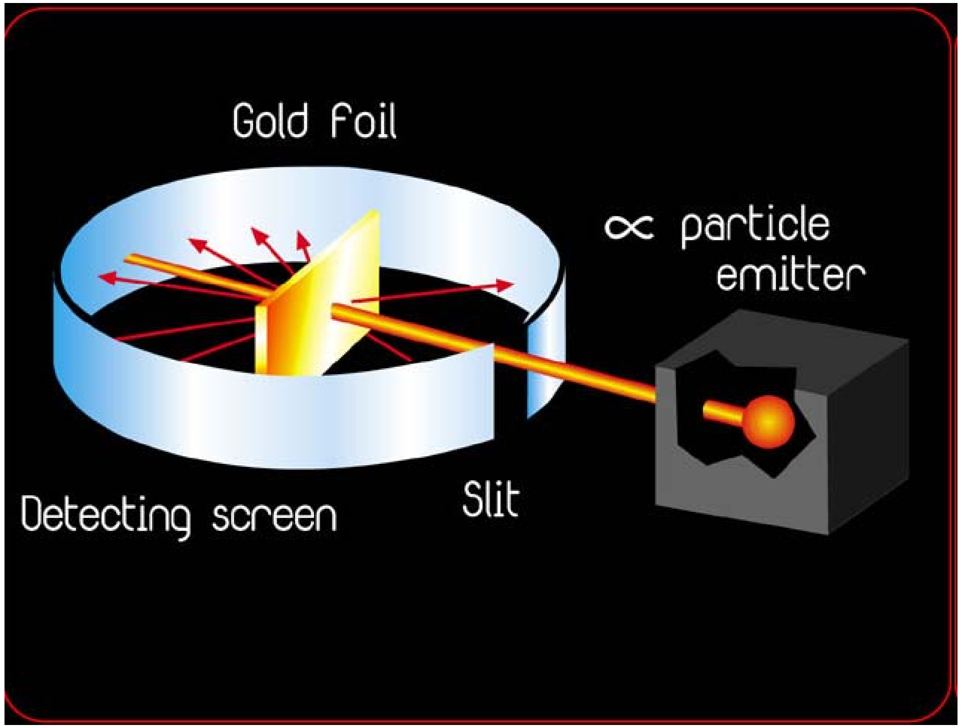
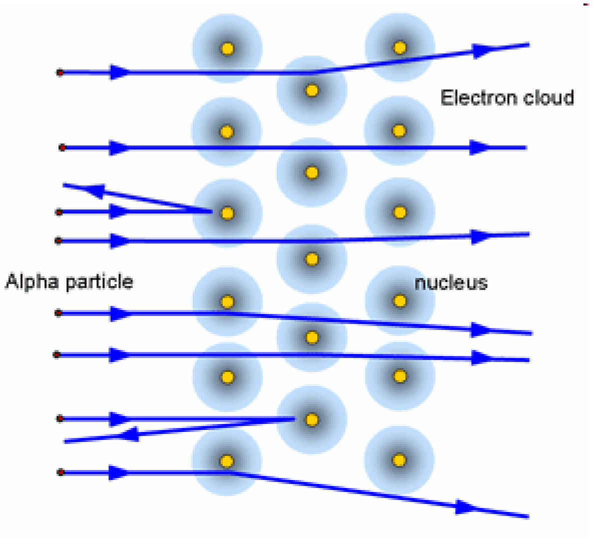
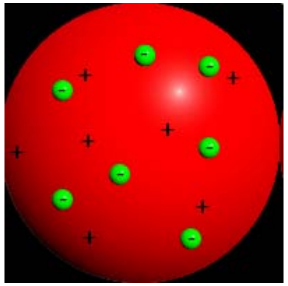
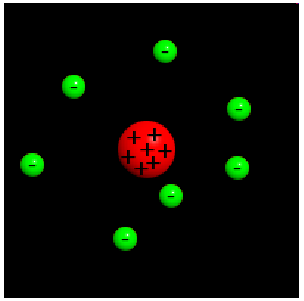
Rutherford-Streuung



