

Ferromagnetic Resonance Absorption in Heusler Alloy

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THE g factors calculated from ferromagnetic resonance absorption measurements at microwave frequencies on nickel,^{1,2} iron,^{1,2} cobalt,¹ Supermalloy,^{3,4,5} and zinc-manganese ferrite,⁶ using the expressions derived by Kittel,⁶ are all significantly greater than the free spin value of 2.00, whereas the apparent g factor deduced from Barnett's⁷ gyromagnetic ratio experiments are all significantly less than 2.00 with one exception, Heusler alloy (Mn-Cu-Al), for which the free spin value was obtained. The reality of this difference in g factor as determined by the two methods now seems well established on the basis of the normal field experiment on Supermalloy⁸ and Hewitt's⁵ measurements on a ferrite sphere. Both experiments demonstrate the correctness of Kittel's resonance formulas for the various test conditions and also the reality of the high g factors obtained in the microwave measurements.

The g factors deduced from a measurement of the Zeeman splitting, as in a microwave resonance experiment, is expected theoretically to be equal to the apparent g factor deduced from a gyromagnetic ratio experiment only if the spin-orbit system is acted on by central fields. In the presence of inhomogeneous crystalline electric fields, the equality no longer holds. This has been shown in the case of paramagnetic salts by Gorter and Kahn.⁹ No detailed treatment of ferromagnetic substances has been given, although Polder¹⁰ has made some pertinent observations.

It seemed probable that in a material such as Heusler alloy for which the apparent g factor from the gyromagnetic measurements is equal to 2.00, the g factor from microwave resonance absorption may also be equal to 2.00. This equality appears to be indicated by the measurements described below.

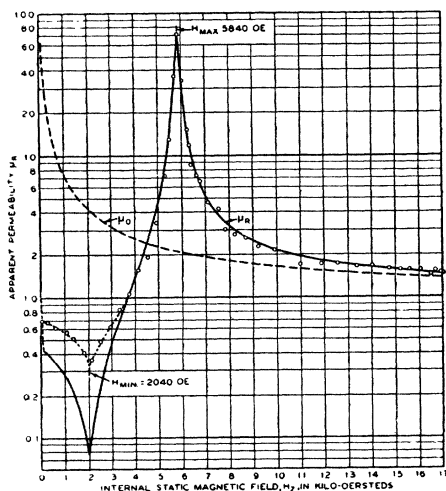


FIG. 1. Ferromagnetic resonance absorption in Heusler alloy at 23,900 Mc.

Test specimens 0.75 inch in diameter and of various thicknesses were machined from a cast ingot of Heusler alloy having the composition: 26 percent Mn, 61 percent Cu, 13 percent Al. They were then heat treated at 750°C in hydrogen for one hour, air cooled, and aged at 200°C for 48 hours. The resonant cavity⁴ previously described was used in this experiment, the resonant frequency being 23,880 megacycles. Figure 1 shows the results obtained on a 0.040-inch thick specimen oriented parallel to the static magnetic field. The plotted field strength has been corrected for the demagnetizing field of $NB_s/4\pi = 260$ oersteds. The equations⁴ for maximum and minimum energy absorption are, respectively,⁵

$$\begin{aligned}\omega &= \gamma[(H_{\max} + B_s)H_{\max}]^{\frac{1}{2}}, \\ \omega &= \gamma(H_{\min} + B_s), \\ \gamma &= ge/2mc.\end{aligned}$$

$B_s = 4\pi M_s$ is the saturation induction and the H 's are the internal static magnetic fields (applied $H - NB_s/4\pi$) for maximum and minimum absorption. The experimental values are: applied $H_{\max} = 6100$ oersteds, applied $H_{\min} = 2300$ oersteds, $\omega = 15.006 \times 10^{10}$ rad./sec. and $N/2\pi = 0.0405$. Solving the equations for g and B_s , we obtain: $g = 2.01$, and $B_s = 6425$. Similar measurements on a 0.020-inch specimen gave the following results: applied $H_{\max} = 6050$ oersteds, applied $H_{\min} = 2370$ oersteds, $\omega = 15.01 \times 10^{10}$ rad./sec., $N/4\pi = 0.0208$, $B_s = 6250$, and $g = 2.01$. Thus it is seen that the g factor of Heusler alloy has essentially the free spin value as determined by both the microwave resonance absorption and Barnett's experiments.

