# The Kinetic Atom.[1]

By Sir OLIVER LODGE, F.R.S.

## EVIDENCE FOR THE NUCLEAR ATOM.

THE steps by which the nuclear atom was established are of such interest that it is worth while to remind ourselves of them. Rutherford was bombarding atoms by the alpha particles projected with known velocities from a deposit of radium C. He has carried out such bombardment many times since, sometimes with surprising and exciting results. But this time he was merely driving the particles through matter and catching them on a fluorescent screen, so as to see how many had been scattered or deflected from their original path, and by how much. If the atoms consisted of a nucleus surrounded by electrons, at planetary distances in proportion to their size, the atom would be as porous as a solar system, and the alpha particles could be trusted to go through it, for the most part, without perceptible perturbation. Some of the electrons might be knocked out, and so the atom become ionised; but the massive alpha particle would take scarcely any notice of minor obstructions, and would proceed untroubled on its way, until it encountered or came exceedingly close to a central nucleus, of mass greater than itself. Such an occurrence would be comparatively rare. Judging by the probable size of the nucleus on this theory, it would not occur more often than 1 in 10,000 times—probably not so often.

The circumstances of such an encounter, whenever it did occur, are amenable to ordinary and, so to speak, elementary dynamical considerations, if the law of inverse square holds good. Accordingly, it was possible to deduce beforehand what would happen in all the likely kinds of collisions—if they can be called collisions where there is no contact. The law of probability could be applied to determine the number of scatterings in each direction; and then, by the aid of Crookes's fluorescent zinc sulphide screen, on which the splashes or flashes caused by the impact of the deflected alpha particles could be seen, the number scattered in any direction by the atoms of a given substance could be counted and compared with theory. The result was triumphantly to uphold the theory. The central solid compact nucleus was established as a reality, and a proof was forthcoming that it exerted force, even in its immediate neighbourhood, as the inverse square of the distance;—the first time, so far as I know, that it was ever established that astronomical laws still hold good, even in the hopelessly ultra-microscopic region in the interior of atoms.

The quantum is there too, as Bohr afterwards showed. There are energy levels, surrounding the nucleus of atoms, which gravitation-like theory does not account for; though it must be admitted that in the solar system Bode's Law has not yet been accounted for either. But ordinary dynamical laws are there also. The quantum does not replace them, but supplements them, as Bohr found in his Correspondence Principle, and as Sommerfeld made use of in his brilliant prediction of the fine structure of spectrum lines. This fine structure, by the way, is too fine to be seen in ordinary visible spectra; but it can be seen well enough in X-ray spectra, where the theory clearly indicates that it ought to be much more pronounced and conspicuous. The treatment of that, however, must be postponed. I want to return to the simple dynamics of Rutherford's scattering experiment.

The problem may be stated thus. Take a massive particle with charge $E$—really equal to $Ne$, where $N$ is Moseley's atomic number; and fire at it, with known velocity $v$, a much less massive particle with a charge $E'$—really $2e$. Consider what happens.

First let the line of fire be absolutely direct. The projectile will approach within a distance $2a$ (Fig. 1), and at that distance (SJ) will rebound and return whence it came. The distance $2a$, which we may call "the stopping distance," is important; for it gives the major axis of all the hyperbolic paths which are the result of a less direct impact between the same particles. The bipolar equation of every one of these hyperbolæ will be

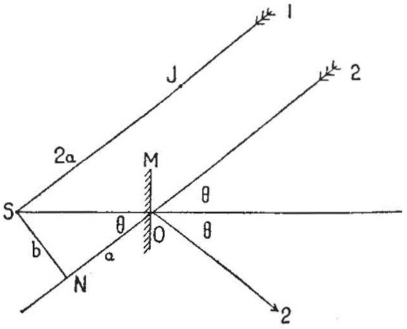

FIG. 1.—Let S be a massive nucleus fired at by an alpha particle, No. 1, correctly aimed. Let SJ be the stopping distance, $EE'/\frac{1}{2}mv^2$, at which the particle will be stopped and driven back. Call this $2a$. Then let a second particle be aimed askew, at a perpendicular distance SN from the nucleus. Call this distance $b$. Then lay off a length NO $= a$ along the line of fire, and join SO. If now a diagrammatic mirror M is set up perpendicular to SO, as shown, the particle No. 2 will appear to rebound from S exactly as if it had struck this mirror M. The angle of reflection is $\theta$, such that $\tan\theta = b/a$. The path is swung round through the angle $\pi - 2\theta$.

