# Letters to the Editor

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## Boundary Effects in the Striated Positive Column

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DURING experiments on the luminosity which has been observed in side tubes connected to tubes in which low pressure spark discharges[1] are being studied, a phenomenon relative to glow discharges was noticed to which the author has seen no reference in the literature. Occasionally, owing to switch leakage, weak glow discharges occurred in the main discharge tube prior to the closing of the switch which set off the spark discharge. This glow discharge exhibited striations in hydrogen gas, which changed position gradually as the current of the discharge increased because of increasing potential of the condenser.

At the junction of the main and side tubes, a remarkable property of the striations was observed. Although stable striations could exist on both sides of this junction, no striation ever existed at $A$, the dotted position in Fig. 1, where the bounding wall is incomplete on one side. Striations were stable on either side of the opening, clinging to the complete walls of the main tube, and even bowing out into the region of instability. But when the vicissitudes of increasing current compelled striation $S_1$ to move, it moved abruptly and very quickly to position $S_2$. In all other positions the striations moved slowly and smoothly along the tube.

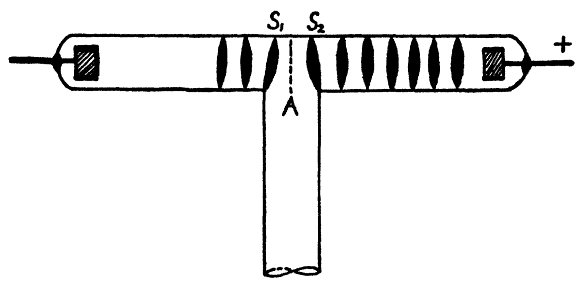


FIG. 1. Branched discharge tube exhibiting a striated glow discharge.

It is suggested that the striations can only exist when completely bounded on their periphery by matter, so that any theory of striations must make use of the concept of boundary conditions.

1 Fowler, Goldstein, and Clotfelter, Phys. Rev. 82, 879 (1951).

## Beta-Inner Bremsstrahlung Angular Correlation

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DURING an extension of previous measurements[1] of the angular correlation between the 885-kev beta-branch and the 85-kev gamma in $Tm^{170}$, a strongly interfering effect was observed which has been established as being due to the angular correlation between beta-particles and gamma-radiation emitted during the beta-emission process.

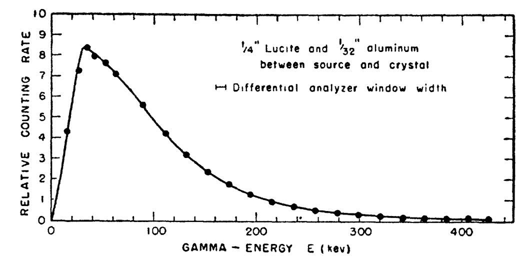


FIG. 1. $P^{32}$ bremsstrahlung NaI(Tl) scintillation spectrometer differential pulse-height analysis.

The theory of this inner bremsstrahlung has been developed by Knipp and Uhlenbeck[2] for allowed spectra and extended to first- and second-forbidden transitions by Wang Chang and Falkoff.[3] The theories predict gamma-emission predominantly in the direction of electron emission. The theoretical angular distribution is not sensitive to the nature of the interaction process in beta-decay.

In order to eliminate true beta-gamma coincidences, the effect was studied in $P^{32}$, which emits no monoenergetic gamma-radiation. The source was mounted in a thin film in a 7-inch diameter plastic vacuum chamber to avoid air scattering of the beta-particles. The beta-particles were detected by a stilbene crystal, ¼ inch thick×1¼-inch diameter, mounted on a 5819 photomultiplier tube. The crystal was in the vacuum, an O-ring real to the face of the photomultiplier being used as a vacuum seal. A 0.2-mg/cm² aluminum foil was placed over the stilbene crystal to increase the collection efficiency of the light pulse and to prevent rapid sublimation of the stilbene.

The beta-detector, source, and vacuum chamber rotated as a unit with respect to the gamma-detector, which consisted of a thallium-activated sodium iodide crystal, ½ inch thick×1¼-inch diameter, mounted on a 5819 photomultiplier tube. A gamma pulse-height analysis of the continuous gamma-radiation from a $P^{32}$ source is shown in Fig. 1. The cutoff in the neighborhood of 40 kev is due to absorption of the gamma-radiation in the plastic chamber wall, which is sufficiently thick to absorb all of the beta-particles.