The points in Fig. 1 represent the experimental data, and the solid curve represents the theoretical variation with $\lambda/H = 2.53 \times 10^6$ rad./sec.-oersteds. The agreement between theory and experiment is good except that the experimental data tend to round off the theoretical minimum. This same behavior has been observed in unpublished data for annealed nickel and to a much lesser extent in annealed Supermalloy.⁴ The resonance in Heusler alloy is much sharper than that observed in nickel and iron and is comparable to that found in annealed Supermalloy.

We are indebted to Dr. C. Kittel and Dr. R. M. Bozorth of these Laboratories for their interest and helpful suggestions in connection with this investigation.

- ¹ J. H. E. Griffiths, *Nature* **158**, 670 (1946).
- ² W. A. Yager, paper in preparation.
- ³ W. A. Yager and R. M. Bozorth, *Phys. Rev.* **72**, 80 (1947).
- ⁴ W. A. Yager, *Phys. Rev.* **75**, 316 (1949).
- ⁵ W. H. Hewitt, Jr., *Phys. Rev.* **73**, 1118 (1948).
- ⁶ C. Kittel, *Phys. Rev.* **71**, 270 (1947); **73**, 155 (1948).
- ⁷ S. J. Barnett, *Proc. Am. Acad. Arts and Sci.* **75**, 109 (1944); *Phys. Rev.* **66**, 224 (1944).
- ⁸ C. Kittel, W. A. Yager, and F. R. Merritt, *Amsterdam Conference on the Physics of Metals, 1948* (to appear in *Physica*).
- ⁹ C. J. Gorter and B. Kahn, *Physica* **7**, 753 (1940).
- ¹⁰ D. Polder, *Phys. Rev.* **73**, 1116 (1948).

Disintegration of Hg²⁰³

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IN a recent letter D. Saxon¹ has given a report on some measurements on 43-days Hg^{203,205}. We have also

investigated this activity lately and though many of our final results agree with Saxon's, we believe that some of these ought to be discussed. First the mass assignment has now been definitely proved (in accordance with Inghram *et al.*²) to be 203 by magnetic isotope separation in this laboratory of the irradiated sample (from Oak Ridge). The activity was then actually depositing on the mass number 203 (paper in course of publication by our separation group in Arkiv. f. Mat., Astr. o. Fys.).

To get the upper limit for the continuous β -spectrum, which in this case is very soft and badly masked by strong internal conversion lines right at the upper limit, one has to base the Fermi analysis mainly on the softer part of the spectrum where on the other hand absorption is most pronounced.

This absorption does not only occur in the counter window but of course also in the source itself. In the case of Hg^{203} where the specific activity was not too good, this latter correction is hard to estimate. To get rid of this difficulty, we have determined the upper limit in another way so that the strong β -line is practically eliminated. Since the whole β -spectrum is followed by the γ -line one would expect the (β, γ) coincidence spectrum taken in the coincidence spectrometer³ to give a distribution corresponding to the simple continuous β -spectrum *without* the β -line. One can then base the Fermi analysis on points which are nearer to the end point, where the absorption ought to be small. One could, however, also expect to get a very small coincidence effect due to the simultaneous

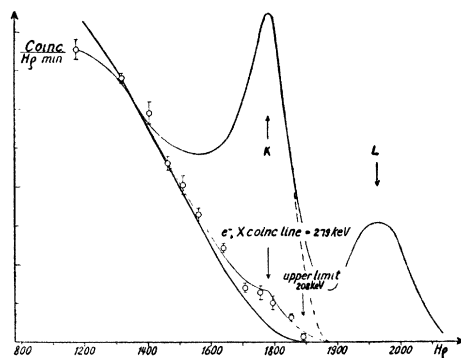


FIG. 1. β -spectrum of Hg^{203} . The thin curve through the measured points belong to the β - γ -coincidence spectrum. The strong curve represents the continuous β -spectrum, when the e^- , X coincidence line is eliminated by the method of least squares.

emission of internal conversion electrons focused in the spectrometer and x-rays emitted when the atomic shell is refilled. The efficiency of the γ -counter for this radiation ($EK_{\alpha} = 70$ kev) is fortunately very low in our arrangement, so that the e^- , X coincidence line would be small in intensity. The coincidence spectrum is shown in Fig. 1. As can be seen, the strong β -lines (K and L) have been replaced by the last part of the continuous spectrum on which a very small e^- , X coincidence line is superimposed. This effect can further easily be corrected for, using the method of least squares. Making the Fermi plot one arrives at a value

of 208 kev for the upper limit of the β -spectrum, which is very nearly the same as that given by Saxon.