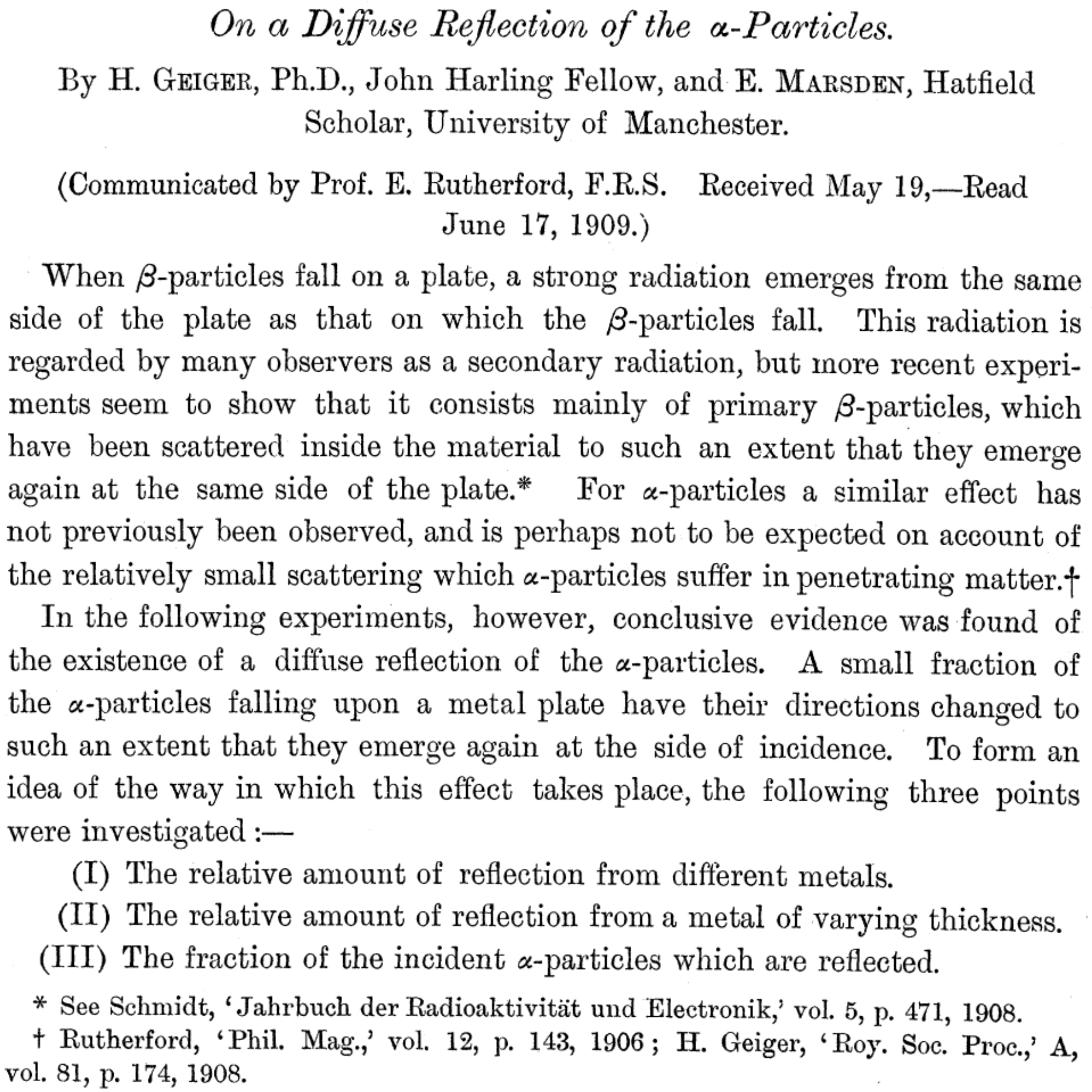




JJ Thomsen vs E Rutherford



Proc. R. Soc. Lond. A 1909 **82**, 495-500



On a Diffuse Reflection of the α-Particles.

By H. GEIGER, Ph.D., John Harling Fellow, and E. MARSDEN, Hatfield
Scholar, University of Manchester.

(Communicated by Prof. E. Rutherford, F.R.S. Received May 19,—Read
June 17, 1909.)

