Letters to the Editor

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Size Effects and Diamagnetism in Finite Systems

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DINGLE[1] has reported a diamagnetism for a finite system of free electrons in weak fields $[H<c(2m\zeta)^{\frac{1}{2}}/eR\sim 5/R]$ in contradiction to a conclusion previously inferred by one of us.[2] We have examined this problem for a cylindrical container using the methods of lattice point problems in the theory of numbers,[3] and have been able to verify the order of magnitude of Dingle's results, thus resolving this controversy.

We have also examined by the same methods the case for strong fields ($H\gtrsim 5/R$) and find, in addition to the Landau and de Haas-van Alphen terms, a non-oscillatory diamagnetic moment per unit volume,

$$M/V=K(2m)^{1/3}e^{2/3}\zeta^{4/3}/R\hbar^{4/3}c^{2/3}H^{1/3}, \quad (1)$$

where $K\sim 0.02$, ζ is the Fermi energy, R is the radius of the cylinder in cm, and H is the magnetic field strength in gauss.

This term arises from the quantization of orbits which intersect the walls of the container, and hence, may be called a surface diamagnetism. It approaches the Dingle diamagnetism as $H\rightarrow 5/R$. Quantization of these orbits also contributes oscillatory terms to the moment which are in most cases negligible compared to the de Haas-van Alphen effect.

The moment in Eq. (1) is larger than the Landau moment for properly chosen fields and specimen sizes, and hence, may well be observable. Thus if $R\sim 1$ cm, and $\zeta\sim 1$ volt, this moment is $\geq$ the Landau moment for $H\lesssim 300$ gauss. If $R\sim 10^{-2}$ cm, this moment is $\geq$ the Landau moment for $H\lesssim 10{,}000$ gauss. Thus it should be possible to observe this effect.

Experimental evidence[4] on the size effect in the diamagnetism of small unoxidized particles appears to be not in agreement with this or Dingle's theory. However, for the applicability of the above calculations, it is essential that the particles be electrically insulated from each other, so that the wave functions are truly bounded by the surface of the particles.

Details of these calculations will be reported subsequently.

[1] R. B. Dingle, Phys. Rev. **82**, 966 (1951).
[2] M. F. M. Osborne, Phys. Rev. **81**, 147 (1951).
[3] M. C. Steele, Proc. of the International Conference on Low Temperature Physics, Oxford, August 22–28, 1951, p. 137.
[4] H. Lessheim, Current Science **5**, 119 (1936).

Hyperfine Structure of the Spectra of Gadolinium and Zirconium

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THE hyperfine structure of the gadolinium spectrum in the visible region was studied, using a water-cooled hollow cathode discharge tube (the cathode contained gadolinium oxide) and a Fabry-Pérot etalon; and the previous measurement of Klinkenberg[1] was greatly improved and extended.

TABLE I. Hyperfine structure of the spectrum of gadolinium.

Type	λ(A)	Combination*	Hfs (10^{-3} cm^{-1}) a	b	c	d
A	4401.8	$4f^7 6s^2 5d a^9D_6 - y^9F_6$	0(6)	59(6)	116(10)	161(4)
	4373.8	$4f^7 6s^2 5d a^9D_4 - y^9F_3$	0(6)	58(6)	111(10)	157(4)
B	4436.1	——	0(7)	74(8)	143(10)	192(3) 233(2)
	4008.3	$4f^7 6s^2 5d a^9D_5 - 4f^7 5d^2 6p z^{11}G_6$	0(6)	79(6)	150(10)	207(3)
	3974.8	$4f^7 6s^2 5d a^9D_6 - 4f^7 5d^2 6p z^{11}G_7$	0(6)	87(6)	160(10)	223(3)
C	5617.9	$4f^7 6s^2 5d a^9D_2 - 4f^7 6s 5d 6p z^9F_3$	0(8)	37(10)	72(10)	115†
	5155.8	$4f^7 6s 5d^2 a^{11}F_6 - 4f^7 5d^2 6p z^{11}G_7$	0(8)	41(10)	81(10)	129†
	5103.4	$4f^7 6s 5d^2 a^{11}F_7 - 4f^7 5d^2 6p z^{11}G_8$	0(8)	42(10)	82(10)	136†
	5015.0	$4f^7 6s 5d^2 a^{11}F_8 - 4f^7 5d^2 6p z^{11}G_9$	0(8)	43(10)	86(10)	143†

* See reference 2.
† The d-component of type C appeared as a weak tail. Its edge on the high frequency side is shown.

