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Lord Kelvin

To cite this article: Lord Kelvin (1907) XXVIII. On the motions of ether produced by collisions of atoms or molecules containing or not containing electrions , Philosophical Magazine Series 6, 14:81, 317-324, DOI: [10.1080/14786440709463688](https://doi.org/10.1080/14786440709463688)

To link to this article: <http://dx.doi.org/10.1080/14786440709463688>



Published online: 16 Apr 2009.



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

[SIXTH SERIES.]

SEPTEMBER 1907.

XXVIII. *On the Motions of Ether produced by Collisions of Atoms or Molecules containing or not containing Electrions.*
By Lord KELVIN*.

§ 1. **B**Y atom is meant an indivisible element of ponderable (gravitational) matter, or of electricity; by molecule, an assemblage of two or more ponderable atoms, held together by mutual attractions balanced by mutual repulsions.

§ 2. In the atomic theory of electricity, electrion means an atom of resinous electricity, commonly hitherto called negative electricity. It is at present commonly assumed, and I believe in all probability rightly assumed, that all electrions are equal and similar.

§ 3. An ancient hypothesis, which has had large consideration among philosophers in all times, assumes that there is only one kind of atom, and that groups of equal and similar atoms constitute the chemical elements, with all their marvellous variety of quality. But, though no doubt some important and interesting differences of quality, such as the difference between ordinary, and red, phosphorus, are due to differences of grouping in assemblages of one kind of atom, it seems extremely improbable that differences of grouping of atoms all equal and similar suffice to explain all the different chemical and other properties of the great number of substances now commonly called chemical elements. It seems

* Communicated by the Author, having been read before Section A of the British Association, August 1, 1907.

Phil. Mag. S. 6. Vol. 14. No. 81. *Sept.* 1907.

indeed almost absolutely certain that there are many different kinds of atom, each eternally invariable in its own specific quality; and that different substances, such as gold, silver, lead, iron, copper, oxygen, nitrogen, hydrogen, consist each of them of atoms of one invariable quality; and that every-one of them is incapable of being transmuted into any other.

§ 4. The sole properties of an atom are:—(1) its mass (being the measure of the inertia of its translatory motion), (2) its law of mutual force between itself and every other gravitational or electrical atom in the universe, varying according to the distance between them. As to the mutual force between ponderable atoms, we have strong reason to believe that this law is practically the Newtonian Law of universal gravitation, for all distances exceeding the millionth of a centimetre. For distances considerably less than the millionth of a centimetre, the Newtonian Law of attraction according to the inverse square of distance merges into repulsions resulting in mutual pressure of two bodies resisting joint occupation of space. For smaller distances, we have attraction again, in the inevitable theory of Boscovich, constituting cohesions and chemical affinities.

§ 5. The assumption, that the mutual force between two atoms depends merely on the distance between their centres, implies that each atom is utterly isotropic. An ælotropic atom, that is to say, an atom having different attractive and repulsive forces in different directions, is conceivable: and may possibly come in future to have a place in atomic theory. Hitherto it has been universally assumed that every atom, whether gravitational or electrical, is thoroughly isotropic, and I do not propose at present to enter upon any theoretical consideration of ælotropic atoms.

§ 6. I do not propose to enter on any atomic theory of ether. It seems to me indeed most probable that in reality ether is structureless; which means that every portion of ether however small has the same elastic properties as any portion however great. There is no difficulty in this conception of an utterly homogeneous elastic solid, occupying the whole of space from infinity to infinity in every direction. We sometimes hear the “luminiferous ether” spoken of as a fluid. More than thirty years ago I abandoned, for reasons which seem to me thoroughly cogent, the idea that ether is a fluid presenting appearances of elasticity due to motion, as in collisions between Helmholtz vortex rings. Abandoning this idea, we are driven to the conclusion that ether is an elastic solid, capable of equi-voluminal waves in which the motive force is elastic resistance against change of shape.

§ 7. We now meet the question :—Is ether incompressible? We should be compelled to answer—Yes, it is incompressible, if it is subject to the law of universal gravitation. But, presently, when we try to account for motion produced in ether, by ponderable or electrical atoms moving through it, we shall feel ourselves persuaded that ether is compressible*. Believing this, we are forced to believe that it is non-gravitational. Thus we find ourselves settled in the conviction that ether is compressible, and that ether experiences no gravitational forces between its parts.

