The assignment of the 25-day phosphorus activity to P^{33} was established beyond any doubt by the fact that the activity appeared at mass 36 ($P^{33}H_3$), but at no higher masses. The β-spectrometer investigation of this P^{33} source, in which the active atoms were distributed uniformly in a thin surface layer,[5,9] gave $E_{max}=250\pm5$ kev.

[9] Brostrøm, Huus, and Koch, Nature **160**, 498 (1947).

After completion of the measurements, knowledge was obtained of the latest result of Nichols *et al.*[10] who found the value 249±2 kev using P^{33} resulting from neutron irradiation of enriched S^{33}.

The authors would like to express their thanks to Professor N. Bohr for the excellent working facilities, and to Dr. J. Koch for help and advice.

[10] R. T. Nichols and E. N. Jensen, Phys. Rev. **94**, 369 (1954).

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Inner Bremsstrahlung in the Electron Capture Process—Ge^{71}†

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The spectral distribution of the inner bremsstrahlung of Ge^{71} has been studied at quantum energies as low as 20 kev. It was observed that the radiation intensity at energies less than ~100 kev is much larger than is indicated by currently available theory. The absolute radiative capture probability has been measured. This latter quantity and the spectral shape are in good agreement with theoretical considerations at energies greater than ~100 kev.

THE gamma-ray continuum (inner bremsstrahlung) emitted in the course of electron capture has been under study in several laboratories. The continuous spectra of a number of different radio-nuclides have been observed, particular emphasis being placed upon obtaining an exact measurement of the energy of the spectral end point, since the disintegration energy is thus determined. The theory of the emission of inner bremsstrahlung has been given, with some restrictions and approximations, by Morrison and Schiff.[1] To obtain confirmation of the theory, most investigators have sought to demonstrate that $(N/E)^{\frac{1}{2}}$ is proportional to E (N being the number of photons per unit range of energy E), but only recently have serious efforts been made to extend comparison of theory and measurement to very low quantum energies.[2]

A source[3] of Ge^{71}, of high specific activity (30 mC/g), was obtained from the Brookhaven reactor (exposure time 15 days). After decay of Ge^{77}, As^{77} was removed by distillation of $GeCl_4$ which was converted to GeO_2. A source of uniform thickness, ~10 mg/cm², and 10 cm² in area was prepared by mixing GeO_2 powder in Formvar solution and making a film.

The spectrum was measured by using a crystal of NaI(Tl) having a diameter of 3.5 cm and thickness

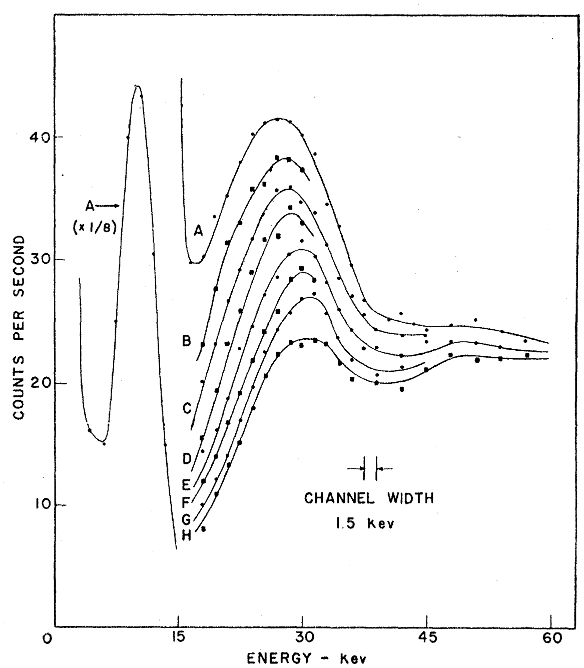

FIG. 1. Low-energy region of the continuous gamma-ray spectrum of Ge^{71} observed through various amounts of absorber. Curve A was obtained with 200 mg/cm² of Al and 100 mg/cm² of MgO intervening; Curves B through G with addition of successive copper absorbers each of the thickness 5 mg/cm²; Curve H with total thickness 40 mg/cm² of additional Cu.

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[1] P. Morrison and L. I. Schiff, Phys. Rev. **58**, 24 (1940).

