measured decay rate, if detected, would not exceed 0.0004 percent. The contribution to the detected radiation from all the calcium isotopes is also quite negligible.

† Published by permission of the Director-General of Scientific Services, Department of Mines and Technical Surveys, Ottawa, Canada.
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Cross Terms in β-Decay

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(Received December 2, 1952)

THE cross terms between S and V and between T and A interaction in β-decay, the so-called Fierz terms, are in general assumed to vanish. This assumption is based on the apparent straightness of Kurie plots for allowed transitions, where the general expression for the β-spectra is given by[1]

$$P_{\mp} = C \cdot pE(E_{max}-E)^2 F(Z, E)(1 \pm b/E),$$

$$b_{\mp} = \pm \frac{2[1-(Z/137)^2]^{\frac{1}{2}}\{g_S g_V |\int 1|^2 + g_T g_A |\int \sigma|^2\}}{[g_S^2 + g_V^2]|\int 1|^2 + [g_T^2 + g_A^2]|\int \sigma|^2}.$$

For low and medium maximum energies, the most important effect of the cross term b/E is a change of the slope of the Kurie plot. This change is, however, not detected since it is equivalent to a change of C. What remains is a curvature which appears as a small deviation from a straight line, the slope of which is adjusted to the experimental points.

If a β-spectrum can be measured accurately from 100 kev up to 100 kev below the maximum energy, and a straight line is drawn in the Kurie plot through these points, the maximum deviation from this line will be a function of E_{max} and b. This function in percent of the ordinate is illustrated in Fig. 1.

It is seen that even large values of $b(-1 \leq b \leq 1)$ give only small deviations and that, consequently, it is difficult to obtain very narrow limits for b. In fact, an analysis of the published β-spectra indicates that in no case can b values as large as 0.4 be excluded. In such experimental comparisons, one should of course remember that b has opposite sign for positron and negatron emission. Furthermore, it should be remembered that b, besides being a function of the coupling constants, also depends on the nuclear matrix elements. The dependence of b on the coupling constants is
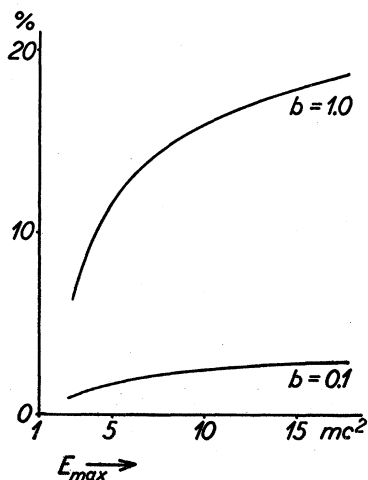

FIG. 1. Maximum deviation of the curved Kurie plot from a straight line drawn through points 100 kev above zero energy and 100 kev below maximum energy for different values of the cross term coefficient b and as a function of E_{max}.
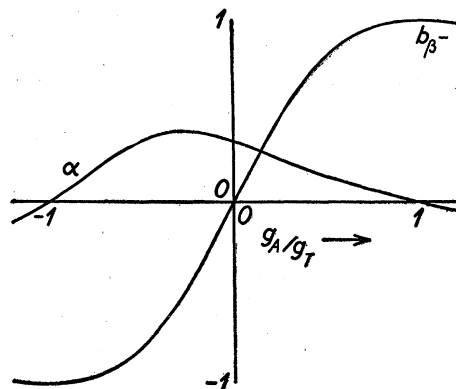

FIG. 2. The experimental angular correlation parameter α and the cross term parameter b_β^- for allowed G-T transitions.

especially simple in the case where either $|\int 1|^2$ or $|\int \sigma|^2$ vanish. In Fig. 2, we have plotted b as a function of g_A/g_T in the $|\int 1|^2 = 0$ case.

The possible existence of cross terms will also influence the interpretation of recoil experiments, where the electron-neutrino angular correlation is investigated. If cross terms exist, this correlation is given by[1]

$$W(\theta_{\beta\nu}) = 1 + a(p/E)\cos\theta_{\beta\nu} + b/E,$$

and the measured angular correlation coefficient will be given by

$$\alpha = a/(1+b/E),$$

where E is a certain mean energy of those electrons for which the angular correlation is measured. In Fig. 2, we have plotted α as a function of g_A/g_T in the case $|\int 1|^2 = 0$ for $E = 2$.