The intensity of the gamma-radiation is low (one gamma of energy greater than 40 kev for several hundred beta-particles). It is thus necessary to use a fairly fast coincidence resolving time in order to obtain a true coincidence rate comparable to the chance coincidence rate and still maintain good angular resolution, i.e., a solid geometry factor of 0.5 percent of 0.06 steradian. By double delay line shaping of the relatively slow rising NaI pulse (*ca* 0.25 μsec) a pulse of 0.08-μsec width was obtained. In spite of a loss of a factor of six in pulse height due to the shaping, a considerable advantage in average pulse height was realized compared with anthracene for gamma-energies below 250 kev, mainly owing to

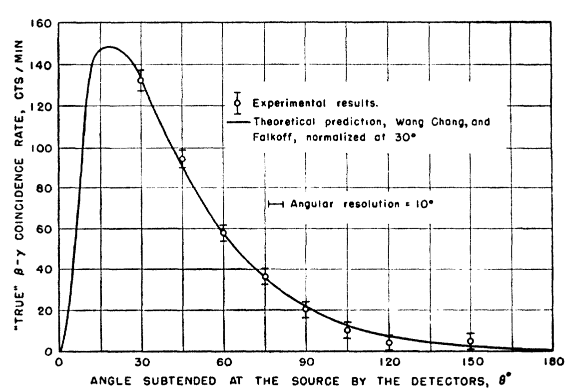


FIG. 2. $P^{32}$ Beta-inner bremsstrahlung angular correlation.

the high photoelectric absorption coefficient in sodium iodide below this energy.[4]

The stilbene beta-pulses were shaped with a shorted delay line to a width of 0.03 $\mu$sec, and an over-all resolving time of 0.11 $\mu$sec was obtained in the coincidence circuit.

The angular correlation measured is shown by the open circles in Fig. 2.

The theoretical angular correlation as given by Wang Chang and Falkoff is

$$d\Phi(v,\theta,\omega)/d\Omega=2\beta^2\sin^2\theta/2\pi\omega(1-\beta\cos\theta)^2,$$

the probability per unit solid angle for an electron with velocity $v$ to emit a quantum of a frequency $\omega$ at an angle $\theta$.

This was averaged over an experimental beta-distribution and over the range of detection of the gamma-ray:

$$\frac{d\Phi}{d\Omega}=c\int_0^{E_{\beta\max}}\int_{40\text{ kev}}^{E_\beta}\frac{N(E_\beta)}{E_\gamma}\frac{\beta^2\sin^2\theta}{(1-\beta\cos\theta)^2}E_\gamma dE_\beta$$
$$=c\int_0^{E_{\beta\max}}\ln(E_\beta/40\text{ kev})N(E_\beta)\frac{\beta^2\sin^2\theta}{(1-\beta\cos\theta)^2}dE_\beta,$$

the probability per unit solid angle for a quantum of energy greater than 40 kev to be detected at an angle $\theta$.

The result of numerical integration of the above expression was normalized to the experimental result at 30°. It can be seen that the data are in excellent agreement with the theory.

A recent article[5] on the intensity and energy distribution of inner-bremsstrahlung mentioned a preliminary experimental affirmation of the angular correlation as found in this work.

[1] T. B. Novey, Phys. Rev. 78, 66 (1950).
[2] J. K. Knipp and G. E. Uhlenbeck, Physica 3, 425 (1936). See also F. Bloch, Phys. Rev. 50, 272 (1936).
[3] C. S. Wang Chang and D. L. Falkoff, Phys. Rev. 76, 365 (1949).
[4] Details of this pulse shaping have been submitted for publication to the *Review of Scientific Instruments*.
[5] L. Madansky and F. Rasetti, Phys. Rev. 83, 187 (1951).

## On the Interaction in Pb of the Secondaries Produced in Penetrating Showers*

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DURING the months from August, 1949, to January, 1950, the cloud-chamber assembly sketched in Fig. 1 was operated at Echo Lake, Colorado (altitude 3260 m, average pressure 706 g cm$^{-2}$), in order to measure the collision mean free path (m.f.p.) in Pb of the secondary particles produced in penetrating showers and to investigate the nature of the penetrating particles in extensive air showers.

