

is about ± 1 Mev at each point. The statistical errors in counting, as well as variations in relative activities as observed from day to day are small compared to effects of uncertainties in positions of samples during the irradiation.

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The Neutron-Electron Interactions

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FOLDY¹ has recently shown that the magnetic moment of the neutron can interact with the electrostatic field of an electron. This interaction is usually expressed as a uniform potential extending over a distance equal to the classical electron radius. If one chooses the neutron moment as -1.91 nuclear magnetons, the interaction is attractive, and its strength is 3900 ev. This surprisingly large value has its origin in the "zitterbewegung" of the magnetic moment of the neutron, which is assumed to be a Dirac particle. This effect does not constitute, however, the total neutron-electron interaction. There is another attractive potential whose physical origin stems from the fact that the neutron is sometimes a proton with a negative meson charge cloud surrounding it.

The two effects differ as follows: They arise from the interaction of the field of the electron with the neutron polarization current in the first case, and with the neutron convection current in the second. Each of these effects can be calculated from meson theory. Although they depend separately on the coupling constant, their ratio is independent of it.

This ratio has been calculated, assuming an interaction of the neutron with symmetric pseudoscalar mesons. Equations (5.10) and (6.11) of Borowitz and Kohn² have been used in conjunction with a meson mass of $282m_e$. The result is that $\delta j_{\mu p} \cdot A_{\mu} / \delta j_{\mu c} \cdot A_{\mu}$ is equal to 3.23; here $\delta j_{\mu p}$ and $\delta j_{\mu c}$ are the corrections to the neutron polarization and convection currents, respectively. If one fixes the coupling constant in order that the theory yield the phenomenological value for the neutron moment, the convection current contribution to the neutron-electron interaction is 1208 ev. The total interaction would thus be equal to 5108 ev. The Slotnick and Heitler³ formulas give 5073 ev if one uses the same meson mass and fixes their coupling constant to give the correct value of the neutron moment. These results are in good agreement with previously reported values,^{4,5} and with the one recently measured by Hughes,⁶ 4200 ± 700 ev.

This agreement, while interesting, is probably fortuitous for the following reasons: (1) The anomalous proton moment using the same coupling constant in the same theory would be about eight times too small. (2) It is unreasonable to suppose that a second-order perturbation calculation is correct, when the expansion parameter is so large.

Foldy's¹ conjecture that Slotnick and Heitler,³ and Dancoff and Drell⁷ have included both parts of the neutron-electron interaction in their results is thus supported. The discrepancy between their results and those of Case⁸ and of Borowitz and Kohn² is largely resolved.⁹

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⁹ Since this letter was completed, similar work by B. D. Fried has appeared [*Phys. Rev.* **86**, 464 (1952)]. The conclusions reached by him are essentially the same as those reported here.

Energy Available for Double Beta-Decay of Sn¹²⁴†

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THERE has been considerable interest in the possibility that double beta-decay may occur with a measurable half-life. This interest has been heightened by Fireman's observation¹ of a half-life of $0.4-0.9 \times 10^{16}$ years for the Sn¹²⁴-Te¹²⁴ transition. However, this observation has not been confirmed,²⁻⁴ and studies of other potential double beta-emitters have yielded⁵⁻⁷ negative results. Since the energy available for the decay is an essential datum for estimating the half-life, we have undertaken to measure this quantity with a mass spectrograph.

The Sn¹²⁴-Ni⁶² and Te¹²⁴-Ni⁶² doublets, photographed at mass number 62, yield the following mass differences: $\frac{1}{2}\text{Sn}^{124}-\text{Ni}^{62} = 0.02378 \pm 12$ amu and $\frac{1}{2}\text{Te}^{124}-\text{Ni}^{62} = 0.02297 \pm 19$ amu. The Sn¹²⁴-Te¹²⁴ mass difference is, therefore, 0.00162 ± 44 amu, or 1.5 ± 0.4 Mev. This value, according to the experiments⁸ of Kalkstein and Libby, gives a lower limit for the lifetime of the Sn¹²⁴ double beta-decay of $2.1 \pm 0.3 \times 10^{17}$ years.

This measurement was in part undertaken at the suggestion of K. G. Standing. The authors wish to acknowledge a most helpful conversation on this general subject with W. F. Libby.

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Theory of Antiferromagnetic Resonance in a Crystal of Rhombic Symmetry at the Absolute Zero

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THE observed antiferromagnetic resonance phenomena in copper chloride, CuCl₂·2H₂O, are only slightly dependent upon temperature at temperatures below about 3°K.¹ It appears to be possible to account for them on the basis of the analysis of antiferromagnetism in a crystal of rhombic symmetry at the absolute zero proposed by Gorter and Haantjes.²

We divide the lattice of magnetic ions into two sublattices i and j . An ion i is supposed to have a moment of momentum $(\hbar/2)\sigma^i$ and a magnetic moment $(\mu_1\sigma_1^i, \mu_2\sigma_2^i, \mu_3\sigma_3^i)$. Let the exchange energy between two neighboring ions i and j be $\sum_k(\gamma_k/z)\sigma_k^i\sigma_k^j$ (z is the number of nearest neighbors).

Introducing $h_k = \mu_k H_k$ (H is the external field), Gorter and Haantjes, who follow the phenomenological treatment of Néel³ and Van Vleck,⁴ find at each value and direction of h three solutions for the magnetic moments which are mathematically permissible. They show which of these solutions will be realized physically. On this basis the resonance problem has been treated following the method used by Kittel⁵ and Nagamiya.⁶

The equation of motion for the sublattice averages of the moments is

$$\alpha \dot{\sigma}_1^i / dt = (2/\hbar) [\bar{\sigma}_2^i (h_3 - \gamma_3 \bar{\sigma}_3^i) - \bar{\sigma}_3^i (h_2 - \gamma_2 \bar{\sigma}_2^i)]$$

(cyclic, and the same for i and j interchanged). Taking the variation of this equation and assuming the dependence upon time of the variations of the variables to be $\exp(i\omega t)$, one finds the resonance condition by putting equal to zero the determinant of the coefficients of the variations of $\bar{\sigma}_1^i, \bar{\sigma}_2^i, \bar{\sigma}_3^i, \bar{\sigma}_1^j, \bar{\sigma}_2^j, \bar{\sigma}_3^j$. To find the resonance condition in the form of a direct relation between h and ω one has to substitute the physically realized solution of Gorter and Haantjes into the equation which is obtained.