When β-particles fall on a plate, a strong radiation emerges from the same side of the plate as that on which the β-particles fall. This radiation is regarded by many observers as a secondary radiation, but more recent experiments seem to show that it consists mainly of primary β-particles, which have been scattered inside the material to such an extent that they emerge again at the same side of the plate.[*] For α-particles a similar effect has not previously been observed, and is perhaps not to be expected on account of the relatively small scattering which α-particles suffer in penetrating matter.[†]

In the following experiments, however, conclusive evidence was found of the existence of a diffuse reflection of the α-particles. A small fraction of the α-particles falling upon a metal plate have their directions changed to such an extent that they emerge again at the side of incidence. To form an idea of the way in which this effect takes place, the following three points were investigated :—

(I) The relative amount of reflection from different metals.
(II) The relative amount of reflection from a metal of varying thickness.
(III) The fraction of the incident α-particles which are reflected.

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[*] See Schmidt, 'Jahrbuch der Radioaktivität und Electronik,' vol. 5, p. 471, 1908.

[†] Rutherford, 'Phil. Mag.,' vol. 12, p. 143, 1906; H. Geiger, 'Roy. Soc. Proc.,' A, vol. 81, p. 174, 1908.

Hans Geiger
1882-1945

Link:

http://dx.doi.org/10.1098%2Frspa.1909.0054

For the observation of the reflected particles the scintillation method was used in all experiments. With regard to the details of the method we refer to the papers of Regener* and of Rutherford and Geiger.†

On account of the fact that the amount of reflection is very small, it was necessary to use a very intense source of α-rays. A tube was employed similar to that which has been proved to be a suitable source in the scattering experiments of one of us.‡ This source consisted of a glass tube AB (fig. 1), drawn down conically and filled with radium emanation, the end B of the tube being closed airtight by means of a mica window. The thickness of the mica was equivalent to about 1 cm. of air, so that the α-particles could easily pass through it.

Since it is of importance that the gas pressure inside this tube should be as low as possible, the emanation was purified according to the methods developed by Prof. Rutherford.§ The tube contained an amount of emanation equivalent to about 20 milligrammes RaBr$_2$ at a pressure of a few centimetres. The number of α-particles expelled per second through the window was, therefore, very great, and, on account of the small pressure inside the tube, the different ranges of the α-particles from the three products (*i.e.* emanation, RaA, and RaC) were sharply defined.

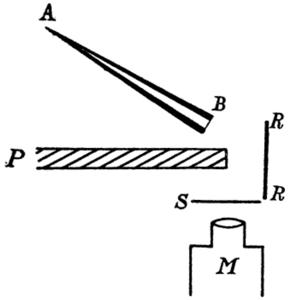

Fig. 1.

The zinc sulphide screen S (fig. 1) was fixed behind the lead plate P, in such a position that no α-particles could strike it directly. When a reflector

AB: Quelle der α-Strahlen
RR: Metallfolie (Target)
S: Scintillationsdetektor (Zinksulfid)
M: Mikroskop
P: Bleischirm

ciable difference was found for different angles. This is due to the fact that,

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* 'Verh. d. D. Phys. Ges.,' vol. 10, p. 78, 1908.

† 'Roy. Soc. Proc.,' A, vol. 81, p. 141, 1908.

‡ Geiger, 'Roy. Soc. Proc.,' A, vol. 81, p. 174, 1908.

§ 'Phil. Mag.,' August, p. 300, 1908.

owing to the necessity of having the tube very near to the reflector, the angle of incidence varied very much. An investigation of the variation of the effect with the angles of incidence and emergence would necessitate a parallel and very intense source of homogeneous α-rays, which can, however, not easily be realised.

In the following table the number of scintillations observed per minute are given in column 3; in column 4 the ratio to the atomic weight is calculated, and it can be seen that this ratio decreases with decreasing atomic weight. The case of lead appears to be an exception which may be due to slight impurities in the lead.

1. Metal.	2. Atomic weight, A.	3. Number of scintillations per minute, Z.	4. A/Z.
Lead	207	62	30
Gold	197	67	34
Platinum	195	63	33
Tin	119	34	28
Silver	108	27	25
Copper	64	14·5	23
Iron	56	10·2	18·5
Aluminium	27	3·4	12·5

Even in the absence of any reflector about one scintillation per minute was observed. It was easy to show that this was due to a reflection from the air through which the α-particles passed. The numbers on the table are corrected for this effect.

