unquestionable; as a possible alternative, $P^{30}$ would be a radiative capture of nitrogen on oxygen, a reaction which is not as probable as one involving emission of two protons.

Nitrogen was bombarded in the form of tantalum nitride, prepared by passing nitrogen over clean tantalum at 1000°C. Upon bombardment, the target showed 2-minute, 10-minute, and 112-minute activities. It is possible that the TaN target contains oxygen contamination. The 2-minute activity may be a mixture of $O^{15}$ produced from the nitrogen in the target and of $Al^{28}$ produced in the oxygen contaminant. The 10-minute half-life can be assigned to $N^{13}$ and arises from a nitrogen-nitrogen reaction. The 110-minute half-life is assigned to $F^{18}$, which may be due entirely to oxygen contamination in the target.

The observable activities are listed in Table II, in the order of decreasing $Q$ values. The $Q$ values were computed from the mass values of Mattauch and Flammersfeld.[3] It is to be noted that in general the reactions observed are the most exoergic ones. For this reason the $F^{18}$ found in the nitrogen is attributed to oxygen contamination. We did not find a 10.1-minute, 20.5-minute, or 118-second activity in any of the carbon targets, even though the formation of the respective isotopes is energetically possible, and easily observable.

We wish to thank Mr. J. B. Dial for the preparation of the deuterium target. It is a pleasure to acknowledge the many fruitful discussions with Dr. J. L. Fowler. We are indebted to Dr. H. L. Reynolds for the beam energy determination in nuclear emulsions.

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## Paramagnetic Resonance in Copper Acetate at 47 000 Mc/sec

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ANOMALOUS paramagnetic resonance absorption in copper acetate was first reported by Lancaster and Gordy.[1] Resonance experiments on single crystals of this substance were made by Bleaney[2] and Kumagai *et al.*,[3] and the experimental results were analyzed by Kambe.[4]

The present experiments were made on single crystals at a wavelength of 6.38 mm. The results were compared with the theory and were found in sufficient agreement with it. Figures 1 and 2 are, respectively, the changes in resonance field and $g$ value with crystal orientation, when the direction of the applied field was varied by 180° in the $(11\bar{1})$ plane of the crystal from the [110] direction, which was perpendicular to the external field.

According to the theory by Kambe and Bleaney, four $Cu^{++}$ ions in a unit cell comprise two pairs of ions and strong exchange forces are postulated between two ions in a pair; the resonance field for a

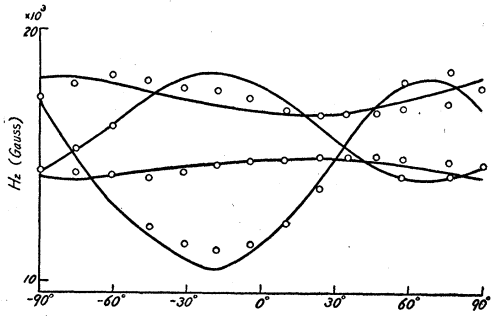


FIG. 1. Resonance field *vs* crystal orientation; the full lines denote the theoretical curves.

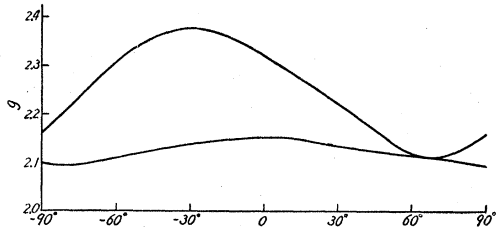


FIG. 2. Angular dependence of $g$ value for each pair of $Cu^{++}$ ions.

pair of $Cu^{++}$ ions is expressed as

$$H=(h\nu/g\beta)\pm P(3\cos^2\theta-1), \quad (1)$$

where $P$ denotes a constant having the dimensions of magnetic field and $\theta$ is the angle between the applied field and an axis passing through two $Cu^{++}$ ions in a pair.

Substituting the observed values, $g_\perp=2.10$, $g_{II}=2.37$ in Eq. (1), where the value of $P$ is taken to be 2000 gauss, the curves in Fig. 1 were obtained by projection on the $(11\bar{1})$ plane; for a pair of curves that had the larger amplitude, the angle between an axis passing through two $Cu^{++}$ ions in a pair and the $(11\bar{1})$ plane was calculated to be 4°, and for another pair of curves that had smaller amplitude the angle was calculated to be 59°.

