that the results were not spurious. The foil was cooled by a stream of vapor from boiling liquid air.

At the lowest temperature, −150°C, five peaks were found at energies greater than the drop at the main Ga K edge by 77, 127, 154, 201, and 248 volts, respectively. The peak at 127 volts appeared as an unresolved shoulder on the 154-volt peak and the 248-volt peak is weak and unverified. The other three peaks are quite strong and definite.

A single run through the structure at −67°C showed only peaks at 63 and 123 volts from the main edge, both of which were broader and less intense than the corresponding peaks at the lower temperature. Runs at room temperature agree with previous observations in showing no structure.

The crystal structure of Ga is unique, and an attempt is to be made to compare the experimental results with Kronig's theory for the Ga structure. A full report of the work will be published soon.

A value of the wave-length of the Ga K edge of 1192.5 X.U. is found, agreeing with the value given by Kievit and Lindsay[2] (1192.9 X.U.) rather than the accepted value of 1190.2 X.U.

W. W. Mutch

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August 26, 1935.

[1] J. D. Hanawalt, Zeits. f. Physik **70**, 293 (1931).
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On the Recombination of Neutrons and Protons

The process of the photoelectric disintegration of the deuteron, and the reverse process (recombination of a neutron and a proton with formation of a deuteron and emission of a γ quantum) have been treated theoretically by Bethe and Peierls.[1] These authors consider the emission or absorption of γ-rays by the ordinary mechanism of the electric dipole radiation. For the recombination cross section they obtain an expression which vanishes in the limit of low relative velocities of the neutron and the proton. This last result seems to be in contradiction with general experimental evidence, that slow neutrons are captured in hydrogenated materials such as paraffin or water. Recently the lifetime of a slow neutron in paraffin has been evaluated by a direct experiment and found to be of the order of magnitude of 10^{-4} second.[2]

I wish to point out that if we take into account also the radiation processes due to oscillations of the magnetic dipole of the neutron-proton system, one finds a probability of capture which is in satisfactory agreement with the above value. The theory is based on the customary assumption that the fundamental state of the deuteron is a ^3S (neutron and proton with parallel spins).

The ordinary theory of impact shows that in the case of slow neutrons only the capture from S states in the continuum is of importance. The usual radiative processes of electric dipole and quadripole are forbidden for these $S-S$ transitions. Instead transitions from a ^1S state in the continuum to the fundamental ^3S state can occur by the mechanism of magnetic dipole radiation.

The ordinary electromagnetic theory gives for the inverse mean life $1/\tau$ of a neutron with velocity v moving in a medium containing n protons per unit volume the following formula:

$$\frac{1}{\tau}=n\cdot\frac{64\pi^4 h\nu^3}{c^3m^2v^2}\mu_0(g_p-g_n)^2\left|\int f\varphi r^2dr\right|^2.$$

m is the neutron mass: ν is the emitted frequency; μ_0 is the nuclear magneton; g_p and g_n are the nuclear g-factors for proton and neutron. The last integral contains the normalized eigenfunction $f(r)$ of the fundamental state and the continuum eigenfunction $\varphi(r)$. This last is normalized in such a way that for large r it goes over into $(1/r)$ sin $(2\pi pr/h+\text{const.})$.

This last integral can be evaluated numerically by methods similar to those used by Bethe and Peierls. The parameter needed for the description of the ^1S eigenfunction can be obtained on the assumption that the high elastic scattering cross section of slow neutrons in hydrogen is mainly due to the ^1S eigenfunction (real or virtual ^1S level close to energy zero). We find for slow neutrons

$$\frac{1}{\tau}=\frac{16\pi^3W^{5/2}}{h^3c^3m^{\frac{1}{2}}}\frac{\mu_0^2(g_p-g_n)^2}{l},$$

where l is the mean free path for the elastic scattering of slow neutrons (for paraffin about 0.5 cm)[3], and $W=2.1\times10^6$ e.v. is the binding energy of the deuteron. Assuming 3 and 1, nuclear magnetons, as magnetic moments of the proton and the deuteron,[4] we get $g_p=6$ and $g_n=-4$. This gives $1/\tau=5.2\times10^3$ in agreement with the experimental result.

The magnetic dipole radiation affects also the process of the photoelectric disintegration of the deuteron. The cross section for the photoelectric absorption of a γ-ray by a deuteron results on the same assumptions

$$\sigma_\gamma=\frac{4\pi^2a^2\alpha^2\mu_0^2(g_p-g_n)^2}{3hc}\frac{(\gamma-1)^{\frac{3}{2}}}{\gamma\{1+a^2\alpha^2(\gamma-1)\}},$$

where $$a^2=\frac{1}{\pi nl},\quad \alpha^2=\frac{4\pi^2mW}{h^2},\quad \gamma=\frac{h\nu}{W}.$$

The cross section must be added to that already calculated by Bethe and Peierls in order to give the total cross section.

Details of this theory will be published elsewhere.

Enrico Fermi

University of Michigan,
August 27, 1935.

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