§ 8. Suppose now that an atom, whether ponderable or electrical, disturbs ether solely by attracting it or repelling it with a force varying according to distance; and that, with no other mutual influence than this, the atom and the ether jointly occupy the same space. If ether were incompressible, this attraction or repulsion would be utterly ineffective. The atom would move through the space occupied by the ether, without giving any motion to the ether, and without itself experiencing any influence of force due to the ether. Hence, in order that atoms may take energy from motions of ether, and that ether may take energy from motions of matter, we must suppose the ether to be compressible and dilatable; and to be compressed, or to be dilated, or compressed at some distances, and dilated at other distances, in virtue of the force exerted on it by the atom.

§ 9. While assuming ether to be compressible, we suppose its resistance to compression (positive or negative) to be so very great that the velocity of condensational-rarefactional waves in pure ether is practically infinite, and that the energy of whatever of such waves may be produced by collisions of atoms or electrions is practically *nil* in comparison with the energy of the equi-voluminal waves, constituting radiant heat and light, which are actually produced by these collisions. It is only under the *enormous* forces of attraction or repulsion exerted by atoms on ether that augmentation or diminution of its density is practically influential.

§ 10. By purely dynamical reasoning, it may be proved to follow from the hypotheses of §§ 4, 6, 8, and 9, that an atom, (supposed for a moment to be infinitely small,) kept moving through ether at any velocity, q , greater than v , the velocity of light, produces no disturbance in the ether in front of a cone having its vertex at the atom and semi-vertical angle equal to $\sin^{-1} \frac{v}{q}$ †; but that the moving atom produces, in its

* 'Baltimore Lectures,' Appendix A; Appendix B, § 3.

† 'Baltimore Lectures,' Appendix B, §§ 6, 7.

rear, wholly within the cone, an ever growing disturbance of ether, and therefore requires the application of a continual pull forward to keep it moving uniformly at any constant velocity exceeding the velocity of light. In 1888, Oliver Heaviside* arrived at a corresponding conclusion by purely mathematical work, from Maxwell's electromagnetic formulas, without any dynamical foundation: and in 1897†, still without assuming any dynamical or chemical properties of ether and atoms, he corrected an erroneous hypothesis, that no force however great could give an atom a velocity equal to the velocity of light, which has been somewhat extensively adopted within the last ten years in speculations and reckonings regarding radioactivity.

§ 11. Purely dynamical reasoning‡ on our physical assumptions of §§ 4, 6, 8, and 9, teaches us further that:—

(a) No force is required to keep an atom moving uniformly through ether, at any velocity less than the velocity of light.

(b) To start an atom suddenly into motion from rest, causes a spherical pulse to travel outwards with the velocity of light, from the place in which the atom was when it was receiving the supposed velocity.

(c) The magnitude of this spherical pulse is a maximum in the plane through the centre perpendicular to the line of motion, and is zero at the two points in which the spherical surface is cut by that line§.

(d) This spherical pulse carries outwards through infinite space a finite quantity of energy, l , due to a part of the work, w , done by the force which was applied to the atom to start it in motion. The sharper the suddenness of the stopping, the greater is l .

(e) If at any time a resisting force suddenly stops the atom, work is done on the ether, in virtue of which another pulse carries away an amount of energy, l' ; and work is done on the stopping agent amounting to $w - l - l'$.

(f) If the suddenness of the stopping is equal and similar to the suddenness of the starting, the second pulse is equal and similar to the first, and l' is equal to l .

§ 12. To understand clearly the meaning of (e), take an example. Let three equal and similar ideal non-electric atoms, A, B, C, be given in a straight line; B at rest, A moving with velocity q towards B, and C moving towards B in the contrary direction with a velocity just great enough that B is

* Heaviside's 'Electrical Papers,' vol. ii. pp. 494, 516.

† Heaviside's 'Electromagnetic Theory,' vol. ii., Appendix G.

‡ 'Baltimore Lectures,' Appendix B, §§ 4...7.