Here we give the results of the first experiment. The two chambers, 24 in.×12 in.×12 in., were filled with argon at about atmospheric pressure, and each contained five ½-inch Pb plates; they were located one above the other and separated by a slab of Pb 6 in. thick. Stereoscopic pictures were taken with a single camera on 70-mm film. The master pulse triggering the expansions was generated whenever a coincidence $2A+3B$ among two or more of the counters of tray $A$ and three or more of the counters of tray $B$ was registered.

In the analysis of the pictures obtained, only the cases were considered in which a penetrating shower was generated either in the plates inside the upper chamber or in the 6-in. absorber between the chambers, showed in the lower chamber penetrating particles recognizable as coming from a common center, and was not accompanied by dense air showers. Among the particles belonging to the showers thus selected, the ones considered for the measurement of the collision mean free path were required to fulfill the following conditions: (a) to be minimum ionizing and to be scattered less than 1° in crossing any plate (except for cases judged to be nuclear scatterings, when the particles were deflected less

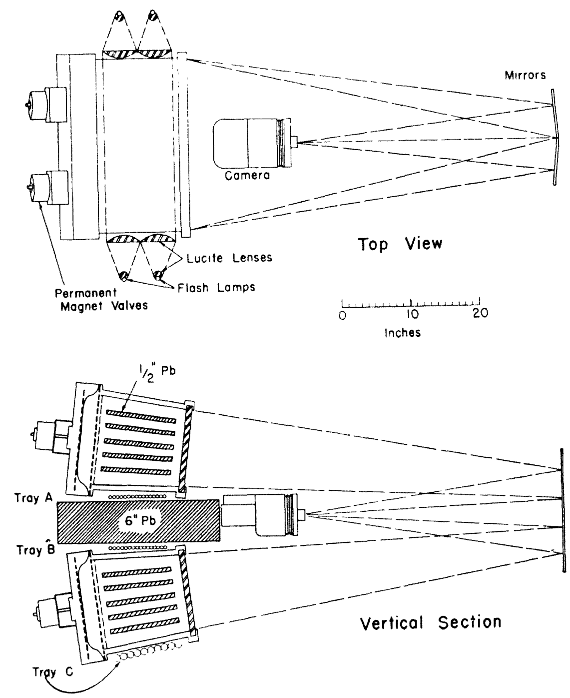


FIG. 1. Diagram of dual cloud-chamber assembly.

than 1° in every plate but one, and more than 10° in that one plate) and (b) to cross at least the middle three plates of the lower chamber in the case of non-interacting particles. In the case of interacting particles the direction of the particle in the space was determined by reprojection on translucent screens, and was required to be such as to cross the middle three plates in the illuminated region. Since particles ionizing 2 times minimum would have been recognized, and since scattering angles larger than 1° were measurable, condition (a) ruled out particles of momentum smaller than $\sim Mc$ or $\sim 2$ Bev/$c$, whichever is larger.

The observed number of plate traversals without interaction by particles fulfilling the conditions (a) and (b) was $N=1977$, while the number of interactions observed was $\Delta N_0=91$. If the condition (b) is modified so as to consider the traversals and interactions in one plate only if the particle is observed to traverse at least the preceding plate,[1] the total number of such traversals without interaction is $N=2568$, and the number of observed interactions $\Delta N_0=111$. The observed collision m.f.p. $\Lambda$ is then

$$\Lambda=h/\ln(1+\Delta N_0/N)=\begin{cases}354\pm39\text{ g cm}^{-2}\text{ of Pb,}\\376\pm40\text{ g cm}^{-2}\text{ of Pb,}\end{cases}$$

where $h=15.9$ g cm$^{-2}$ is the thickness of the Pb plates averaged over the zenith distribution of the particles. The errors given are the statistical ones. The two values practically coincide.

$\Lambda$ is certainly larger than the real collision m.f.p., $\lambda$, because an appreciable number of interactions occurring inside the plates do not give rise to secondaries of energy sufficient to escape from the plates and be seen.

The correction can be evaluated with the aid of Fig. 2, where is plotted the number of interactions observed to start at various depths inside the plates.[2] The point where the interaction occurred inside the plates was identified with the common point of origin of the secondary tracks. From Fig. 2 it clearly appears that many of the interactions occurring inside the plates were lost. An examination of the particles emitted shows that the ratio of the number of heavy prongs to that of light prongs sharply decreases when the interaction occurs more deeply inside the plate; this indicates that the less energetic interactions are more likely