Hyperfine structures of some Gd I lines[2] that were measured in the present investigation are listed in Table I. Numbers in parentheses indicate visually estimated intensities. The lines of type A were observed to consist of four components, of which a, b, and d were assigned to Gd^{160}, Gd^{158}, and Gd^{155}, respectively, while c was regarded as the result of superposition of the Gd^{157} and Gd^{156} components; in these lines both of the splittings of the Gd^{157} and Gd^{155} components are very small. In the lines of type B the hyperfine structures were similar to those of A-type lines, except that in the former type the d-component showed a measurable broadening. In the lines of type C, the d-component appeared as a weak tail broadened continuously from c towards higher frequency side and unresolved weak background was also observed between the components b and c; a, b, and c were interpreted as caused by the even isotopes Gd^{160}, Gd^{158}, and Gd^{156}, respectively, and the weak background and the tail as caused by the odd isotopes Gd^{157} and Gd^{155}.

As to the isotope shift, the ratios

$$r_1=\Delta\nu(Gd^{157}-Gd^{160})/\Delta\nu(Gd^{158}-Gd^{160})=1.94\pm 0.25$$

and

$$r_2=\Delta\nu(Gd^{155}-Gd^{160})/\Delta\nu(Gd^{158}-Gd^{160})=2.71\pm 0.02$$

were determined from the structure of λλ4401.8 and 4373.8. The distances $b-a$ in several lines show that the isotope shift per one 6s-electron in the neutral atom per addition of two neutrons[3] is 0.046 ± 0.005 cm^{-1} for $Gd^{158}-Gd^{160}$.

In λ5015.0 ($4f^7 6s 5d^2 a^{11}F_8 - 4f^7 5d^2 6p z^{11}G_9$), which is most suited for determining the nuclear moments of the odd isotopes, intensity distribution of the components caused by the odd isotopes indicates that the spins of both isotopes are $\frac{3}{2}$ or greater. Assuming that the above-mentioned ratios r_1 and r_2 are the same in all lines with respect to the centers of gravity of the components of the odd isotopes, the total splittings for Gd^{157} and Gd^{155} in λ5015.0 were estimated. Neglecting any splitting of the initial term, and using the Goudsmit-Fermi-Segrè formula for the 6s-electron in the term $4f^7 6s 5d^2 a^{11}F_8$, a rough estimate of the magnitudes of the magnetic moments of Gd^{157} and Gd^{155},

$$|\mu(Gd^{157})|=0.3\pm 0.2 \text{ nm}, \quad |\mu(Gd^{155})|=0.25\pm 0.15 \text{ nm},$$

was obtained, although the signs of the magnetic moments and the spins for both isotopes could not be determined.

In the study of the hyperfine structure of the spectrum of Zr I, the cathode contained powdered zirconium and was cooled with liquid air. In some lines, shift of the components caused by the even isotopes Zr^{90}, Zr^{92}, and Zr^{94} was detected, although complete resolution was not attained owing to the Doppler broadening of the components. For example, in the line λ4081.2 ($4d^3 5s^5F_5 - 4d^3 5p x^5D_4$)[4] the distance $Zr^{90}-Zr^{94}=0.020\pm 0.003$ cm^{-1} was measured, the Zr^{90} component lying on the higher frequency side.

The hyperfine structure of Zr^{91}, which isotope is known[5] to have a spin of 5/2, was also observed in some lines. Recently Arroe,[6] using an enriched isotope of Zr^{91}, measured the hyperfine