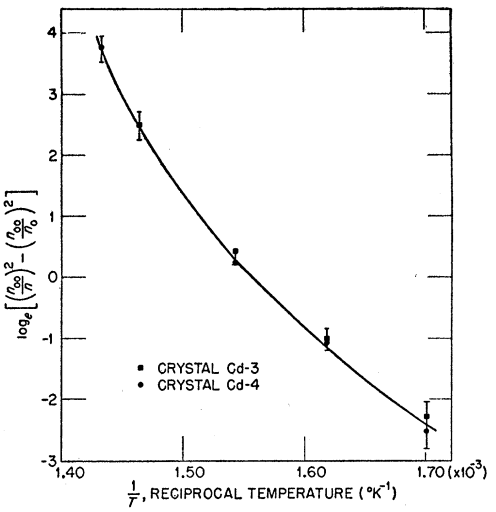

FIG. 2. Annealing data assuming a third-order process.

large as the data of reference 1 for equivalent irradiations. It is possible that the temperature of irradiation was much higher in Keating's experiment, annealing the lattice expansion.

The jump frequency, or frequency with which the defect takes an atomic step, may be estimated from our data. The fractional rate of decrease of the defect concentration is $-(1/n)(dn/dt)$, and the number of random atomic steps taken before a vacancy meets an interstitial is $1/n$. Therefore, the jump frequency is

$$\nu=-(1/n^2)(dn/dt)=ce^{-E/kT}.$$

For the temperature T_0 at which the left-hand side of Eq. (1) is zero, we have

$$c=(1/n_{00}t)e^{E/kT_0}.$$

The temperature T_0 may be obtained from Fig. 1, but n_{00} can only be estimated. We take n_{00} as equal to $(\Delta a/a)_p$ (for the irradiated condition) within an order of magnitude. Then $n_{00}\approx 8\times10^{-4}$, $t=600$ sec, $1/T_0=1.52\times10^{-3}$, and the jump frequency is

$$\nu\approx 6\times10^{11}e^{-E/kT}\ \text{sec}^{-1}.$$

[1] D. Binder and W. J. Sturm, Phys. Rev. **96**, 1519 (1954).
[2] D. T. Keating, Phys. Rev. **97**, 832 (1955).

Anisotropy of Bremsstrahlung and Pair Production in Single Crystals

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IT has been pointed out by Landau[1] that the Bethe-Heitler formulas for bremsstrahlung and pair production will need modification for electrons and photons of energy greater than 10^{12} ev passing through condensed matter. The Bethe-Heitler theory requires that charged particle and photon interact coherently over a path length of the order of

$$L=\lambda[1-(v/c)\cos\theta]^{-1}, \quad (1)$$

where λ is the photon wavelength, v the charged particle velocity, and θ the angle between the directions of charged particle and photon. When the charged particle energy E is relativistic, the angles of emission will in general be such that

$$L\sim\lambda E^2/m^2. \quad (2)$$

Landau observes that multiple Coulomb scattering will reduce the longitudinal distance traveled by the electron by

$$\Delta=KL^2/E^2, \quad (3)$$

over a path length L, where K is the Coulomb scattering constant of the material. The Bethe-Heitler theory will break down when $\Delta>\lambda$, i.e., when

$$K\lambda E^2>m^4. \quad (4)$$

In lead, this condition is satisfied for all photons when the electron energy reaches 5×10^{12} ev.

We here consider a quite different effect of the coherent path-length idea, which should be easily observable at energies of the order of 500 Mev, for example with the Cornell synchrotron beam. Suppose an electron is incident on a single crystal of lead, at an angle α to a line of nearest-neighbor atoms, i.e., at an angle $(90°-\alpha)$ to a (110) plane. The spacing of the atoms in the line is $d=3.5$ A. The number of atoms included within the path length (2) will be

$$N=(\lambda_0/d)(E/m)=7\times10^{-3}(E/m) \quad (5)$$

for photon energy equal to E, and will be greater than this for photons of lower energy. Here $\lambda_0=24\times10^{-11}$ cm is the Compton wavelength. Thus for $E=500$ Mev, $N\geq 7$ for all photons. Now a large matrix element for bremsstrahlung arises when the electron passes through an atom within the Thomas-Fermi screening radius

$$R=a_0Z^{-\frac{1}{3}}=1.2\times10^{-9}\ \text{cm}. \quad (6)$$

When the angle α is less than

$$\alpha_0=(R/Nd)=137Z^{-\frac{1}{3}}(m/2\pi E)=0.3°, \quad (7)$$

the effective matrix element will be multiplied by N each time such a passage occurs, while the effective number of targets will be reduced by a factor N.