$$r_1 - r_2 = 2a.$$

The value of $2a$ can be calculated at once as

$$2a = \frac{EE'}{\frac{1}{2}mv^2};$$

for that is the distance at which the kinetic energy of approach will be converted into the potential energy of recoil, and so the bombarding projectile will there be brought momentarily to rest before being driven back to its source.

In practice, absolute direct impact or accurate aim is infinitely unlikely. Let us take the case then of slightly oblique aim, so that the line of fire approaches the nucleus within a perpendicular distance $b$. The path will now be a hyperbola, with the above value of $a$ for its semi-axis major, and with $b$ for its semi-axis minor. The equation to the hyperbola being, as stated, $r_1 - r_2 = 2a$, its eccentricity is $\sqrt{(1 - b^2/a^2)}$, or what we may call $\sec\theta$. The asymptotic path of the particle will be swung round through an

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[1] An expository portion of a presidential address on "X-Rays and the Atom," of which other parts were delivered to the Röntgen Society on November 6.

angle $\pi - 2\theta$, where $\tan \theta = b/a$. In other words the particle will be reflected as if it had struck a mirror in a certain position and with a certain inclination (which can be best depicted in a diagram), and as if it had rebounded from it according to the usual law of reflection (Fig. 1).

Of course, it does not really strike anything: there is no clash or blow of any kind. The path is a perfectly regular curve, as shown in Fig. 2. But all the appearance as seen from a distance, or as estimated from the result, will be as if it had been suddenly reflected, from the mirror M, according to the exact geometrical conditions of Fig. 1.

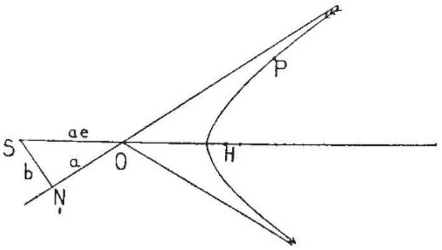

FIG. 2.—The particle in Fig. 1 does not really strike anything, and its path only appears to be straight and angular when seen from a distance. If we could approach close to, we should see the actual path curved, as in this Fig. The real path of the particle is one branch of a hyperbola with major axis $2a$ and minor axis $2b$, with the two foci S and H, and with its centre O equidistant between them. The distance from O to the vertex of the hyperbola is $a$, while its eccentricity is $e = SO/NO = \sec \theta$. Also $SH = 2ae$. Taking any point P on the path of the particle, its equation is $SP - HP = 2a$. If the particle were attracted instead of repelled by the nucleus, the path would be the same, but the nucleus would be at H instead of at S.

If we consider the projectile as having a sign of electric charge opposite to that of the central nucleus, so that it is attracted instead of repelled, then the circumstances will be very similar. There will still be the appearance of reflection, as in a mirror; the angle turned through will be just the same for the same line of aim; and the same hyperbolic path will be described; but the central attracting particle will be in the other focus. H instead of S.

The accompanying figures, 1 and 2, give a good idea of what a "collision" between charged particles is really like when the inverse square law is obeyed.

In these bombardment experiments, it would appear as if the quantum does not enter. One can scarcely suppose that the line of aim is regulated by quantum conditions, so that the perpendicular distance $b$ for different shots is in arithmetical progression. If, however, we did make such a supposition, we should then have a series of quantised hyperbolic orbits, all with the same major axis $2a$ and the different minor axes $2b$, which are quite analogous with the family of quantised elliptic orbits, in the recognised theory of Sommerfeld and others.

