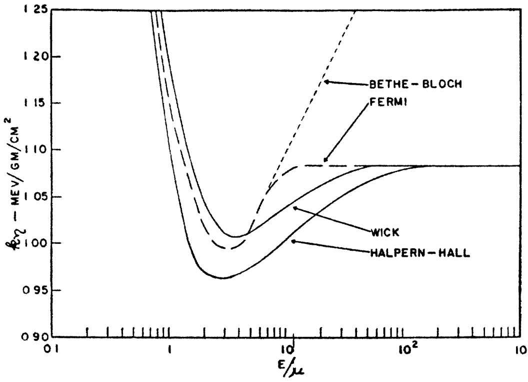

FIG. 1. Theoretical curves for the rate of energy loss in ionizing collisions in iron. Energy transfers less than 10 kev are included. Effective ionization potentials; Bethe-Bloch and Fermi, $I'=26\times 13.5$; Wick, $I'=16\times 13.5$; Halpern-Hall, $I'=32\times 13.5$ ev.

so that the mean grain density for high energy electrons (>20 Mev) in each plate[8] corresponds to the rate of energy loss for AgBr calculated from Fermi's theory for the polarization correction, and the Bethe-Bloch formula, i.e., 1.02 Mev, cm^2/g. It is assumed that the production of ions in AgBr crystals only leads to developable grains, and there is no contribution from ionization in the gelatin of the emulsion. The high energy plateau is in agreement with observations by Corson and Keck,[9] who reported the grain density to be constant within two percent for electrons having energies from 10 to 180 Mev; i.e., E/μ from 20 to 360.

To detect a relativistic increase in ionization, it would seem to be necessary that the corresponding energy loss occurs within the AgBr crystal traversed, and is not dispersed in neighboring crystals or gelatin. As is shown by Bohr's treatment,[5] the limiting distance from the path of a particle for ionizing collisions for the plateau will be $\sim c/\nu$; $\nu^2=4\pi ne^2/m$, where n = electron density in the medium, i.e., $\sim 10^{-6}$ cm, which is less than the dimensions of the undeveloped AgBr crystal ($\sim 3.10^{-5}$ cm).[10] It can also be seen that the plateau sets in at a value of $E/\mu \sim \nu_0/\nu$, where ν_0 is the frequency corresponding to the effective ionization potential, e.g., for iron and AgBr, E/μ (cut-off)$\sim$20 and 30, respectively, in qualitative agreement with the curves in Figs. 1 and 2.

The experimental results seem to indicate the existence of a small increase in ionization beyond minimum up to a limiting plateau. It is hoped to confirm this increase by further observations and it may be possible to compare experimental results with the different theories. If anything, the present results seem to favor that of Wick[11] rather than of Halpern and Hall.[11]

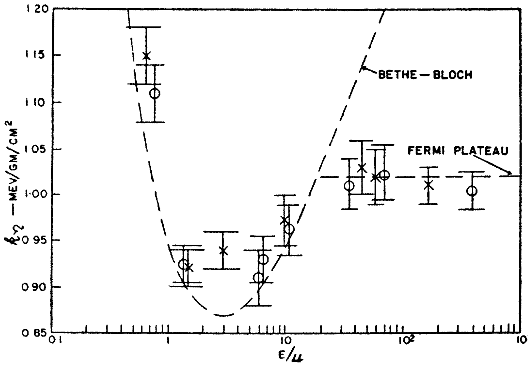

FIG. 2. Dashed curves show Bethe-Bloch energy loss, and Fermi plateau for AgBr. Experimental points, with standard deviations indicated; ○—μ-meson decay electrons, and relativistic μ-mesons in sea-level plate. ×—high energy electrons, protons, and shower π-mesons in high altitude plate.

We wish to thank Mr. I. B. McDiarmid for assistance with the grain counting and scattering measurements.

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[1] W. F. G. Swann, J. Franklin Inst. **226**, 598 (1938).
[2] E. Fermi, Phys. Rev. **57**, 485 (1940).
[3] O. Halpern and H. Hall, Phys. Rev. **73**, 477 (1948).
[4] G. C. Wick, Nuovo Cimento **I**, 302 (1943).
[5] A. Bohr, Kgl. Dansk. Vid. Sels. Math-fys. Medd. **24**, No. 19 (1948).
[6] B. Rossi and K. Greisen, Rev. Mod. Phys. **13**, 240 (1941).
[7] L. Voyvodic, Can. J. Research **28**, 315 (1950).
[8] The actual grain densities were 31.7 and 35.7 grains/100μ, with standard deviations of 0.6 grain/100μ.
[9] D. R. Corson and M. R. Keck, Phys. Rev. **79**, 209 (1950).
[10] J. H. Webb, Phys. Rev. **74**, 511 (1948).
[11] Theoretical curves for AgBr have not yet been calculated, and will probably be a few percent different from those for iron.