It is interesting to note here that for β-particles the number of reflected particles also decreases with the atomic weight of the reflector.* But while for β-particles the number reflected from gold is only about twice as great as for aluminium, for α-particles the same ratio amounts to about twenty.

(II) We have already pointed out that the diffuse reflection of the α-particles is a consequence of their scattering. According to this point of view, the number of particles reflected must vary with the thickness of the reflecting screen. Since gold can be obtained in very thin and uniform foils, different numbers of these foils were used as reflectors. Each foil was equivalent in stopping power to about 0·4 mm. of air. It was necessary to mount the foils on glass plates, but the number reflected from the glass itself was found to be very small compared even with the number from one gold foil. The curve, fig. 2, gives the result of the measurements.

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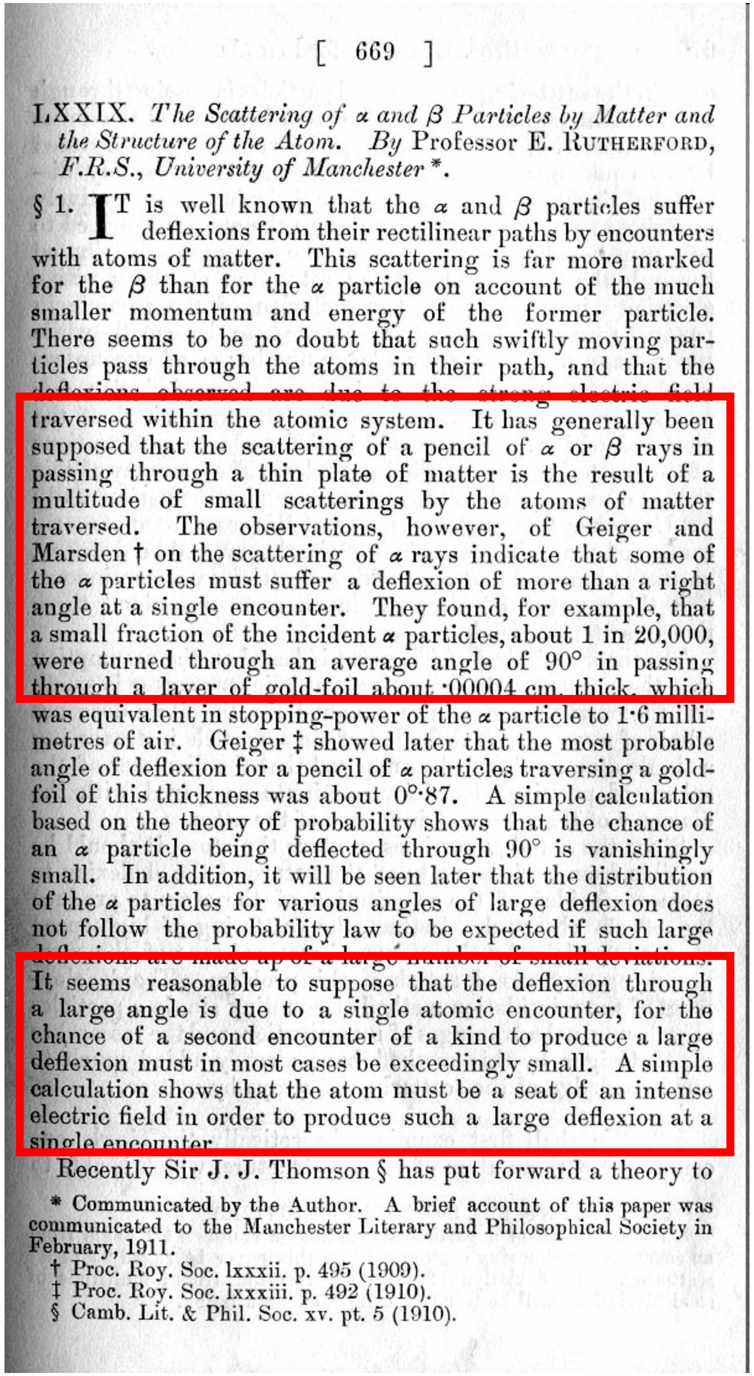
* McClelland, 'Dublin Trans.,' vol. 9, p. 9, 1906.