The γ -energy was also determined by a newly built large double focusing β -spectrometer with $\rho = 50$ cm (in course of publication). Figure 2 shows the internal con-

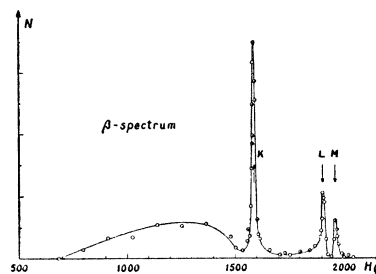


FIG. 2. β -spectrum of Hg^{203} obtained with the double focusing spectrometer with high resolving power.

version spectrum. The window was not very thin, which makes an analysis of the continuous spectrum difficult. To get the required resolution the sample furthermore had to be evaporated in a thin layer which limited the statistical accuracy of individual points. However, we were then able to resolve the L - and M -conversion electron lines completely. The intensity ratio between the K - and L -lines is in good agreement with Saxon's value, namely, equal to ~ 3 . The ratio between the L - and M -lines, not resolved by Saxon but estimated to be ≥ 12 , is however considerably smaller. The photoelectron spectrum was also investigated using a lead foil 3μ thick (Fig. 3). K -, L - and M -photo lines can be observed. The spectrograph was calibrated with the annihilation radiation and also with the ThB F-line (1383.8 H_p). The energy of the γ -line can be determined from both the three internal conversion lines and the three lead photo-lines. Since the evaporated sample could not be considered as infinitely thin, the correct calibration factor to be used in the case of the internal conversion measurement should be somewhere between the annihilation radiation factor and the ThB F-line factor.

The former factor gives too high values and the latter too low. The photoelectron spectrum should give correct results, provided one can extrapolate the factor obtained from the annihilation radiation at 511 kev with the 3μ thick lead foil down to these lower energies. Table I shows the results. As can be seen, the agreement between the different values is quite close. As a mean value of the

TABLE I.

Line	Energy of γ -line in kev	
	with ThB calibration	with annh. calibration
K - β -line	278	280
L - β -line	277	279
M - β -line	279	281
K -photo-line		279
L -photo-line		279
M -photo-line		278

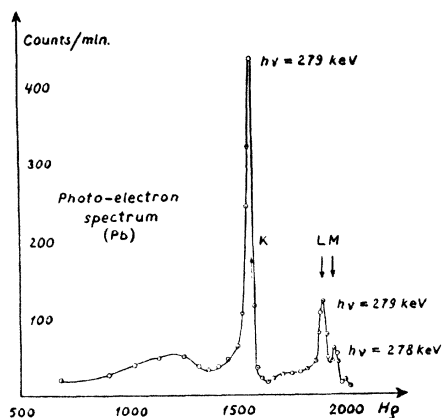


FIG. 3. Photoelectron spectrum from 3- μ Pb converter, released by the 279-keV Hg^{203} γ -ray.

γ -energy we can use $E_{\gamma} = 279 \pm 2$ kev. The corresponding value of Saxon is 286 ± 5 kev.

Another point of interest is that the 279-kev excited level in Ta^{203} can also be obtained in a different way. A. Lutz, M. Pool, and J. Kurbatov⁴ when examining the β -radiation from 52-hour Pb (ascribed by them to Pb^{205}) found internal conversion lines corresponding to γ -rays of 270 and (possibly) 470 kev (explained as Compton electrons). Since the 270-kev radiation is very probably the same γ -line as our 279 kev, it is then almost certain that the 52-hour Pb has the mass 203 and decays by K-capture to Ta^{203} with emission of a γ -ray of 279 kev. A fuller description will appear in *Arkiv. f. Mat., Astr. o. Fys.*

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² M. G. Inghram, D. C. Hess, Jr., and R. J. Hayden, *Phys. Rev.* **71**, 561 (1947).