### VARIETIES OF POSSIBLE ORBITS.

As every one knows, Kepler discovered that in a planetary orbit the rate of sweeping areas is constant, and that this gives the law of velocity of a planet at every part of its orbit. Newton showed that this was a necessary characteristic of all central orbits, no matter what the law of force was. The moment of momentum, or angular momentum, is constant, the moment of acceleration being zero. Bohr made the assumption—and justified it by results, after the manner of Kepler—that this rate of sweeping areas, admittedly constant for any one orbit, must proceed by definite integer multiples from orbit to orbit, and that only those orbits were stable for which the rate of sweeping areas was characterised by an integer. These, therefore, represent Bohr's energy levels. The most natural kind of orbit to associate with an energy level is circular: and what we have just said means that $vr$ proceeds by steps like the integer $n$. Ordinary mechanics show that $v^2r$ is equal to a known constant independent of $n$; and from these two very simple equations a great many things follow.

In general, we may expect that different orbits will correspond to different energy levels; and that is so in the main. But it is possible to have different orbits at one and the same energy level, in the form of a set of ellipses with all their major axes the same. Their periods of revolution will also be the same, since this depends on the major axis. The rate of sweeping areas will be the area of any orbit divided by its periodic time: and since the periods are all equal, the rate of sweeping areas (or the moment of momentum) will be proportional to the area of each orbit. If, then, this has to proceed by integers, in accordance with the quantum, the minor axes of the only possible elliptic orbits are certain definite fractions of the major axis. Thus, suppose the major axis is 4, the minor axis might be either 3, 2, or 1. If the major axis is 6, the minor axis can be 5, 4, 3, 2, or 1. If the major axis is 3, the minor could be naturally 2 or 1. If the major axis is 2, there is only one alternative possible, namely, 1; and if the major axis is 1, no other orbit except a circular one is possible. The number applied to the major axis corresponds to the number of the stable circular orbits surrounding the nucleus in Bohr's theory; $K$ being No. 1, $L$, No. 2, and so on; their radii being proportional to $n^2$. These represent the primary or fundamental energy levels; but at all the higher levels elliptic orbits are permissible too. The permissible orbits for main orbit No. 3 are shown in Fig. 3.

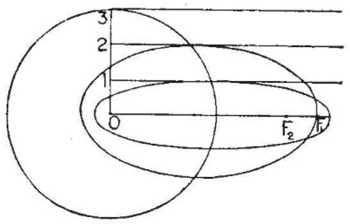

FIG. 3.—To draw the varieties of orbit possible at a given energy level. Let the energy levels $K$, $L$, $M$, $N$, etc., be called 1, 2, 3, 4, etc. Connect two pins by a single length of string: put the two pins together at O, and with the loop draw a circle. Subdivide its radius into sections equal to the particular number of the energy level to be represented—say 3, as in this Fig.; and draw parellel lines at these points perpendicular to the radius selected. Then, after replacing the string and pencil, separate the pins along the line through O, until the pencil in the loop of string is brought down first to one and then to another of these lines, and each time draw an ellipse. These will be the varieties of possible orbits at the M level; and they are in their right position, with O as common focus. Electrons describing any of these orbits have all the same period, and the same energy except for a cumulative perturbation due to fluctuating speed; but their angular momenta are, like the elliptic areas, as 3 : 2 : 1. A similar construction serves for any level.

### EFFECT OF ELLIPTICITY ON THE SPECTRUM.

These alternative elliptic orbits, being in the main at the same energy level as the circular one of which they are variations, will be responsible for the same spectral lines as the circular one, when electrons drop into them. If this were accurately so, they would not be worthy of attention; but it is not accurately so. The electrical theory of matter, and the consequent variation of inertia at high speeds, necessitates further analysis. The speed in a circular orbit is constant; but is not so in an elliptic orbit. Hence the mass in an elliptic orbit is not constant either. The result can be shown, astronomically, to be a cumulative progression of the apses: that is to say, a revolution of the orbit in its own plane,—like that which has long been familiar in the planets, especially in the planet Mercury[2]—the particle describing a kind of rosette instead of a really closed curve. This progressive elliptic motion can be compounded of two opposite circular motions of nearly but not quite the same period, and nearly but not quite the same energy; accordingly it has the effect of doubling the line which would otherwise be emitted. That is its main effect. Other perturbations are possible too, which will give multiple lines—what is called the fine structure of the spectrum—all which has been worked out in detail by Sommerfeld, and found to agree with observation; though the observations in the visible part of the spectrum are very difficult and delicate, and some of them quite recent.

