The frequency at which the magnetic field was modulated was 25 cycles, large enough to affect the shape of the otherwise sharp deuteron signal by frequency modulation effects.[2] A study of these effects showed that our line shapes could be correctly described by applying the analysis of Karplus[3] to our arrangement. We were able to show that by operating with dispersion unbalance of the r-f bridge, use of the center of symmetry of the resonance pattern in making the frequency comparisons was justified. The strength of the r-f signal was kept well below the saturation level, and the amplitude of the magnetic field modulation was 0.024 gauss, small enough so that the line widths were not excessively broadened.

Results of seven independent measurements are given in Table I. The stated uncertainty is about twice the usual probable error.

TABLE I. Measured values of μ_H/μ_D.

Run	Pressure H_2	lb/in.^{2} D_2	μ_H/μ_D	
47	300	700	3.25719876	
49	300	500	3.25719803	
56	520	880	3.25719818	
57	300	500	3.25720074	
58	320	880	3.25720064	
59	660	740	3.25719854	Coils rotated 90°
60	660	740	3.25719825	Coils rotated 90°
			Mean 3.25719902 ± 0.00000060	

In an earlier measurement with H_2O-D_2O mixtures, we obtained $\mu_H/\mu_D = 3.25719986 \pm 0.00000045$.

The corrections for magnetic shielding calculated for H_2 and D_2 using Ramsey's formula[4] and new values for the rotational magnetic field[5, 6] are very nearly the same. However, a difference in the magnetic shielding constant σ arises from changes in the amplitude of the molecular vibration.[7] For the first term in Ramsey's formula, Newell[8] has calculated that the contribution to σ is greater for D_2 by $(1.1 \pm 0.2) \times 10^{-7}$. He points out that this change could be canceled by the effect of the molecular vibration in the second term. Accordingly, we give for the ratio of the magnetic moments

$$\mu_p/\mu_d = 3.2571990 \pm 0.0000010.$$

This result is in agreement with, but ten times more accurate than that obtained by Levinthal.[9] It lies outside the experimental error of the result of Lindström.[10]

This result is comparable in accuracy with the new measurements by Prodell and Kusch[11] of the hyperfine structure in hydrogen and deuterium. Taken together these measurements provide a critical test of the theory of the structure of the deuteron.[12]

* Institute for Nuclear Studies, University of Chicago, Chicago, Illinois.
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A Model for Photo-Nuclear Reactions

LUIS MARQUEZ
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
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MANY of the features of photo-nuclear reactions induced by gamma-rays from 6 to 100 Mev can be explained by using a model which assumes the gamma-ray to be absorbed by a single nucleon in a process similar to the photoelectric effect[1] and the photo-disintegration of the deuteron.[2]

In this process the cross section for the photo-nuclear absorption for one nucleon is

$$\sigma(W) = (8\pi^3 e^2 \nu / c) |z_{OE}|^2,$$

where

$$z_{OE} = \int U_0[(A-Z)/A] z\phi_E d\tau \cong \tfrac{1}{2} \int U_0 z\phi_E d\tau$$

for a proton, and

$$z_{OE} = \int U_0(-Z/A) z\phi_E d\tau \cong -\tfrac{1}{2} \int U_0 z\phi_E d\tau$$

for a neutron. All symbols have their usual meanings, and $A \cong 2Z$. The energy of the outgoing nucleon, aside from a small correction for momentum conservation, is $E_N = W - \epsilon_N$, where ϵ_N is the binding energy of the nucleon, and $W = h\nu$ is the energy of the gamma-ray. The total cross section is $\sigma_T = A\sigma(W)$; and the sum rule gives for the integrated cross section

$$\int_0^\infty \sigma_T dW = \pi^2 e^2 \hbar A / 2Mc = 0.015A \text{ Mev-barn},$$

as given by Levinger and Bethe.[3] The cross section, $\sigma(W)$, as a function of W will depend on the wave functions, which are not known. However, from analogy with similar processes[1-4] one would expect a rise at the threshold, ϵ_N, a maximum at about $2\epsilon_N$, and then a tail-off. This explains why the cross section for photo-emission of one nucleon is larger than two, and so on.