Neutron Capture γ-Rays from Cd, Cl, and C

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SPECIMENS of Cd and of CCl_4 were placed in a beam of thermal neutrons from the graphite pile, *BEPO*. The capture γ-rays were measured by measuring the pulse-height distribution of photo-protons from disintegration of deuterium in an ionization chamber counter[1] placed behind the specimen. A small bismuth block in the center of the neutron beam attenuated the direct pile γ-radiation. The background of pile γ-rays was measured by interposing a neutron absorbing shutter of lithium and boron, which had a transmission of about five percent, equal to that of the CCl_4 sample.

Two similar counters were used. The first was filled with 11 atmos. deuterium gas and was operated at 16 kv, and the second was filled with a mixture of 5 atmos. CH_4 and 6 atmos. of H_2, and was operated at 8 kv. Both counters were made of a 1-mm thick aluminium alloy, which did not capture neutrons appreciably. The sensitive volume was enclosed in a sphere of 4 cm diameter.

The first counter had a trace of nitrogen present, and at first trouble was experienced with a large background from the reaction $N^{14}(n-p)C^{14}$. Later, the proton energy[2] of 630 kev from this reaction was used for calibration and to estimate the resolution. The resolution was ±15 percent of the proton energy, being caused partly by ionization chamber defects, which are observable in the n-p reaction distribution, and partly by the influence of the γ-ray momentum on the pulse-height distribution of the photo-protons. This pure deuterium-filled counter had too low a stopping power to detect γ-rays above about 8 Mev. In order to plot the high energy portion of the spectrum, the second counter filled with the methane-deuterium mixture was used. In this counter, however, electron pulses caused too high a background to detect

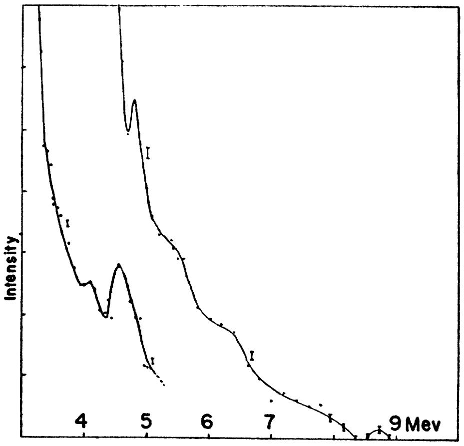

FIG. 1. Neutron capture γ-ray spectrum from cadmium.

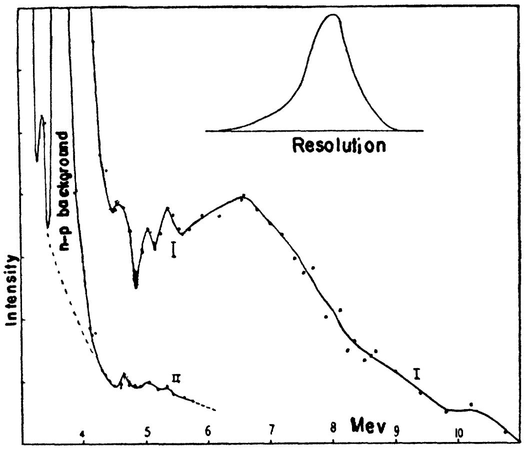

FIG. 2. Neutron capture γ-ray spectrum of carbon tetrachloride. The resolution curve shown is estimated for 8.5-Mev γ-rays; for lower energy γ-rays the resolution is better.

γ-rays below 4 Mev or to detect the $N^{14}(n-p)C^{14}$ reaction. The calibration in this case was made by measuring the saturation characteristics of both counters, and making use of the calibration of the first counter. The way the γ-ray curves overlap in the case of chlorine gives a gratifying justification of this procedure. The overlap for the cadmium spectrum is not so gratifying.

Figures 1 to 3 present the relative intensities of γ-rays of various energies; corrections have been applied to the pulse-height distribution curves for wall effect[1] and for the variation of the photo-disintegration cross section with energy. The statistical standard deviations are not given for each point, but are shown alongside the curves for clarity. The cadmium spectrum is the shape one would expect from the statistics of a many level nucleus. Even here, however, there are distinct signs of a peaked distribution, probably caused by a grouping of levels rather than by single γ-ray transitions. It is not certain, with the low statistics available, whether the slight peak at 8.7 Mev, indicating a direct transition to the ground state, is genuine or not. The chlorine spectrum shows definite signs of level structure. The background ($n-p$) reaction prevents data being obtained in the energy region shown.

