urged is, How do we account for the motion reaching us from the sun? We may do this in two ways: first, we may fill the space between the sun and earth with the luminiferous ether, and give this ether the property of non-miscibility with the atmosphere; or, secondly, we may assume the unlimited extent of our atmosphere. Either of these assumptions would be sufficient to account for the phenomena; and both have before been made.

Let us now see if these difficulties we have mentioned in regard to the conception of the ether are lessened if we consider the particles of matter to vibrate. It is evident that a condensation of matter does occur around the celestial bodies, and also that a gradual increase of the refractive power occurs as we approach large masses. We have here no difficulty in conceiving the cause of the difference in the refractive powers of bodies; it is simply due to the different density of the bodies and to the mode of grouping of the molecules interfering with perfect freedom of motion of these molecules. A glance at what may be termed the experimental difficulties given above will suffice to show the ability of this theory to satisfactorily account for these experiments.

Numerous experimental facts support this assumption in an

indirect manner. For instance, the greater the atomic weight of the substance the greater ought to be the refractive power or the less the velocity in the body. Unfortunately, however, this rule cannot be generally applied, because of other conditions which prevent the free motion of the molecule. But we know that in the gaseous condition the molecules are less hampered than in the liquid and solid states; the refractive indices of gases ought therefore to exhibit some increase with the density. The following are the indices of refraction and densities of the five simple gases:—

Gas.	Refractive Power.		Density.
	Index.	Compared with Air.	
Hydrogen	1·000138	0·470	0·069
Nitrogen	1·000300	1·020	0·971
Air	1·000294	1·000	1·000
Oxygen	1·000272	0·924	1·106
Chlorine	1·000772	2·623	2·470

And it will be seen that, with the exception of oxygen, this fulfils the condition mentioned above. But the position of air is most instructive: it is seen that, like its density, its refractive power is intermediate between that of its constituents. What stronger indirect evidence than this can we have that the velocity in a medium is due to the density of the molecules of that medium?

A further examination of this list is of value. We notice that oxygen is an exception. Now the other three gases are what chemists call monads; oxygen, on the contrary, is a dyad. The molecule of oxygen, let us assume, consists of one atom*, while the molecules of H, N, and Cl consist of two. Altering, then, the density of oxygen to one half that given, we find it occupies its proper place in the list. The following table exhibits this and other relations:—

Gas.	Density of Molecule.	Sq. Rt. of Density.	Sq. Rt. of Density. H=1.	Refractive Power. Air=1.	
				Calculated.	Observed.
Hydrogen ...	2	1·414	1	·470	·470
Oxygen	16	4·000	2·8	1·3160	·924
Nitrogen ...	28	5·2915	3·7	1·7390	1·020
Chlorine ...	71	8·426	5·9	2·7730	2·623

* Other considerations lead us to consider that the molecule of O consists of two atoms; if this be so, we must consider O an exception.

It is impossible not to be struck with the relation which is here exhibited, especially when we remember how many influences are at work interfering with the perfect freedom of motion which is necessary for this law to be rigorously true. Numerous confirmations of this molecular theory occur when we examine tables of the refractive indices of various bodies. We extract the following passages from the article "Light" in 'Watt's Dictionary of Chemistry,' vol. iii. pp. 616-618:—

"Generally speaking, the refractive power of *any one substance* increases with its density."

"The refracting power of liquids is diminished when they are expanded by heat."

Biot and Arago "found that at pressures not exceeding that of the atmosphere, the quantity $\mu^2 - 1$, which is called the absolute refractive power, is proportional to the density of the gas."

"Dulong has shown that the refractive power of a mixture of gases is equal to the mean of those of the constituent gases calculated for the pressure to which each gas is actually subjected in the mixture."

Compare the self-evident explanation offered of these results on the molecular theory with the complicated and unsatisfactory nature of that afforded by the ether theory, even after assuming the existence and all-pervading properties of this substance.

Again, in the complicated phenomena of interference and polarization, how few are the assumptions which we have to make! No difference in elasticity of a contained medium, owing to the different molecular groupings, but these different molecular groupings themselves all-sufficient to account for the phenomena.

Colour and chemical action are also found to be very much more easily explained, when we consider the molecules of bodies to vibrate instead of the molecules of the ether.

Summing these conclusions, we have:—

a. The molecular theory makes no departure in its assumptions from the analogies observed in nature.

β. The phenomena of refraction follow as a consequence of this theory.

γ. The complicated phenomena of colour, double refraction, polarization, and interference are all explained without making assumptions which have no analogies in observed facts.

δ. Independent phenomena, especially the increase of the refractive powers of gases with the increase of their densities, support this theory.

ε. The turning of the plane of polarization by the passage

of light through various substances placed in the magnetic field follows as a consequence of the influence exerted by the magnet on the molecules of the body.

In conclusion, in the following Table is drawn up a comparative view of the explanations and assumptions made in the two theories of the various phenomena of light.

Phenomena.	Ether Theory.	Molecular Theory.
Fundamental assumption.	Light is transmitted by the vibrations of an elastic and all-pervading medium.	Light is transmitted by the vibrations of the molecules of bodies.
Refraction ...	The elasticity or density of the ether is altered by its contiguity to the molecules of the refracting body.	The molecules of different bodies move with different degrees of freedom.
Colour	The ether particles vibrate with different degrees of velocity for different colours.	The molecules vibrate more rapidly for some colours than for others.
Calorescence and fluorescence.	The impact of the <i>etherical</i> waves causes the ether in the bodies to vibrate, sometimes with greater, sometimes with less velocity than the particles of ether in these waves.	The impact of the <i>molecular</i> waves causes the molecules of the bodies to vibrate.
Radiation and absorption...	The oscillation of the molecules of the radiating body throws the particles of ether in the surrounding medium into vibration. This vibration causes the ether in the absorbing body to vibrate; and the vibration of this ether causes the molecules of the absorbing body to vibrate.	The molecules of the radiating body vibrate; this throws the molecules of the surrounding medium into vibration; and these throw the molecules of the absorbing body into vibration.
Double refraction	Owing to the different grouping of the molecules of the crystal, the elasticity or density of the ether in which these molecules are contained is altered.	The freedom of the molecules to vibrate is different in different planes, owing to the molecular constitution of the crystal.
Chemical action	The vibration of the particles of the ether in which the molecules of the body are contained shakes these molecules, so as in one case to overcome the bond of chemical union between the atoms of the molecule, in the other case to cause the atoms to combine.	The vibration of the molecules of the body causes in one case the force of chemical affinity to be suspended; in the other, it causes the force to be brought into action.