[2] The writer has previously studied the low-energy region of Cs^{131} [Phys. Rev. **94**, 642 (1954)], A^{37}, and Fe^{55} where significant deviations from theory have been noted of the same nature as those described in this paper. Subsequent discussions with Dr. Franco Rasetti have revealed that he and his associates have noted similar effects in Fe^{55}. The measurements are as yet unpublished. *Note added in proof.*—See Madansky and Rasetti, Phys. Rev. **94**, 407 (1954).

[3] Saraf, Varma, and Mandeville, Phys. Rev. **91**, 1216 (1953).

of 3.5 cm. The source to crystal distance was 1.25 cm. The crystal assembly introduced an absorption of 200 mg/cm^2 of Al and 100 mg/cm^2 of MgO. These intervening materials also served as a filter to reduce the intensity of the K x-radiation of Ga. The residual x-ray peak is shown as part of curve A in Fig. 1. The experimentally observed spectrum was corrected to take into account self-absorption in the source, absorption in Al and MgO, finite energy resolution[4] detection efficiency, and escape of x-rays of iodine. Any correction for Compton effect is negligible[5] for the energies under consideration (0 to 200 kev). The energy resolution (full width at half-maximum) was 25 percent for x-rays of Xe of energy 30 kev.

To correct for initial absorption, the low-energy portion of the spectrum below 60 kev where absorption is greatest, was observed through various thicknesses of copper. The counting rate at each channel setting is plotted as a function of copper absorber thickness in the curves of Fig. 1. In a separate figure not shown, a semilog plot of the counting rate in each channel was

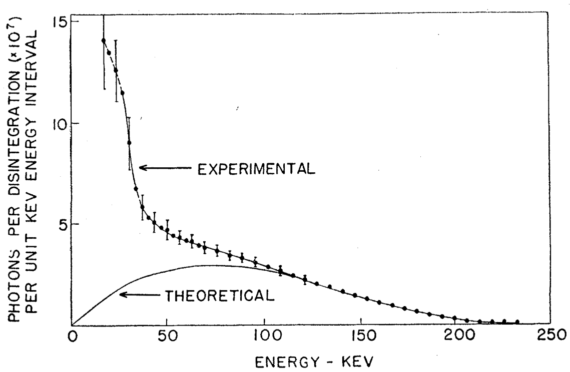

FIG. 2. Energy distribution of the inner bremsstrahlung of Ge^{71}. The indicated probable errors of the experimental curve include systematic errors.

[4] T. B. Novey, Phys. Rev. **89**, 672 (1953).
[5] See Fig. 5 of reference 2.

extrapolated to zero absorber thickness. The experimentally observed curve, corrected in all aspects, is shown in Fig. 2 where it is seen to differ considerably from the theoretically expected result. The indicated probable errors include estimates of systematic errors in the various corrections and far exceed the actual statistical probable errors. The ordinates of the experimental curve of Fig. 2 were determined in the absolute sense by dissolving the GeO_2 source in NaOH and measuring the absolute counting rate of the gallium x-rays of a known volumetric subdivision in a scintillation spectrometer. Agreement of the curves at high energies is fortuitous, since the absolute source strength determination could be in error by as much as thirty percent.

Cutkosky[6] has calculated the radiation probability associated with p electrons of the L shell. His expression is

$$dp_{L\text{II}}=\frac{\alpha^3Z^2}{32\pi}\frac{[3m^2-2(m-w)^2]}{4m^2w}\left(1-\frac{w}{w_0}\right)^2dw,$$

where $dp_{L\text{II}}$ is the probability of emission of a bremsstrahlung of energy between w and $w+dw$. This quantity becomes equal to dp_K at $\sim$40 kev. However, Marshak's formula[7] shows that p-electron capture has only about 0.2 percent of the probability of K-electron capture. It may be suggested that the additional radiation observed at low energies is bremsstrahlung associated with the magnetic moment of the neutrino. However, theoretical calculations of expected intensity of this effect are not sufficiently accurate for comparison.

The writer wishes to express his appreciation to Dr. F. R. Metzger and Dr. C. E. Mandeville for discussions in connection with this problem, and to Dr. W. F. G. Swann for his continued interest.

[6] R. E. Cutkosky, Ph.D. thesis, Carnegie Institute of Technology, 1953 (unpublished).
[7] R. A. Marshak, Phys. Rev. **61**, 431 (1942).