Possible Narrowing of Compton Line Breadth by Preferentially Directed Electron Momenta in Ceylon Graphite

According to a theory of the author first published in Phys. Rev. **33**, 643 (1929), the considerable natural spectral breadth of the Compton modified line was ascribed to the initial momenta of electrons in the scattering body and as one consequence a mathematical expression was derived for the behavior of this breadth as a function of the primary wave-length and scattering angle (formula 23, page 657, above article). The breadth due to scattering by an assemblage of electrons all of the same speed βc but with perfectly random direction was given as

$$\Delta\lambda = 4\beta\lambda^* \tag{1}$$

where $\lambda^* = \frac{1}{2}(\lambda_c^2 + \lambda_1^2 - 2\lambda_c\lambda_1 \cos\theta)^{1/2}$

θ = scattering angle

λ_1 = primary wave-length

$\lambda_c = \lambda_1 + 2(h/mc)\sin^2 \frac{1}{2}\theta$

= Compton shifted wave-length for stationary electrons.

Since λ_c is nearly equal to λ_1, formula (1) is nearly expressed by

$$\Delta\lambda = 4\beta\lambda_1 \sin\tfrac{1}{2}\theta \tag{2}$$

that is to say the breadth of the Compton line should be nearly proportional to primary wave-length on the one hand and nearly proportional to the sine of half the scattering angle on the other *provided initial electron momenta* are responsible for the breadth.

Both these predictions have since been verified by the author in collaboration with H. A. Kirkpatrick with the multicrystal spectrograph (Phys. Rev. **37**, 136 (1931) and Phys. Rev. **38**, 1094 (1931)). *This verification gives excellent support for the theory and hence for its basic assumption that the breadth of the Compton line is an effect of initial electron momenta.*

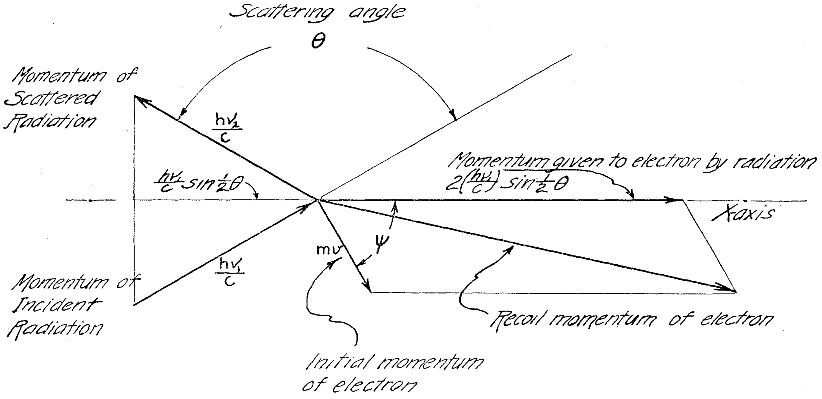

Fig. 1.

By an easy approximate analysis of the momentum balance for the case of an electron with initial momentum, *mv*, making an angle ψ with an axis of reference which bisects the angle formed by the incident and scattered x-ray momenta the author has shown that *only the component momentum* along this axis of reference contributes to the broadening of the Compton line (Phys. Rev. **38**, 1094 (1931)).

Referring to Fig. 1 it turns out that the shift of wave-length for one elementary, scattering process by an electron of initial momentum making angle ψ with the natural reference axis x, is given by

$$\lambda_2 - \lambda_1 = 2(h/mc)\sin^2\tfrac{1}{2}\theta + 2\lambda\left(\frac{v}{c}\cos\psi\right)\sin\tfrac{1}{2}\theta \tag{3}$$

The first term in the right hand member of this equation is the Compton shift while the second term explains the breadth given in Eqs. (1) and (2) *when we consider the directions of electron momenta to be a random distribution.*

If, however, the directions of the initial electron momenta are not random it is evident that the Compton line may be narrower than the value given in Eqs. (1) and (2). In particular if the momenta for some fairly large and isolated class of electrons in the scattering body are all restricted very closely to a plane normal to the above natural axis of reference, then cos ψ in Eq. (3) will vanish and the contribution to the Compton line by these electrons should be a sharp line—the sharper the more accurately the restriction to this normal plane is fulfilled.

Now it is possible that the outer electrons which may have very long orbits in some crystal lattices may be definitely related to the crystal structure. After considering a number of crystalline elements in the hope of selecting one which might conceivably have outer electron orbits restricted in some fairly definite plane, Dr. Alexander Goetz of this Institute suggested that Ceylon graphite might meet the requirement. Ceylon graphite, which crystallizes in small flat hexagonal plates, cleaves practically only along (0001), i.e., in a direction parallel to the flake. Also it is highly diamagnetically anisotropic.

Work was immediately started by Dr. Goetz and his collaborators to study Ceylon graphite and to prepare blocks of this material consisting of the tiny flakes stuck together with an adhesive

By a very ingenious method described in detail by Dr. Goetz in the same issue of this Journal the flakes are compelled to align themselves horizontally so that the whole block forms a sort of artificial single crystal. Dr. Goetz found that by taking special precautions (which he describes in his letter) amazing diamagnetic anisotropy ratios as high as twenty to one could be obtained for the blocks. This ratio can easily be acounted for by the assumption that the *anisotropy of each flake is complete* but that the flakes deviate by a "spread" of three or four degrees from mutual parallelism. This, together with the great disparity in cleavability parallel and perpendicular to the plate, lends hope that perhaps the orbits of the outer electrons in the flakes are fairly well restricted to one plane, though of course it is not absolute proof of this fact.

