of -0.0256 being shifted far enough so that it no longer coincides with the corresponding component in the resonance source.[4]

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[1] *Phil. Mag.*, **47**, 832.

[2] *Zs. Phys.*, **31**, 617.

[3] von Keussler (*Ann. Phys.*, **82**, No. 6) had previously shown that with a wide line source (arc) the polarization became complete in 7900 gausses.

[4] MacNair, these PROCEEDINGS, **13**, 430, 1927.

THE SPACE-DISTRIBUTION OF THE PHOTO-ELECTRONS EJECTED BY X-RAYS

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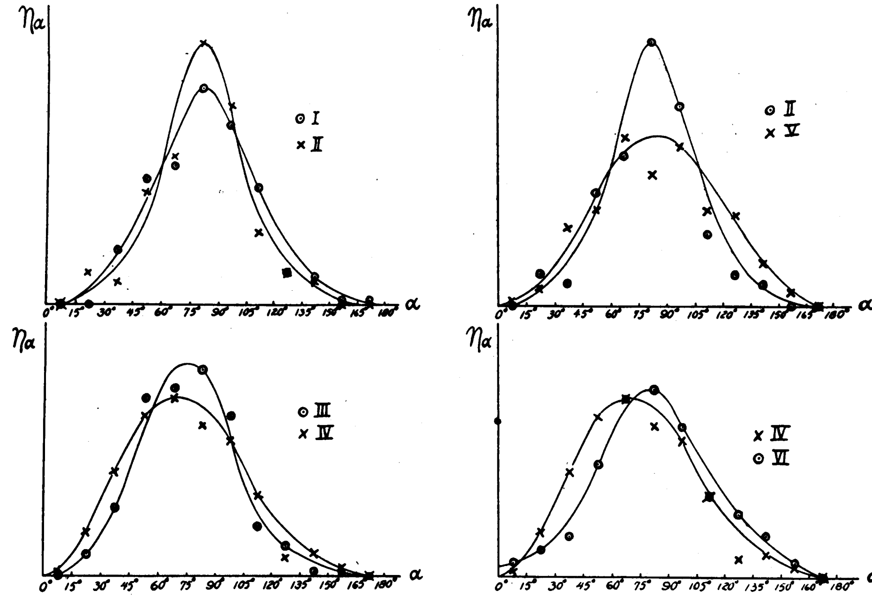
The experiments of Wilson,[1] Auger,[2] Bothe,[3] Bubb,[4] Loughridge[5] and Kirchner[6] by the C. T. R. Wilson cloud expansion-chamber method have shown that while the most probable direction of the photo-electron tracks in a gas traversed by X-rays is nearly the direction of the electric vector of the incident radiation, there is apparently a very considerable "spread" in the direction of the tracks. Magnetic spectra of the electrons ejected from very thin metallic films at various angles show similar effects.[7] Theories to account for this apparent emission from the atom over a wide range of angles instead of in one definite direction have been given by Bubb,[8] Bothe,[9] Auger and Perrin,[10] Wentzel[11] and Beck,[12] but none of them is satisfactory in explaining all the now known experimental facts. The purpose of this paper is to point out that nuclear scattering of the sort postulated by Rutherford with such brilliant success in the case of α-particles has not been sufficiently considered in this connection and that it probably will account for the whole effect.

I. *Experimental Facts.*—The experiments bearing upon this question have been of two general types: (*a*) those which make use of unpolarized X-rays and study the distribution of electrons about the direction of the X-ray beam (this we shall for convenience call the *longitudinal distribution*) and (*b*) those which use polarized X-rays and study the distribution about the direction of the electric vector in a plane perpendicular to the direction of the X-ray beam (this we shall call the *lateral distribution*). It is necessary for the present paper and important, in general, that the present experimental situation be precisely stated and as this has nowhere been done, the following brief summary is given:

(1) The longitudinal distribution function has a pronounced maximum in a direction a little forward of perpendicular to the direction of the X-rays beam and falls to zero at approximately 90° either side of this maximum (this is agreed upon by all observers).