It is seen that a determination of α does not permit a unique determination of g_A/g_T, and therefore, it seems valuable to combine β-spectroscopic measurements with the recoil experiments.

Precision measurements of the shape of allowed β-spectra with high maximum energy are therefore very desirable, and especially for transitions where the ratio $|\int 1|^2/|\int \sigma|^2$ can be estimated so that one can interpret the results in terms of the coupling constants.

A more detailed account of these considerations will be given in *Kongelige Danske Videnskabernes Selskab, Matematisk-fysiske Meddelelser.*

[1] See, e.g., S. R. de Groot and H. A. Tolhoek, Physica 16, 456 (1950).

Heat Pulses in Liquid Helium II below 1°K

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(Received November 21, 1952)

GORTER[1] has suggested that the propagation of heat pulses in liquid helium II well below 1°K can be explained if we assume that the phenomena are not due to second sound but to normal thermal conduction. The purpose of this letter is to agree partially with this suggestion, while pointing out that it is not, as Gorter suggests, inconsistent with the views of Landau,[2] but receives a satisfactory explanation in terms of the development of these views by Khalatnikov.[3,4]

According to Khalatnikov, the mean free path of a phonon at 0.2°K is of the order of 10^3 cm and this is incompatible with the propagation of second sound with a wavelength less than this. The events resulting in the propagation of a heat pulse may therefore be visualized as follows. Phonons are generated at the transmitter and subsequently describe paths during which they suffer no collisions with other phonons. A few phonons travel directly to the

receiver, and the received signal starts after a finite time determined by the velocity of first sound u_1. In this respect the situation cannot be adequately described by the classical equations of thermal conduction, which always give a received signal starting at time zero. Most phonons travel to the wall of the propagation tube where they are diffusely scattered once or many times before reaching the receiver. The signal therefore builds up gradually and the apparent arrival time may depend on the noise level or amplification of the receiver giving an apparent velocity somewhat less than u_1.

The thermal conductivity of the material of the propagation tube is usually so low that heat generated inside the tube leaks out with a long relaxation time of the order of several milliseconds. The excess phonons therefore distribute themselves uniformly throughout the enclosure, producing inside it a uniform excess temperature which then dies away with this long relaxation time, thus producing the long tail observed on the received pulse. It is worth noticing that the maximum amplitude depends only on the heat supplied per pulse and the thermal capacity of the enclosed liquid, suggesting a possible method for measuring the specific heat of the liquid at very low temperatures.

These considerations apply only to the lowest temperatures where the mean free path is large. Khalatnikov's theory would restrict their validity to the temperature range below about 0.6°K. The rise in the velocity of second sound just below 1°K is not so readily explained in terms of dispersion effects. Applying, for example, Dingle's[5] theory of viscous attenuation, the 20 percent rise[6] in velocity at 0.85°K would require a viscosity of the order of 0.1 poise, which appears rather large. A complete set of velocity and attenuation measurements in this region must be available before it can be concluded that the rise in velocity can be explained in any other way than that suggested by Landau.

I should like to thank Professor W. H. Watson for many stimulating discussions.

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Pseudo-Quadrupole Effect for Nuclei in Molecules*

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(Received December 4, 1952)

S EVERAL years ago, Foley,[1] following a suggestion of Van Vleck,[2] calculated the pseudo-quadrupole effect for nuclei in diatomic molecules. This effect was a perturbation of the energy levels similar to that by a nuclear electrical quadrupole moment but due instead to the second-order paramagnetic interaction between the nuclear magnetic moment and the electron orbital moments.

It is the purpose of this note to point out that in addition to the effect considered by Foley there are two other magnetic terms which give rise to apparent nuclear quadrupole moments which are of similar magnitude to the term considered by Foley. One of these corresponds to the direct or low frequency term in the diamagnetic susceptibility of molecules.[3] The terms considered by Foley correspond to high frequency[3] (or second-order paramagnetism) terms of the diamagnetic susceptibility. The other new contribution is that due to the electron spins of the molecule. As recently pointed out by Ramsey and Purcell,[4] the effects of the electron spins cannot be neglected even in $^1\Sigma$ molecules when the perturbations entering in a second-order perturbation calculation correspond to magnetic fields that are not uniform throughout the molecule. In such cases the second-order contributions from the triplet state must be included. Since the magnetic field of the

nuclear magnetic moment is far from uniform in the molecule, the contribution from the interaction between the nuclear magnetic moment and electron spin magnetic moment must therefore be included.