We expect therefore that the total bremsstrahlung intensity will be enhanced by a factor $N\sim7$ when the electron beam is within 0.3° of a line of nearest neighbor atoms. Exact quantum-mechanical calculations are being undertaken to confirm the existence of the effect and to estimate its magnitude. Even if the crude classical argument in this letter is optimistic by a factor of

50, the effect should be easily visible. The softer part of the bremsstrahlung spectrum should show a more intense enhancement over a finer range of angles.

Calculations have shown that the coherence effect disappears when averaged over crystal orientation, to a high degree of accuracy. The Bethe-Heitler theory therefore remains valid for polycrystalline materials, except at very much higher energies when the Landau effect becomes important.

It occurs to us that the bremsstrahlung anisotropy might in certain circumstances be a useful adjunct to x-ray crystallography, in determining the structure of organic molecules. It would have the advantage of giving direct information concerning the angles between pairs of atoms in the molecule, without the complications introduced by Fourier analysis. Of course, an experimental test is required to find out whether this will be either possible or useful.

We are indebted to Professor G. Cocconi for some helpful conversations.

[1] L. Landau and I. Pomeranchuk, Doklady Akad. Nauk. **92**, 535 and 735 (1953).

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Proceedings of the American Physical Society

Minutes of the 1955 Spring Meeting Held at Washington, D. C., April 28–30, 1955

(Corresponding to *Bulletin of the American Physical Society*, Volume 30, No. 3)

THE 1955 Spring Meeting of the American Physical Society was held at Washington, D. C., on Thursday, Friday, and Saturday, April 28–30, 1955. Though neither the time nor the place of this meeting deviated from tradition, there were three new features which deserve special mention. First, the heavy task of administering the meeting fell upon a new Chairman of the Local Committee, R. D. Huntoon of the National Bureau of Standards. He was ably assisted by W. R. Tilley also of the Bureau, serving as Secretary of the Local Committee, and by the other members of the Committee, who were Ralph Alpher (APL), D. F. Bleil (NOL), Wayne C. Hall (NRL), R. J. Seeger (NSF), and Howard Tatel (DTM), Mrs. L. S. Taylor, who served Chairman of the Ladies' Programme Committee, and by nearly one hundred others. We must not forget either that Hugh Odishaw, Huntoon's predecessor, lent the aid afforded by his long experience. Warmest thanks to all!

Second, all of the sessions were held in the Sheraton Park Hotel, excepting six in the East Building of the National Bureau of Standards and one of which there will be further mention. We thus attained a degree of compactness not previously achieved in Washington since the old days when there were not more than three simultaneous sessions and the Bureau could receive them all. It is somewhat astonishing that one hotel could provide so many halls, and in spite of the fact that the largest hall in the building was not quite ready for our sessions.

Third, we borrowed the Lisner Auditorium of George Washington University (and for the gratuitous use thereof we owe thanks to President Marvin of the University) for one of the most impressive sessions in the history of the Society—a memorial to Enrico Fermi. H. L. Anderson, E. J. Konopinski, Emilio Segrè, Frederick Seitz, and W. H. Zinn gave a series of excellent papers that reviewed Fermi's life and work from the beginning to the end of his glorious career. These papers were not without allusions to other work that sprang directly from Fermi's own. The Chairman of this memorial session, H. A. Bethe, was also its organizer. Those who did not hear it, and also those who did, will welcome the news that these speeches will be published in *Reviews of Modern Physics*. The hall with its 1500 seats was full.

The remaining invited speakers of the meeting were chosen, as is the custom, mainly but not altogether from the Washington area. Elias Burstein selected three in semiconductor physics, and the Division of Chemical Physics arranged a Symposium. Contributed papers numbered 394, not quite up to last year's total. Registration amounted to 1832.

The banquet of the Society was held on Friday evening. I should have listed a fourth unprecedented feature: this banquet was the very first event in the history of the new Main Ballroom of the Sheraton Park Hotel, in which Ballroom workmen were still putting on the finishing touches less than half-an-