The fate of the nucleon which absorbed the gamma-ray will be determined by the size of the nucleus. In light elements, the nucleon will probably escape without being very much disturbed, and $\sigma(\gamma, p)/\sigma(\gamma, n) \cong 1$. In medium and heavy nuclei, the nucleon will collide with other nucleons and form a compound nucleus; protons will be affected by the potential barrier. In the compound nucleus the emission of neutrons is more probable than the emission of protons, and (γ, n) will be favored over (γ, p). If there is enough energy available, several nucleons can be emitted. All this is in agreement with the presence of high energy protons in gamma-ray bombardment,[5] and with the (γ, p) and (γ, n) yields.[6, 7]

Even in the medium and heavy elements, the nucleon that absorbs the gamma-ray near the surface can escape. Therefore, in bombardments of medium nuclei with monoenergetic gamma-rays, one expects that the ratio $\sigma(\gamma, p)/\sigma(\gamma, n)$ is proportional to $A^{-\frac{1}{3}}$ as long as $E_N > B$, where B is the potential barrier; and this is in rough agreement with Wäffler's results.[8]

Empirically, $\sigma(W)$ can be found in the light elements from the energy distribution of nucleons from gamma-ray bombardments if the gamma-ray spectrum is known; and it is always possible to find $\sigma(W)$ if the cross sections for $\sigma(\gamma, p)$, $\sigma(\gamma, n)$, $\sigma(\gamma, pn)$, $\sigma(\gamma, 2n)$, etc., are all known as functions of W: their addition will give $\sigma(W)$. A crucial test of the model is the energy distribution of protons from light elements irradiated with high energy monochromatic gamma-rays.

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On the Branching Ratio of the π^+ Meson*

FRANCES M. SMITH
Radiation Laboratory, University of California, Berkeley, California
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EARLY experiments on π^+ mesons, using photographic emulsions as detectors, have seemed to show[1] that some of the π^+ mesons, upon stopping in matter, do not decay into μ^+ mesons.

These studies were concerned with mesons of fairly low energy so that the emulsion would be the only stopping material. Ilford

C_2 and C_3 emulsions were used in order to facilitate the identification of the mesons. In many cases the processed emulsions showed an apparent non-uniformity in sensitivity, and since the μ-meson track is rather tenuous in the region of the terminus of the π-track, there is a chance of missing the decay. For a more intensive study of the decay scheme, a much more sensitive emulsion is required. Ilford G_5 and Eastman NTB_3 emulsions were chosen for the present study.

The apparatus used in this study consisted of a brass chamber for holding the plates and the target. The target was 0.036-inch carbon. This assembly was mounted on a probe and inserted into the vacuum chamber of the 184-inch cyclotron. The circulating beam of 345-Mev protons irradiated the target. Mesons emitted in the backward direction entered a channel cut into the brass holder. This channel was of such dimensions that π^+ mesons from the target, with energies between 6 and 8 Mev only, will enter the emulsion after a turn of 180°. No μ-mesons from decay of the π stopping in the target can get into the plate chamber. μ-mesons from decay in flight of the π-mesons could get into the emulsion only if they were emitted in a narrow cone in the forward or backward direction. These would not be confusable with π-mesons from the target as their ranges in the emulsion would be too great or too small to have the correct energy.

The plates were studied using a high power microscope. Only those mesons which stopped in the emulsion at a distance greater than 10 microns from either surface of the undeveloped emulsion were counted.

Meson scattering from the channel walls gave a background fairly uniformly distributed, with respect to range, in the emulsion.

The analysis of the results consisted of a calculation of the number of background μ-mesons expected to fall in the main distribution. This number was subtracted from the number of mesons showing no decay found in the main distribution.