§ 'Baltimore Lectures,' Lec. viii., p. 88; Lec. xiv., p. 197.

left at rest after its collision with C. The initial distances must be such that the collision between A and B precedes the collision between B and C. Amounts of energy equal to l and l' are carried away into infinite space in the pulses produced by the two collisions. In the arrangement now described, the suddennesses of the starting and stopping of B are not precisely equal and similar; and, because of their difference, l' might generally be somewhat less than l ; but the law of force between the atoms might be such as to render l' equal to, or greater than, l , for certain ranges of values of q .

Take an analogous case of collisions between three ideal billiard balls, each perfectly elastic. The clicks of A on B, and of B on C, cause losses of energy, l and l' , to be carried off through air by sound-waves.

§ 13. Consider now the collisions in a non-electrified monatomic gas, that is to say, an assemblage of single atoms, each having within it its neutralizing quantum of electrions; except a small proportion, from or to which electrions may have been temporarily taken or given. For simplicity we shall first take the case in which a single electrion is the electric neutralizing quantum for each ponderable atom. The collisions will keep the electrions continually in a state of vibration within the atoms; except, in the comparatively rare case of an electrion being knocked out of an atom, or in the infinitely rare case of the relative motion of an atom and electrion being reduced exactly to zero, by a collision.

§ 14. The law of force between the electrion and atom may be such that the centre of the atom is the only position of stable equilibrium for an electrion within it.

§ 15. Or the law of force may be such that there are any number, i , of concentric spherical surfaces within the atom, on each of which an electrion may rest in equilibrium radially stable; and others, on each of which an electrion would be in equilibrium radially unstable*. In the statistical average of collisions, the electrion may, immediately after a particular collision, be ranging, in non-sinusoidal vibration, across several spherical surfaces of stable and unstable equilibrium, and losing energy by sending out irregularly reciprocating waves through ether. Before the next collision, the electrion may probably have settled down into very approximately sinusoidal vibrations in and out across any one of the surfaces of radial stability.

§ 16. This last condition we may suppose to be generally prevalent during the greater part of the free path between

* "Plan of an Atom to be capable of storing an Electrion with Enormous Energy for Radio-activity," by Lord Kelvin, *Phil. Mag.* Dec. 1905.

successive collisions. We may indeed suppose it to be more frequently the immediate result of a collision than the wilder vibration described in § 15, which, however, must undoubtedly be an occasional, though probably a rare, condition immediately after a collision.

§ 17. We are not bound to assume that a single electrion is the saturating quantum of any particular ponderable atom: nor are we bound to suppose that it is electrically neutralized by any integral number of electrions*. The most general supposition we can make is that, with j electrions to each atom, the atom and electrions act externally as a vitreously electrified body, and, with $j+1$ electrions, the atom and electrions act as a resinously electrified body.

§ 18. It seems to me indeed exceedingly probable that the persistence of the two-atom molecule in the common diatomic gases, O_2 , N_2 , H_2 , Cl_2 , is due to the impossibility of electrically neutralizing the ponderable atom by any integral number of electrions. Suppose for example that one electrion suffices to electrically neutralize two atoms of Nitrogen. A monatomic Nitrogen gas (N), if non-electrified as a whole, would have half of its atoms without electrions, and therefore vitreously electric, with electric quantity equal and opposite to half that of a single electrion. Each of the other half of its whole number of atoms would have one electrion within it, and therefore its external action would be resinous, with half the potency of a single electrion. Thus there would be a strong electric attraction between the atoms destitute of electrions and the atoms each containing one electrion, within it. This attraction would tend to bring the atoms together in pairs, N_2 , each pair containing one electrion, of which one position of equilibrium would be at the middle of the line joining the centres of the two ponderable atoms. It seems quite probable that this is the real condition of ponderable atoms and electrions, in the ordinary diatomic gases.

§ 19. The dissociation of a considerable number of such pairs of atoms would be exactly the "ionization" by which, following Schuster's and J. J. Thomson's theory of the conduction of electricity through gases, the latest developed theories of radio-activity explain the specially induced electric conductivity of diatomic gases, such as Lenard found to be produced in air by ultra-violet light traversing it, and Becquerel found in air all round an apparently inert piece of metallic Uranium, or a Uranium salt.

