the shape of the hole pockets (but compare $0.15m_0$ observed experimentally by Gunnersen from the temperature variation of the de Haas–van Alphen oscillations).

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DETECTION OF COHERENT BREMSSTRAHLUNG FROM CRYSTALS*

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When fast electrons (of several hundred Mev or more) pass through a crystal we expect the bremsstrahlung to be enhanced[1] and linearly polarized[2] if the electrons travel in a direction nearly parallel to some densely occupied rows of atoms. In simple terms, the reason is that an electron of energy $E_1 = \gamma_1 mc^2$ ($\gamma_1 \gg 1$) has a speed of $v = c[1 - 1/(2\gamma_1^2)]$ and can travel a distance $A = 2\gamma_1^2 ƛ$ before falling back by $ƛ$ behind a quantum (of wavelength $\lambda = 2\pi ƛ$) which it is racing. This "coherence length" A can be several times the distance a between atoms in a row, and if an electron travels parallel to such a row one would expect A/a nuclei to cooperate coherently in the emission of a bremsstrahlung quantum; compared to a crystal not so aligned, the radiation should be stronger by a factor A/a. This factor is reduced[1] by thermal vibrations and by multiple scattering but may be still well above unity.

In estimating A, we have ignored the fact that after emitting the quantum the electron has less energy $E_2 = \gamma_2 mc^2 = E_1 - \hbar c/ƛ$. The semiclassical argument above cannot allow for this; but the uncertainty principle gives the right answer. If both the electron and the emitted quantum go in the forward direction then the momentum that has to be taken up by the lattice is calculated as $P_L = (mc/2)(\gamma_2^{-1} - \gamma_1^{-1})$. The place where such a small momentum has been deposited cannot be located better than within $\hbar/P_L = 2\gamma_1\gamma_2 ƛ$; this must be the correct expression for A and indeed agrees with the previous expression if γ_1 and γ_2 are taken as equal.

Alignment has to be accurate to about $r_B/Z^{1/3}A$ or the enhancement will be reduced (r_B = Bohr radius = 5.3×10^{-9} cm). Deliberate misalignment of that order will produce fairly strong linear polarization of the quanta,[2] and such radiation may be of value for the study of photonuclear reactions; indeed this should give greater intensity than one gets in the fringe[3] of a beam from an ordinary target.

We have found, experimentally, about the expected enhancement, using a small crystal of germanium. It was mounted in the Cornell synchrotron in such a way that the 1-Bev electrons, spiralling in when the rf accelerating voltage was turned off, would cut across one of its edges, approximately in the [110] direction (face diagonal) on which there is a nucleus every 4.0 A. This produced the usual narrow beam of bremsstrahlung; the central portion (one milliradian around the axis) was selected by a lead collimator and cleared of charged particles by a magnetic field (in vacuo). It then passed successively through two plastic scintillation counters S and H, separated by 5 cm of lead and preceded by 3 mm of lead. Because of showers developing in the lead, the second counter H would be more sensitive to hard quanta whereas S would respond about equally to all quanta above 50 Mev. An increase in the ratio S/H should indicate, despite fluctuations in beam intensity, the expected enhancement of the softer x-rays as the crystal approached the correct alignment.

The crystal was aligned within about 2° on the basis of its Laue pattern; it could then be turned in small steps about a horizontal and a vertical

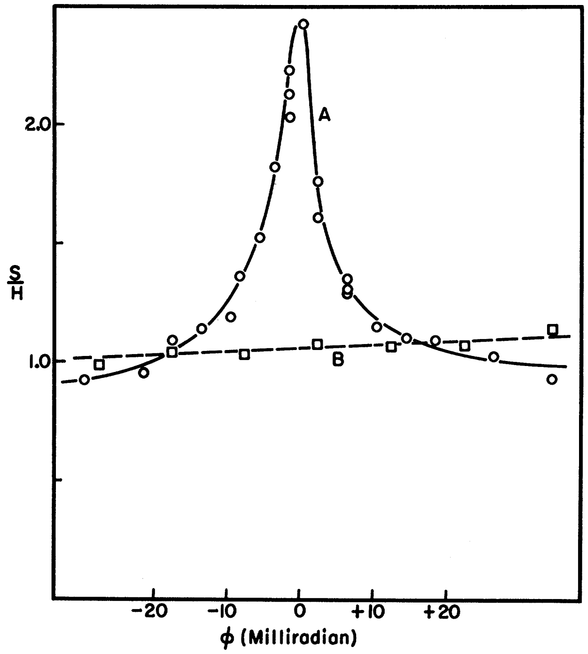

FIG. 1. The relative change measured in the ratio of soft quanta to hard quanta (S/H) as the crystal was turned through ϕ with $\psi \simeq 0$ (curve A) and $\psi \simeq 20$ milliradians (curve B).

axis (both normal to the electron beam) by angles ϕ and ψ, respectively. Usually a change in either ϕ or ψ caused only a small gradual change (Fig. 1, curve B) in S/H, due perhaps to the changed aspect of the crystal as seen by the beam. But for one particular combination of ϕ and ψ S/H is about doubled (curve A). The half-width of the effect is about 0.3°, both for ϕ and ψ. If we assume that the change in S/H is chiefly caused by the enhancement of radiation around 100 Mev, we find $A = 4\times 10^{-7}$ cm and $\Delta\phi = 4$ mrad in reasonable agreement with the observed width.

There seems little doubt that the enhancement we find is the Überall effect even though it is much smaller than $A/a \simeq 10$. It would have been desirable to verify the polarization, but our work had to be stopped at this point. We can offer no explanation for the negative result of Panofsky and Saxena[4]; compared to their arrangement, the strong collimation we used and the fact that our counter S was sensitive down to low x-ray energies would both tend to increase the coherence effect.

We wish to thank E. Belmont of the Red Bank, New Jersey, Division of Bendix Aviation Corporation for supplying us with germanium crystals and Dr. R. R. Addiss and Mr. R. L. Schwoebel for orienting them by taking Laue photographs. One of us (O.R.F.) is most grateful to Professor R. R. Wilson for the hospitality extended to him at the Newman Laboratory of Nuclear Studies during his sabbatic leave from the University of Cambridge, Cambridge, England.

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DE-EXCITATION OF μ-MESONIC ATOMS

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Experiments by Stearns and Stearns[1] have shown that during the de-excitation of a μ-mesonic atom, as the μ seeks its ground state, some nonradiative process competes much more favorably with radiative transitions than does the usual Auger process.[2] It has been suggested[3] that collisions with neighboring atoms could cause the μ meson to fall from the $2p$ to the $1s$ level, with the released energy used to eject an electron from the colliding atom. The size of this effect was found to be too small to explain Stearns' data.[4]

The subject of this Letter is the possibility of collisional de-excitation of the radiating $2p$ mesonic atom level to the metastable $2s$ level, whose radiative lifetime is long enough to permit Auger