[669]

LXXIX. *The Scattering of α and β Particles by Matter and the Structure of the Atom.* By Professor E. Rutherford, *F.R.S., University of Manchester* *.

§ 1. It is well known that the α and β particles suffer deflexions from their rectilinear paths by encounters with atoms of matter. This scattering is far more marked for the β than for the α particle on account of the much smaller momentum and energy of the former particle. There seems to be no doubt that such swiftly moving particles pass through the atoms in their path, and that the deflexions observed are due to the strong electric field traversed within the atomic system. It has generally been supposed that the scattering of a pencil of α or β rays in passing through a thin plate of matter is the result of a multitude of small scatterings by the atoms of matter traversed. The observations, however, of Geiger and Marsden † on the scattering of α rays indicate that some of the α particles must suffer a deflexion of more than a right angle at a single encounter. They found, for example, that a small fraction of the incident α particles, about 1 in 20,000, were turned through an average angle of 90° in passing through a layer of gold-foil about ·00004 cm. thick, which was equivalent in stopping-power of the α particle to 1·6 millimetres of air. Geiger ‡ showed later that the most probable angle of deflexion for a pencil of α particles traversing a gold-foil of this thickness was about 0°·87. A simple calculation based on the theory of probability shows that the chance of an α particle being deflected through 90° is vanishingly small. In addition, it will be seen later that the distribution of the α particles for various angles of large deflexion does not follow the probability law to be expected if such large deflexions are made up of a large number of small deviations. It seems reasonable to suppose that the deflexion through a large angle is due to a single atomic encounter, for the chance of a second encounter of a kind to produce a large deflexion must in most cases be exceedingly small. A simple calculation shows that the atom must be a seat of an intense electric field in order to produce such a large deflexion at a single encounter.

Recently Sir J. J. Thomson § has put forward a theory to

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* Communicated by the Author. A brief account of this paper was communicated to the Manchester Literary and Philosophical Society in February, 1911.

† Proc. Roy. Soc. lxxxii. p. 495 (1909).

‡ Proc. Roy. Soc. lxxxiii. p. 492 (1910).

§ Camb. Lit. & Phil. Soc. xv. pt. 5 (1910).

E. Rutherford,
The scattering of alpha and beta particles by matter and the structure of the atom,
Philosophical Magazine,
vol. **21** (1911), p. 669-688.

Ernest Rutherford
1871-1937

Link:

http://www.math.ubc.ca/~cass/rutherford/rutherford.html explain the scattering of electrified particles in passing through small thicknesses of matter. The atom is supposed to consist of a number N of negatively charged corpuscles, accompanied by an equal quantity of positive electricity uniformly distributed throughout a sphere. The deflexion of a negatively electrified particle in passing through the atom is ascribed to two causes—(1) the repulsion of the corpuscles distributed through the atom, and (2) the attraction of the positive electricity in the atom. The deflexion of the particle in passing through the atom is supposed to be small, while the average deflexion after a large number m of encounters was taken as $\sqrt{m}\,.\,\theta$, where θ is the average deflexion due to a single atom. It was shown that the number N of the electrons within the atom could be deduced from observations of the scattering of electrified particles. The accuracy of this theory of compound scattering was examined experimentally by Crowther * in a later paper. His results apparently confirmed the main conclusions of the theory, and he deduced, on the assumption that the positive electricity was continuous, that the number of electrons in an atom was about three times its atomic weight. ?

The theory of Sir J. J. Thomson is based on the assumption that the scattering due to a single atomic encounter is small, and the particular structure assumed for the atom does not admit of a very large deflexion of an α particle in traversing a single atom, unless it be supposed that the diameter of the sphere of positive electricity is minute compared with the diameter of the sphere of influence of the atom.

Since the α and β particles traverse the atom, it should be possible from a close study of the nature of the deflexion to form some idea of the constitution of the atom to produce the effects observed. In fact, the scattering of high-speed charged particles by the atoms of matter is one of the most promising methods of attack of this problem. The development of the scintillation method of counting single α particles affords unusual advantages of investigation, and the researches of H. Geiger by this method have already added much to our knowledge of the scattering of α rays by matter.