§ 20. But, to give electric conductivity to a monatomic gas,

* "Aepinus Atomized," §§ 5, 6; Baltimore Lectures, Appendix E.

the "ionization" could not be anything else than dissociation of electrions from ponderable atoms. This kind of dissociation might be produced in a very hot gas by mere impacts between the atoms of the gas itself, with the large translational velocities to which high temperatures are due. Or it might be produced by extraneous bodies, such as the " α " or " β " particles shot out with high velocities from radioactive substances. We are now however chiefly concerned with the motions of ether produced by collisions of atoms, in circumstances less abnormal than those in which dissociations and recombinations are largely influential.

§ 21. The pulses described in §§ 11, 12, as due merely to mutual collisions between ponderable atoms (without consideration of electrions whether present or not), constitute a kind of motion in the ether, which, if intense enough to produce visible light, would, when analysed by the spectroscope, show a continuous spectrum without the bright lines, which, when seen, prove the existence of long-continued trains of sinusoidal vibrations of particles of ether, in the eye perceiving them, and therefore also in the source, and in all the ether between the source and the eye. On the other hand, the vibrations of electrions referred to in § 13 would, if intense enough, produce bright lines in the spectrum.

§ 22. There is another kind of vibration in the source, which might produce, and which probably does produce, bright lines in the spectrum. If there are two or more ponderable atoms in the molecule of a glowing gas, not dissociated by the violence of the collisions, each atom of the molecule must have a vibratory motion, of which an isolated ponderable atom is incapable; and these vibratory motions of the atoms of a group must give rise to bright lines in the spectrum, when the frequency of the vibrations in any one, or in all, of the vibrating modes, is between four hundred million million and eight hundred million million per second, if we take this as the range of frequencies for visible light.

§ 23. The spectroscopic phenomena to be accounted for in a dynamical theory of light include continuous spectrums, with large numbers of bright lines superimposed on the more or less bright background of continuous spectrum. Even when every care has been taken, in artificial sources of light, to eliminate influence of more than one of the substances commonly called chemical elements, the number of bright lines is generally very large: indeed we are not sure that we have been able to count the whole number of those which are presumably due to any single element.

§ 24. In a glowing monatomic gas, with just one electrion

to each atom, and only the central position of stable equilibrium for the electrion in the atom, there could be only one bright line in the spectrum. But in reality, every one of the known monatomic gases, Mercury vapour, Argon, Helium, Neon, Krypton, Xenon, gives a highly complicated spectrum with a large number of bright lines. We infer; that, if there is just one electrion to each atom, it has many positions of stable equilibrium; or that there are many electrions, with only the central position of equilibrium for one of them alone; or that there are several electrions, and several stable positions for one of them alone in the atom.

§ 25. It seems as if only on the third supposition—several electrions and several positions of stable equilibrium—we can imagine the great number of bright lines, and the great complexity of their arrangement in the spectrums of the monatomic gases.

§ 26. But we can feel little satisfaction in this, or any other, attempt to discover details of dynamical theory, unless it gives some reasonably acceptable explanation of the laws of arrangement of trains of bright lines in the spectrums of different chemical elements, which have been experimentally discovered by Runge, Kayser, Rydberg, Schuster, and others.

XXIX. *The Unit-Stere Theory: The Demonstration of a Natural Relation between the Volumes of the Atoms in Compounds under Corresponding Conditions and that of Combined Hydrogen.* By GERVAISE LE BAS, B.Sc.*

I.

THE RELATIVE VOLUMES OF CARBON AND HYDROGEN IN THE LIQUID NORMAL PARAFFINS C_nH_{2n+2} UNDER CORRESPONDING CONDITIONS.

THE author has shown (Trans. Chem. Soc. 1907, xci. p. 112) that, in the liquid normal hydrocarbons from undecane $C_{11}H_{24}$ to pentatriacontane $C_{35}H_{72}$ at the melting-point, carbon has a volume almost exactly four times that of combined hydrogen. This ratio is similar to the one existing between the fundamental valency numbers of the above atoms. It thus follows that the molecular volumes of the paraffins in question are, at the melting-point, proportional to their respective valency numbers. These facts are regarded as evidence in favour of the view that valency is a volume property.

* Communicated by Prof. W. J. Pope, F.R.S.