A preliminary estimate of the percentage of π-mesons from the target which do not decay into μ-mesons is, $R=0.3\pm0.4$ percent. This indicates that the branching ratio of the π^+ mesons is less than 1 percent and probably zero. A more complete account of this work will be published at a later date.

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Neutron Capture Cross Sections and Level Density

H. Hurwitz, Jr.
Knolls Atomic Power Laboratory, Schenectady, New York
AND
H. A. Bethe*
Cornell University, Ithaca, New York
January 11, 1951

IT is known experimentally that neutron capture cross sections as well as nuclear binding energies exhibit fluctuations from isotope to isotope, which are related to whether the neutron and proton numbers are odd, even, or magic. It is difficult to understand the relation between the fluctuations in these two quantities if one assumes that level densities depend primarily on excitation energies measured from the ground state. The fluctuations can be correlated qualitatively, however, by the hypothesis that the significant quantity in determining level densities is the excitation energy measured not from the ground state but from a characteristic level which depends in a smooth way on the number of neutrons and protons in the nucleus.[1] This would imply that those factors which make the ground state low for even-even nuclei or nuclei with a magic number of neutrons or protons do not have an appreciable influence on the level densities at excitations corresponding to that of the compound nucleus in a capture process. In terms of the supermultiplet theory, the hypothesis is equivalent to saying that the odd, even, or magic property of N and Z has a strong influence on the supermultiplets of high symmetry but has comparatively little influence on the distribution of multiplets of low symmetry which correspond to high excitation. The same situation would be expected from the shell model since nuclei with almost completed shells and high binding energy should have fewer low lying states than nuclei with partially filled shells and relatively lower binding energy. Experiments of Kinsey, at Chalk River, on capture gamma-ray spectra indicate the correctness of this picture by showing few low lying levels for magic and near magic nuclei.[2] (These experiments give information on level densities in an excitation range lower than that at which the compound nucleus is initially formed in a capture process.)

This hypothesis implies that the neutron capture cross section is determined primarily by the binding energy of the target nucleus rather than that of the final nucleus. If the target nucleus has high binding energy, the initial system of free neutron plus target nucleus will have low energy so that the compound nucleus will be formed with low energy as compared to the smoothly varying characteristic energy. The level density will therefore be small, and hence, the capture cross section will tend to be small. One would therefore conclude that the number of neutron resonances and the average capture cross section would be large for odd-odd nuclei, intermediate for odd-even and even-odd nuclei, and small for even-even nuclei.[3] Nuclei with magic numbers of either protons or neutrons should have particularly few resonances for low energy incident neutrons and hence, small capture cross sections.

If the alternative assumption were made that the level density depends primarily on excitation measured from the ground state, it would follow that the capture cross sections should be largest where the total energy released in the capture process is largest. Thus, even Z-odd N nuclei would be expected to have higher level densities and average capture cross sections than do odd Z-even N nuclei, and odd Z-even N nuclei would be expected to have roughly the same capture cross sections as do even-even nuclei. Actually, it appears that even Z-odd N nuclei do not have larger capture cross sections than do odd Z-even N nuclei, and that even Z-even N nuclei have smaller cross sections than do odd Z-even N nuclei.

Since the neutron width, Γ_n, is roughly proportional to the level spacing, the capture cross section, when averaged over a neutron spectrum which is broad compared with the level spacing, will not depend strongly on the level spacing if the neutron width is small compared with the gamma-width.[4] Therefore, the above conclusions on average capture cross sections apply particularly to incident neutron energies in the range of a few kilovolts and above, where the ratio Γ_n/Γ_r is not small.

* Consultant, Knolls Atomic Power Laboratory.

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An Investigation of the Existence of a Sodium Lithium Molecule*

B. B. Phillips,† H. M. Froslie,‡ and R. H. McFarland
Kansas State College, Manhattan, Kansas
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THE vapors of the alkali metals have been examined extensively for absorption spectra. It has been established from their band absorption that these metals form diatomic molecules in both pure metals and in combinations of two dissimilar metals.