The author proposes to employ a curving scattering body made out of blocks of this especially prepared Ceylon graphite as a scatterer in the multicrystal spectrograph. If the outer electrons describe orbits which are nearly plane and parallel to the plane of the graphite flake then the flakes should be placed so that the normal to their flat faces bisects the angle between the primary and scattered x-ray beams. Under these conditions we may expect perhaps to get a very narrow spectral contribution to the Compton shifted line from the scattering by the outer electrons. This narrow peak will of course be superposed upon a broader base due to the contribution to shifted scattering of the remaining electrons in the graphite crystals.

The construction of the special graphite scatterer is now well advanced and the results should be obtained in a few weeks.

It is interesting to consider the bearings that either positive or negative results in this experiment may have in several fields of physics.

First, if the result is positive and a narrow shifted line appears:

1. This will be a tremendously convincing corroboration of the correctness of the author's explanation of Compton shifted line breadth as an effect of atomic electron velocities; for if the breadth can be shown to depend on the *orientation* of the crystalline scatterer the cause of the breadth must be some *vector quantity* (the electron momentum). If the breadth is to be explained in this way, its existence and amount are of the greatest importance since they furnish direct experimental evidence of the dynamic atom with electron velocities of the order of magnitude postulated by Bohr (still present with only slight modification in the more modern theory of quantum mechanics). All other spectral evidence for the dynamic atom must be considered as extremely indirect since such evidence is based on observations of *energy* effects. The observations on the breadth of the Compton line and its behavior constitute direct observations of atomic electron *momentum* in which respect they are unique. Energy may be either kinetic or potential but momentum can mean only one thing—*motion*.

2. Several reliable investigators, using the double crystal spectrometer, have reported much narrower Compton shifted lines than those obtained by the author and his coworkers. Some of these men, in particular P. A. Ross, in later investigations have obtained results which agree very satisfactorily with ours, however. Furthermore, those who obtained narrower line structures than ours disagree with each other to some extent as to the breadth. *All of these men used graphite scatterers.* If the author's guess proves correct and a positive result is obtained in the experiment now under discussion these perplexing disagreements may perhaps be completely explained. The author's broad line structures were the result of scattering from synthetic Acheson graphite, which is practically amor-

phous (or if it contains microcrystals, their orientation must be completely random). On the other hand, the investigators in disagreement with the author, and with each other in respect to line breadth, may have used *crystalline graphite more or less fortuitously orientated* so as to produce narrower Compton lines. In this connection it is interesting to note that on the author's theory *any departure from perfectly random electron momenta will have some narrowing effect.*

3. If the results are positive it may be possible from this experiment to obtain exceedingly valuable information as to the behavior of the outer electrons in crystalline graphite. If these electrons in preferentially orientated orbits form an isolated class well differentiated from the remainder, it may be possible to determine their number relative to the total number of electrons by comparing the area of the sharp peak they contribute with the area of the broader structure associated with the remainder. The interesting bearing of this experiment on the explanation of diamagnetism in crystals is also evident. The breadth of the narrow peak will give perhaps some evidence as to the degree of flatness of these preferentially orientated graphite crystal orbits. Many interesting considerations bearing on the nature of the solid state of matter and the mechanical properties of solid bodies may be closely connected with just such questions.

Second, if the results are negative and no narrow line appears:

1. This will decidedly *not* be negative evidence for the author's theory of Compton line breadth as an effect of atomic electron velocities. *That theory is the only one yet proposed which satisfactorily explains the observed behavior of the breadth as a function of scattering angle and primary wave-length* and this is the strongest possible argument for its correctness.

2. A negative result can be interpreted only as evidence that the outer *electron momenta* in the graphite crystals are not preferentially orientated as postulated above. It will not necessarily mean that the outer electron orbits are not conditioned geometrically by the crystal structure for they may each depart so far from flatness as to approximate an almost random distribution of direction. Or again they may be flat but have such a large number of quantized orientations as to approximate a random distribution to within the power of detection afforded by this method. Thus even a negative result will be to some extent information as to the dynamics of outer electrons in solids.

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December 5, 1931.

The Production of Large Artificial Graphite Crystals

There are two problems brought into the focus of interest very recently which seem to make it desirable to obtain single crystals of graphite of several cm^3 size free from occlusions and chemical impurities.

One problem because of which possible methods of producing such crystals had to be considered is the investigation of the dependence of crystal diamagnetism on the size of crystals below certain "critical" dimensions as has been studied by Vaidyanathan,[1] Rao,[2] Mathur and Varma,[3] and in our laboratory in connection with other effects influencing crystal diamagnetism.[4]

The desirability of producing crystals of graphite was furthermore enhanced by the experiments on the Compton radiation from Acheson graphite by Dr. DuMond of this Institute, where the spectral breadth of the modified line has been interpreted by him[5] as due to the fact that the momenta of the electrons of the atoms of the scatterer are oriented at random in a microcrystalline material such as artificial graphite. These considerations led to the planning of the use of single crystalline scatterers as described by him in detail in a letter in this issue of the PHYSICAL REVIEW.

Since the occurrence of single crystals of graphite in nature, sufficiently large and perfect for the proposed types of experiments, is too scarce, (for DuMond's multicrystal spec-

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[1] V. L. Vaidyanathan, Ind. Journ. of Phys. **5**, 559 (1930).

[2] S. R. Rao, Ind. Journ. of Phys. **6**, 241 (1931); Nature **128**, 153 (1931).

[3] R. N. Mathur and M. R. Varma, Ind. Journ. of Phys. **6**, 181 (1931).

[4] A. Goetz and A. B. Focke, Phys. Rev. **38**, 1569 (1931).

[5] J. W. M. DuMond, Phys. Rev. **33**, 643 (1929).