(2) The lateral distribution function has a pronounced maximum in exactly the direction of the electric vector and does *not* fall to zero at 90° from this direction (this last difference between 1 and 2 has not hitherto



I.—K-electrons of oxygen or nitrogen ejected by 15 kv. primary X-rays
II.—K-electrons of oxygen or nitrogen ejected by 20 kv. primary X-rays
III.—K-electrons of argon ejected by 80 kv. primary X-rays
IV.—L-electrons of xenon ejected by 80 kv. primary X-rays
V.—K-electrons of krypton ejected by 22 kv. primary X-rays
VI.—K-electrons of xenon ejected by 45 kv. primary X-rays

FIGURE 1

Longitudinal distribution of photo-electrons ejected by X-rays as found by Auger.

been sharply pointed out and failure to recognize it has led to some confusion).

(3) The longitudinal distribution function is asymmetrical, particularly if X-rays of high frequency are used, being steeper on one side of the maximum than on the other, while the lateral distribution function is symmetrical about the direction of the electric vector (this was first noticed by Loughridge and was communicated to the writer by him, but not published).

(4) Under similar experimental conditions the maximum of the lateral

distribution is less pronounced than that of the longitudinal or in other words, its "spread" is greater (this has not been pointed out hitherto).

(5) The amount of the "spread" decreases as the frequency of the incident X-rays increases and the atomic weight of the atoms from which the ejection takes place decreases (this is contrary to some previous conclusions).

These results are shown graphically in figures 1 and 2, the first of which represents the writer's new plotting of Auger's[13] data on the *longitudinal* distribution, the second Bubb's and Kirchner's results on the *lateral* distribution.

II. *Application of the Nuclear Theory of Scattering to the Problem.*—It

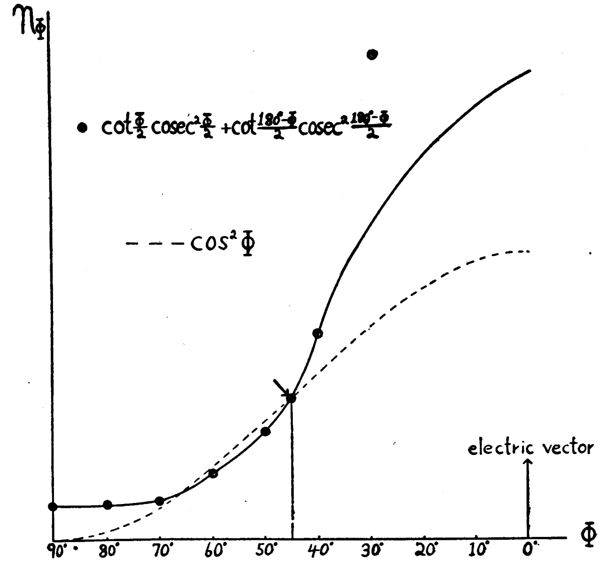


FIGURE 2
Lateral Distribution of Photo-Electrons Ejected by X-Rays as Given by the Theory of Nuclear Scattering.

has hitherto been universally assumed that the cloud expansion-chamber experiments give the actual directions of the electrons as they leave the individual atoms. This is not the case, however. The X-ray when it ejects an electron ionizes the atom and a water droplet condenses upon it. The diameter of this initial droplet was found by direct measurement on Loughridge's plates to be from 0.7 to 0.8 mm. Any change in direction of the ejected electron which took place in this distance was, therefore, unobservable. To decide then whether nuclear scattering affects the space-distribution it is only necessary to calculate the fraction of the whole number of tracks which will experience any given deflection is going a distance of 0.08 cm. If we assume that the electrons are always ejected in the direction of the electric vector, the geometry of the situation which gives rise to the lateral distribution will be different from that which gives rise to the longitudinal distribution and we must treat, in the first case, scattering from a line, in the second case, scattering from a plane.