³ K. Siegbahn and A. Johansson, *Arkiv. f. Mat., Astr. o. Fys.* **34A**, No. 10 (1946).

⁴ A. L. Lutz, M. L. Pool, and J. D. Kurbatov, *Phys. Rev.* **65**, 61 (1944).

Single Crystal Growth of Scheelite

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SCHEELITE, CaWO_4 , has been shown to be one of the most efficient crystals for gamma-ray counter applications.¹ For this purpose clear, transparent, single crystal material of reasonable size (~ 0.5 cc) is required. Since natural scheelite of sufficient purity and size is quite rare, it is necessary to resort to some laboratory growth technique.

Our experiments show that scheelite of sufficient purity and size can be grown by either of two techniques: (a) by flame fusion, the Vernueil process, and (b) from the melt by the gradient technique.

The flame fusion process, such as is used for production of synthetic sapphires, has been described elsewhere.² In this process the feed material is carried, as a fine powder, into one of the lines of an oxygen-hydrogen burner and caused to melt in the flame. The molten material is collected on a refractory support and is caused to grow into a single

crystal by suitable manipulation of the flame, feed, etc. The conditions necessary to cause satisfactory growth unfortunately cannot be precisely stated and contain a large personal factor. Our burner was of standard design and consisted of two concentric cylindrical tubes, 25 mm and 2.5 mm I.D., respectively. The central tube extended to within 25 mm of the outer tube face. It was through this central tube, connected to an overhead hopper, that the powder (-200 mesh) was introduced into the flame. CaWO_4 of fluorescent grade, made either by sintering or precipitation, was first used as a feed material and yielded cloudy polycrystalline boules. We attribute this result to the WO_3 deficiency of the powder or to volatilization of WO_3 or to both of these factors. Clear boules were first obtained after 4–10 percent by weight of WO_3 (-200 mesh) was mechanically incorporated into the feed, thus reducing the loss of WO_3 during growth. Any excess was apparently volatilized although best results were obtained with 4 percent WO_3 addition. Considerable trouble was experienced with cracking of the boules during cooling. This cracking was reduced by the use of a smaller radiation space around the boule. Material of the size $4 \times 4 \times 4$ mm was obtained by this method.

Much larger and more satisfactory material was grown from the melt by the gradient technique. In this process a melt of the material in a cone-shaped crucible was slowly lowered through a temperature gradient.³ Platinum crucibles, 18 or 31 mm in diameter with 60-degree cone tips, have been used in our work. The crucible, filled with the melt, was held in a platinum resistance furnace at 1625°C^* and slowly lowered through the furnace gradient (an average of 59 degrees/cm for an elevator lowering of 125 cm) at a speed of 3.2 hours/cm. The raw material was fluorescent grade CaWO_4 without any addition.

We have obtained satisfactory single crystal boules yielding fragments $5 \times 5 \times 5$ mm by this process but as described above serious cracking of the boules was experienced unless it was allowed to cool quite slowly after solidification.

The fluorescent and counter behavior of scheelite by either technique was entirely satisfactory.

* The melting point of scheelite has not been reported in the literature. As determined by us it is $1576^\circ \pm 5^\circ\text{C}$.

¹ Robert J. Moon, *Phys. Rev.* **73**, 1210 (1948).

² FIAT Final Report No. 655, 12/28/45, *Bull. Acad. Sci. U.S.S.R. Physics Series* No. 5-6, p. 505-8 (1946).

³ *Rev. Sci. Inst.* **7**, 133 (1936); *Phys. Rev.* **36**, 1663 (1930); O. F. Tuttle and P. H. Eglil, *J. Chem. Phys.* **14**, 571 (1946).

Nuclear Shell Structure and Isomerism*

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THE shell structures¹⁻⁴

$$\begin{aligned} &(1s)^2 \\ &(1s)^2 (2p)^6 \\ &(1s)^2 (2p)^6 (2s)^2 \\ &(1s)^2 (2p)^6 (2s)^2 (3d)^{10} \\ &(1s)^2 (2p)^6 (3d)^{10} (4f)^{14} (5g)^{18} \end{aligned}$$