These terms can best be discussed quantitatively with the aid of the Hamiltonian used by Ramsey and Purcell:[4]

$$\mathfrak{IC} = \mathfrak{IC}_1 + \mathfrak{IC}_2 + \mathfrak{IC}_3,$$

where

$$\mathfrak{IC}_1 = \Sigma_k [1/2m_k][(\hbar/i)\nabla_k + (e\hbar/c)\Sigma_l \gamma_l \mathbf{I}_l \times \mathbf{r}_{kl}/r_{kl}{}^3]^2$$
$$+ V + \mathfrak{IC}_{LS} + \mathfrak{IC}_{SS} + \mathfrak{IC}_{II},$$
$$\mathfrak{IC}_2 = 2\beta\hbar \Sigma_{kl} \gamma_l \{3(\mathbf{S}_k \cdot \mathbf{r}_{kl})(\mathbf{I}_l \cdot \mathbf{r}_{kl})r_{kl}{}^{-5} - \mathbf{I}_l \cdot \mathbf{S}_k r_{kl}{}^{-3}\},$$
$$\mathfrak{IC}_3 = (16\pi\beta\hbar/3)\Sigma_{kl} \gamma_l \delta(\mathbf{r}_k - \mathbf{r}_l)\mathbf{S}_k \cdot \mathbf{I}_l.$$

The only terms that were considered by Foley were the cross products of the two terms inside the bracket of $\mathfrak{IC}_1$. The additional term corresponding to simple diamagnetism is the square of the second term in the bracket of $\mathfrak{IC}_1$. Since Foley's term enters only in second order, these two contributions are of comparable magnitude. The other, and, in general, larger effect from the electron spin is that which results from $\mathfrak{IC}_2$, $\mathfrak{IC}_3$, and their cross terms. Although the term $\mathfrak{IC}_3$ gives rise to the largest matrix elements for a molecule such as D_2, it alone, even in a second-order perturbation calculation, gives rise to no pseudo-quadrupole effect since it is independent of the molecular orientation. However, the cross terms between $\mathfrak{IC}_2$ and $\mathfrak{IC}_3$ in the second-order perturbation and the terms dependent on $\mathfrak{IC}_2$ alone both give rise to pseudo-quadrupole effects with the contribution of the former considerably exceeding the latter in the case of D_2. If Q' is the apparent electric quadrupole moment of the nucleus produced by these magnetic interactions, the apparent quadrupole interaction $eQ'(\partial^2 V^{\text{ext}}/\partial z^2)$ produced by Foley's term for D_2 is approximately -1 cycle per second when estimated by the procedure in his paper. The contribution of the simple diamagnetic term is approximately $+0.4$ cycle per second when estimated with Heitler-London wave functions. The contribution of the electron spins when estimated with Heitler-London wave functions is -2.4 cycles per second. Although all of these pseudo-quadrupole interactions are smaller than those of any nuclear quadrupole moment so far measured, they are comparable to the effects which can be measured in present precision experiments.

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A New Approach to the Problem of Higher Order Corrections in the Meson Theory of Nuclear Forces

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(Received November 28, 1952)

T HE method of successive approximations,[1] outlined for classical meson field equations in a previous note,[2] is here applied to consistent quantum-mechanical calculations. For the sake of generality we present here a formalism, which contains both classical and quantum mesodynamics. Adopting the usual notations, all the equations for the meson fields can be written in the general form

$$(\square - \mu^2)\varphi = -4\pi\Omega\delta(\mathbf{x} - \mathbf{x}_{(1)}), \tag{1}$$

where $\delta(\mathbf{x})$ is the three-dimensional Dirac function, $\mathbf{x}$ is the vector of position in ordinary space, and Ω is a linear operator characterizing the sources of the meson field component φ. In all cases considered we assume that Ω commutes with the Laplacian operator Δ.