For the first case the nuclear theory of scattering developed by Rutherford[14] and applied by Schonland[15] to the case of electrons demands that the number dN of the electrons which are scattered between angles ϕ and $\phi + d\phi$ be given by

$$dN = \pi nNt\left(\frac{Ze^2}{2T}\right)^2\left[\cot\frac{\phi}{2}\operatorname{cosec}^2\frac{\phi}{2} + \cot\frac{180°-\phi}{2}\operatorname{cosec}^2\frac{180°-\phi}{2}\right]d\phi \quad (1)$$

where t is the thickness of the scattering material, n the number of nuclei per unit volume, N the total number of electrons scattered, Ze the charge on each nucleus, and T the kinetic energy of the electrons which are scattered. This equation gives not only the absolute *magnitude* of the "spread" but it also gives the *form* of the lateral distribution curve with surprising accuracy. The solid line in figure 2 was drawn so as to fit the experimental points of Bubb and Kirchner as accurately as possible. Equation (1) is represented by the circles. The dotted curve shows how inadequate in comparison is the cosine-square distribution obtained by Auger and Perrin, Wentzel and Beck.

For the case of the longitudinal distribution we get similarly

$$dN = 2\pi nNt\left(\frac{Ze^2}{2T}\right)^2\cot\phi\operatorname{cosec}^2\phi d\phi. \quad (2)$$

The distribution in this case is, therefore, a function of the whole angle instead of the half angle as in the case of the lateral distribution and so it falls to zero at 90° either side of the maximum. Moreover, since the cotangent of half the angle is always larger than the cotangent of the whole angle, the "spread" of the lateral distribution will be greater than that of the longitudinal under similar experimental conditions. The differences between the lateral and longitudinal distributions are, therefore, satisfactorily explained.

The asymmetry of the longitudinal distribution is also accounted for as follows: Since the most probable direction of ejection of the electrons is a little forward of the normal to the X-ray beam, we should have treated, instead of scattering from a plane, scattering from the surface of a cone whose axis is the direction of the X-ray beam and whose semi-angle is a little less than 90°. Such a treatment leads to the equation

$$dN = \tfrac{1}{2}\pi nNt\left(\frac{Ze^2}{2T}\right)^2\left[\frac{1}{\sin^2\frac{\alpha+\beta}{2}} + \frac{1}{\sin^2\frac{\alpha-\beta}{2}}\right]\frac{\sin\alpha d\alpha}{\cos\beta - \cos\alpha} \quad (3)$$

where α is the angle of scattering measured now from the forward direction of the X-ray beam and β is the semi-angle of the cone. This equation gives the form of the longitudinal distribution very satisfactorily.

Equations (1) to (3) require, moreover, that the amount of the scattering and, therefore, the space-distribution depend upon both T and Z. The results of Auger given in figure 1 show this to be the case, as do also the results of other observers. Proof of this as well as of the other considerations here presented will be published in detail elsewhere.

We conclude, therefore, that the theory of nuclear scattering together with the assumption that the electrons all start from the parent atom in the same direction explains in a satisfactory way all the details of the observed space-distribution of the photo-electrons ejected by X-rays.

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[5] Loughridge, D. H., *Ibid.*, **26**, 1925 (697–700); second paper in press.

[6] Kirchner, F., *Phys. Zs.*, **27**, 1926 (385–389; 799–801).

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[11] Wentzel, G., *Zs. Phys.*, **40**, 1926 (574–589).

[12] Beck, G., *Ibid.*, **41**, 1927 (443–452).

[13] Auger, P., *J. Phys. Rad.*, **8**, 1927 (85–92).

[14] See Rutherford and Chadwick, *Phil. Mag.*, **50**, 1925 (889) and references there given.

[15] Schonland, B. F. J., *Proc. Roy. Soc.*, **113**, 1926 (87–106).

SURFACE TENSION OF MOLTEN METALS. I. COPPER

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Except for those that melt at temperatures sufficiently low to allow the use of glass vessels, no accurate data are available concerning the surface tensions of the metals. The writer is engaged in determining the capillary constants of the metals that melt above 900°C. and the present paper is an abstract of the work on copper soon to be published in detail as an Engineering Experiment Station Bulletin of the University of Illinois.

Theory.—The surface of a liquid in contact with a vertical plane which it does not wet is depressed. The magnitude of this depression h (see Fig. 1) is given by the equation