The end points of the spectra can be identified with mass differences and are Cd$\sim$8.5$\pm$0.5 Mev, Cl$\sim$10.5$\pm$0.3 Mev. These figures may be compared with the results of Kubitshek and Dancoff.[3]

The capture in carbon was much smaller, and to avoid background a different arrangement was necessary. The first counter was surrounded with boron to absorb slow neutrons which would otherwise cause an ($n-p$) reaction, and placed to one side of the neutron beam, shielded from the direct radiation from the pile by the pile wall of cadmium and lead. Large blocks of graphite were placed in the beam, of such a size that the mean free path for Compton scattering of γ-rays in the carbon was approximately the dimensions of the block. The background was measured as before by blocking the beam with a boron lithium shutter. The arrangement was such that appreciable capture could have occurred in surrounding materials, particularly the lead wall of the pile; it is therefore not certain whether the spectrum shown is due to neutron capture in carbon alone, or also to capture in impurities and surroundings. Calibration of the counter was made from the $N^{14}(n-p)C^{14}$ reaction as before. The spectrum shown is corrected as before for wall effect and for variation of photo-disintegration cross section with energy.

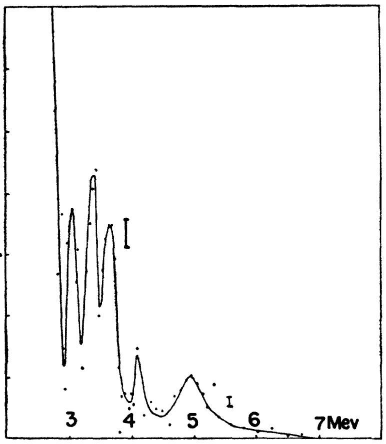

FIG. 3. Neutron capture γ-ray spectrum from graphite.

Gamma-ray peaks were found at 3.05, 3.4, 3.65, 4.1, and 4.95 $\pm$0.05 Mev. The last appears to be a transition direct to the ground state of C^{13}, and agrees well with the value 4.951 Mev found by Kinsey,[4] whose work was published after these measurements were completed. The 4.1-Mev γ-ray is probably a transition[5] to the 0.8-Mev metastable state of C^{13}, and the 3.05-Mev γ-ray may be a transition from the 3.1-Mev excited level to the ground state. The 3.4- and 3.6-Mev γ-rays may come from levels not previously reported, or from impurity capture. The statistics, however, are not good.

No γ-ray of 8 Mev corresponding to capture in C^{13} was found, and it seems probable that 80 percent of the capture in carbon is due to C^{13}.

It is a pleasure to acknowledge the assistance given by Mr. F. W. Fenning and others of the Pile Physics division, and to thank the Director, A. E. R. E. Harwell, for allowing the experiment to be performed. I would also like to thank Dr. H. Halban of the Clarendon Laboratory, for suggesting the experiment.

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[1] Wilson, Beghian, Collie, Halban, and Bishop, Rev. Sci. Inst. **21**, 699 (1950).

[2] Franzen, Halpern, and Stephens, Phys. Rev. **77**, 641 (1950).

[3] H. E. Kubitshek and S. M. Dancoff, Phys. Rev. **76**, 531 (1949).

[4] Kinsey, Bartholemew, and Walker, Phys. Rev. **77**, 723 (1950).

[5] Fowler, Lauritsen, and Lauritsen, Rev. Mod. Phys. **20**, 236 (1948).

A Standard Substance for Precise Electron Diffraction Measurements

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DURING the course of some work dealing with the variation of the lattice constants of very small crystals with crystal size, it was necessary to look into the question of a standard reference substance for precision electron diffraction measurements. The conditions to be met are as follows: (1) The recorded pattern should consist of several very sharp rings so that a good average value of the constant to be found can be obtained. (2) When prepared, the material should remain chemically stable and without physical change, such as growth in crystal size, over a period of several days. (3) The lattice constant and crystal structure must be known and be independent of the method of preparation.

Gold has been used as a standard material by several workers. However, Lu and Malmberg[1] have reported thin gold foil to have a lattice constant less than the usual x-ray value, and our results on evaporated gold films corroborate this result. Thin films of alkali halides are unsuitable since, in most cases, the crystals grow on exposure to air. ZnO has been suggested as a standard material. However, both Finch and Wilman[2] and Cosslett[3] have reported that in some cases the lattice constant of ZnO as determined by electron diffraction differs from the x-ray value, and varies with the age of the specimen.