§ 2. We shall first examine theoretically the single encounters † with an atom of simple structure, which is able to

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* Crowther, Proc. Roy. Soc. lxxxiv. p. 226 (1910).

† The deviation of a particle throughout a considerable angle from an encounter with a single atom will in this paper be called "single" scattering. The deviation of a particle resulting from a multitude of small deviations will be termed "compound" scattering.

produce large deflexions of an α particle, and then compare the deductions from the theory with the experimental data available.

Consider an atom which contains a charge $\pm Ne$ at its centre surrounded by a sphere of electrification containing a charge $\mp Ne$ supposed uniformly distributed throughout a sphere of radius R. e is the fundamental unit of charge, which in this paper is taken as $4{\cdot}65 \times 10^{-10}$ E.S. unit. We shall suppose that for distances less than 10^{-12} cm. the central charge and also the charge on the α particle may be supposed to be concentrated at a point. It will be shown that the main deductions from the theory are independent of whether the central charge is supposed to be positive or negative. For convenience, the sign will be assumed to be positive. The question of the stability of the atom proposed need not be considered at this stage, for this will obviously depend upon the minute structure of the atom, and on the motion of the constituent charged parts.

In order to form some idea of the forces required to deflect an α particle through a large angle, consider an atom containing a positive charge Ne at its centre, and surrounded by a distribution of negative electricity Ne uniformly distributed within a sphere of radius R. The electric force X and the potential V at a distance r from the centre of an atom for a point inside the atom, are given by

$$X = Ne\left(\frac{1}{r^2} - \frac{r}{R^3}\right)$$

$$V = Ne\left(\frac{1}{r} - \frac{3}{2R} + \frac{r^2}{2R^3}\right).$$

Suppose an α particle of mass m and velocity u and charge E shot directly towards the centre of the atom. It will be brought to rest at a distance b from the centre given by

$$\tfrac{1}{2}mu^2 = NeE\left(\frac{1}{b} - \frac{3}{2R} + \frac{b^2}{2R^3}\right).$$

It will be seen that b is an important quantity in later calculations. Assuming that the central charge is $100\,e$, it can be calculated that the value of b for an α particle of velocity $2{\cdot}09 \times 10^9$ cms. per second is about $3{\cdot}4 \times 10^{-12}$ cm. In this calculation b is supposed to be very small compared with R. Since R is supposed to be of the order of the radius of the atom, viz. 10^{-8} cm., it is obvious that the α particle before being turned back penetrates so close to produce large deflexions of an α particle, and then compare the deductions from the theory with the experimental data available.

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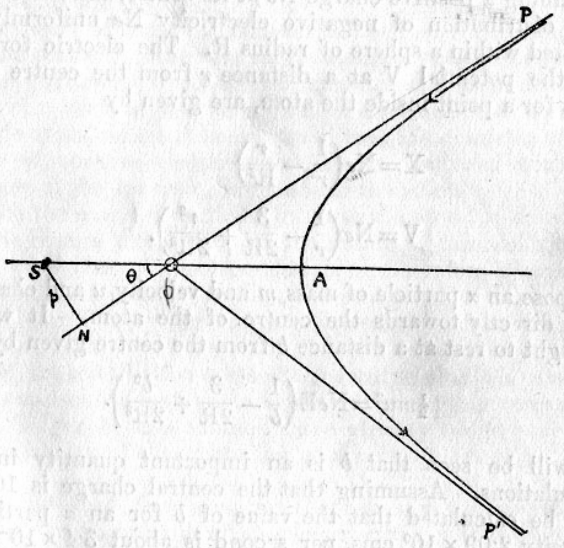
Consider the passage of a positive electrified particle close to the centre of an atom. Supposing that the velocity of the particle is not appreciably changed by its passage through the atom, the path of the particle under the influence of a repulsive force varying inversely as the square of the distance will be an hyperbola with the centre of the atom S as the external focus. Suppose the particle to enter the atom in the direction PO (fig. 1), and that the direction of motion on escaping the atom is OP′. OP and OP′ make equal angles with the line SA, where A is the apse of the hyperbola. $p = SN =$ perpendicular distance from centre on direction of initial motion of particle.