With X-ray frequencies, these effects are more marked; and it is in the X-ray spectrum that they were first discovered. The fact that they can be accounted for in accordance with astronomical laws, supplemented by the electrical theory of matter, is surely a remarkable testimony to the general validity of what may be called the astronomical theory of the atom.

They strengthen the position of the kinetic atom of the physicist, as against the static atom of the chemist, beyond any reasonable doubt: though for chemical purposes and molecule-building, the static atom is certainly attractive, and, I expect, useful.

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[2] See, for example, *Phil. Mag.* for August 1917, *et seq.* If $m = \beta m_0$ a revolution through $2\pi\beta$ is needed for a journey from one perihelion to the next.

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## The Scientific Renaissance in China.

By Prof. J. W. GREGORY, F.R.S.

THE political changes in China during the last decade have had two opposite effects on the intellectual sides of Chinese life. The Revolution of 1911 gave a powerful stimulus which enabled the intellectual aristocracy to revolt successfully against the domination of tradition, and to advance a scheme of education free from the chains of classicism; but the concurrent political disorder has led to a reactionist triumph in administration. The reform in education which was regarded in 1911 as of primary importance was the replacement of the old written language by one based on an alphabet. The debt China owes to its written characters is incalculable. They have formed the real bond between the many provinces and races of the Empire, and long training in their use has given the Chinese their precision in observation, tenacious memories, and fine artistic perception. These great benefits have been attended by serious drawbacks. Learning the characters practically monopolises all school time. Each character has to be learnt by a distinct effort of memory. A child learns in the four years in the lower primary classes 700 or 1000 characters and a little arithmetic; and if it leaves school with a knowledge of only that number, it in time falls into the ranks of the illiterate. Knowledge of 4000 characters is required for general purposes, and a well-educated man is expected to know 8000 or 10,000. Hence the seven years spent at the lower and higher primary schools, and most of the subsequent four years at a secondary school, are occupied in learning to read and write.

There have accordingly been repeated attempts during the past 2200 years to replace the ideographic by an alphabetic system; but they have failed owing to the inherent advantages of the old system. The primary difficulty is that while the written characters are the same throughout China, the meaning of the words alters with the tone of expression, and the pronunciation varies from province to province. A phonetic rendering of a given character would mean different things in different localities. A uniform alphabetic system is possible only if the same pronunciation be adopted in all parts of China. The first step is therefore the establishment of a standard pronunciation for the whole country. Such a system having been prepared and enacted, the second step is the invention of a set of phonetic alphabetic characters. A Commission for the Unification of the National Language adopted an alphabet of 39 letters, and the teaching of its system was begun experimentally in 1915. In 1918 the scheme was regarded as satisfactory, and it was introduced into the schools. The 39 letters having proved insufficient, another was added in 1920, and in addition to the established 40, others will be required for some dialects, such as Cantonese, which are exceptionally rich in sounds.

This system would give China a unified colloquial language which people could learn to read in a few months instead of requiring a decade of daily toil; it would enable the schools and colleges to give a liberal and scientific education, and would render possible the development of a living literature. The reformers hope that this system will be established throughout China in twenty years.

Concomitant with this reform, a new system of Chinese popular and higher education was promulgated in 1912 by a National Education Conference. This system consists of a universal compulsory course for four years; a higher primary course of three years; a secondary school course of four years; a preparatory course for the colleges of three years; and, finally, three years in colleges or professional institutions for pupils of the ages of 21-24. The scheme included four national universities—Pekin for the north-east, Nanking for the middle east, Wuchang for the north-west, and Canton for the south and south-west. Each of these universities was intended to have faculties in literature, science, medicine, law, commerce, agriculture, and industry.

These noble schemes have been to a large extent frustrated by the political disorders that followed the Revolution. After the collapse of the Manchu Government, the local military leaders seized the reins of power and the revenues. The old officials, who had been selected by severe competitive examination, were replaced by nominees of the military. A riot of corruption and inefficiency has ruined the provincial govern-