The authors wish to express their thanks for valuable discussions with Dr. H. Kumagai and Mr. E. Abe at the Institute of Science and Technology, Tokyo University.

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## The Half-Life of $W^{187}$†

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THE half-life of $W^{187}$ has been determined by a number of workers since it was first discovered in 1935.[1,2] Most of these measurements resulted in a half-life value of 24.0±0.1 hours.[3–6] More recently, however, Cork, Keller, and Stoddard[7] have published a value of 25.0 hours, well above previous readings. As a knowledge of the half-life of this isotope was considered important for some experiments carried out in this laboratory, a careful redetermination of the half-life has been carried out.

The measurements were performed by means of an argon-filled pressure ionization chamber, a vibrating reed electrometer, and a pen recorder. The stability of this apparatus has been described before[8] and is more than adequate for the purpose. Two samples were used, a chemically pure calcium tungstate powder and a piece of pure tungsten metal. Each sample was irradiated for one day with slow neutrons from a radium-veryllium source with paraffin moderator. The decay of each sample was plotted over a period of four half-lives, two different runs being carried out on both samples. Both samples were analyzed spectrographically for impurities. The calcium tungstate contained less than 0.1 percent Mg and trace amounts of Fe, Sn, Cu, and K. The tungsten metal contained trace amounts of Mo, Fe, Si, and Cu, all less than 0.05 percent.

The weighted mean obtained from the four determinations by least squares analysis of each decay curve was 23.85±0.08 hours.

Weighting was carried out by taking into account the probable error of the individual runs. The error includes contributions from the other wolfram isotopes which are very small, $W^{181}$ has a half-life of 140 days and its production rate is very low; $W^{183}$ has a half-life of 5.5 sec. $W^{185}$ emits only very soft gamma-rays and in its normal isotopic abundance contributes not more than 0.08 percent of the total initial activity. Over three days its contribution to the

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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THE cross terms between $S$ and $V$ and between $T$ and $A$ interaction in $\beta$-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 $\beta$-spectra is given by[1]

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

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

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 $\beta$-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 $\beta$-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

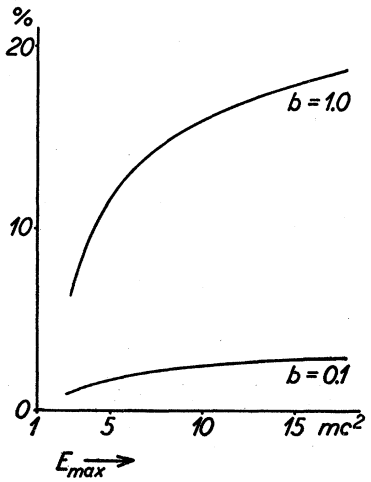


FIG. 1. Maximum deviation of the curved Kurie plot from a straight line drawn through points 100 kev above zero energy and 100 kev below maximum energy for different values of the cross term coefficient $b$ and as a function of $E_{\max}$.

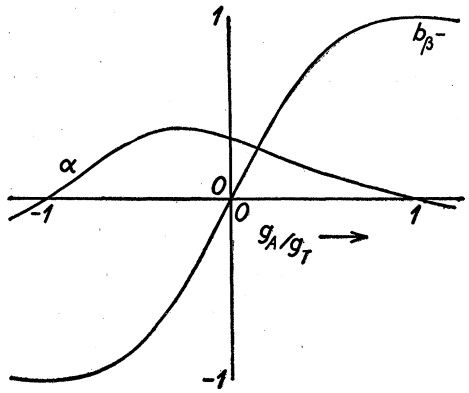


FIG. 2. The experimental angular correlation parameter $\alpha$ and the cross term parameter $b_{\beta^-}$ for allowed G-T transitions.

especially simple in the case where either $|\int 1|^2$ or $|\int\boldsymbol{\sigma}|^2$ 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 $\alpha$ 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 $\alpha$ does not permit a unique determination of $g_A/g_T$, and therefore, it seems valuable to combine $\beta$-spectroscopic measurements with the recoil experiments.

Precision measurements of the shape of allowed $\beta$-spectra with high maximum energy are therefore very desirable, and especially for transitions where the ratio $|\int 1|^2/|\int\boldsymbol{\sigma}|^2$ 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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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