Fig. 1.



Let angle $\mathrm{POA}=\theta$.

Let V=velocity of particle on entering the atom, v its velocity at A, then from consideration of angular momentum

$$p\mathrm{V}=\mathrm{SA}\,.\,v.$$

From conservation of energy

$$\tfrac{1}{2}m\mathrm{V}^2=\tfrac{1}{2}mv^2+\frac{\mathrm{N}e\mathrm{E}}{\mathrm{SA}},$$

$$v^2=\mathrm{V}^2\left(1-\frac{b}{\mathrm{SA}}\right).$$

Since the eccentricity is $\sec\theta$,

$$\begin{aligned}\mathrm{SA}=\mathrm{SO}+\mathrm{OA}&=p\,\mathrm{cosec}\,\theta(1+\cos\theta)\\&=p\cot\theta/2,\end{aligned}$$

$$p^2=\mathrm{SA}(\mathrm{SA}-b)=p\cot\theta/2(p\cot\theta/2-b),$$

$$\therefore\quad b=2p.\cot\theta.$$

The angle of deviation ϕ of the particle is $\pi-2\theta$ and

$$\cot\phi/2=\frac{2p}{b}{}^{*}\quad\ldots\quad.\quad.\quad.\quad.\quad.\quad.\qquad(1)$$

This gives the angle of deviation of the particle in terms of b, and the perpendicular distance of the direction of projection from the centre of the atom.

For illustration, the angle of deviation ϕ for different values of p/b are shown in the following table :—

p/b	10	5	2	1	·5	·25	·125
ϕ	5°·7	11°·4	28°	53°	90°	127°	152°

§ 3. *Probability of single deflexion through any angle.*

Suppose a pencil of electrified particles to fall normally on a thin screen of matter of thickness t. With the exception of the few particles which are scattered through a large angle, the particles are supposed to pass nearly normally through the plate with only a small change of velocity. Let n=number of atoms in unit volume of material. Then the number of collisions of the particle with the atom of radius R is $\pi\mathrm{R}^2nt$ in the thickness t.

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[*] A simple consideration shows that the deflexion is unaltered if the forces are attractive instead of repulsive.

The probabilty m of entering an atom within a distance p of its centre is given by

$$m=\pi p^2nt.$$

Chance dm of striking within radii p and $p+dp$ is given by

$$dm=2\pi pnt\,.\,dp=\frac{\pi}{4}ntb^2\cot\phi/2\,\mathrm{cosec}^2\,\phi/2\,d\phi,\ .\qquad(2)$$

since

$$\cot\phi/2=2p/b.$$

The value of dm gives the *fraction* of the total number of particles which are deviated between the angles ϕ and $\phi+d\phi$.

The fraction ρ of the total number of particles which are deflected through an angle greater than ϕ is given by

$$\rho=\frac{\pi}{4}ntb^2\cot^2\phi/2.\quad.\quad.\quad.\quad.\quad.\qquad(3)$$

The fraction ρ which is deflected between the angles ϕ_1 and ϕ_2 is given by

$$\rho=\frac{\pi}{4}ntb^2\left(\cot^2\frac{\phi_1}{2}-\cot^2\frac{\phi_2}{2}\right).\quad.\quad.\quad.\qquad(4)$$

It is convenient to express the equation (2) in another form for comparison with experiment. In the case of the α rays, the number of scintillations appearing on a *constant* area of a zinc sulphide screen are counted for different angles with the direction of incidence of the particles. Let r = distance from point of incidence of α rays on scattering material, then if Q be the total number of particles falling on the scattering material, the number y of α particles falling on unit area which are deflected through an angle ϕ is given by

$$y=\frac{\mathrm{Q}dm}{2\pi r^2\sin\phi\,.\,d\phi}=\frac{ntb^2\,.\,\mathrm{Q}\,.\,\mathrm{cosec}^4\,\phi/2}{16r^2}.\quad.\quad.\qquad(5)$$

Since $b=\dfrac{2\mathrm{N}e\mathrm{E}}{mu^2}$, we see from this equation that the number of α particles (scintillations) per unit area of zinc sulphide screen at a given distance r from the point of

Large Hadron Collider at CERN:

Atlas-Detektor