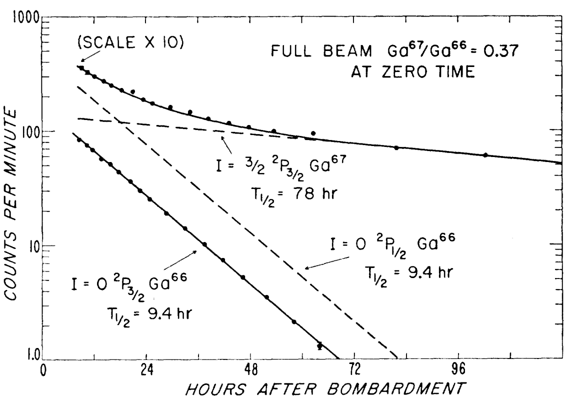

FIG. 1. Decay of gallium spin samples. Decay curve of a spin-0 sample and a spin-$\frac{3}{2}$ sample. The decay serves to identify the specific even-A and odd-A isotopes as Ga^{66} and Ga^{67}, respectively.

bardment of copper in the Berkeley 60-inch cyclotron, and identification made from a half-life analysis of beam exposures taken at appropriate values of radio-frequency and magnetic field (Fig. 1). The observed decay is in good agreement with assignments in the literature.[1–5]

The ground-state fine structure of gallium is 826 cm^{-1}, and the beam temperature 1100°C; therefore, both the $4p\,{}^2P_{\frac{3}{2}}$ and ${}^2P_{\frac{1}{2}}$ levels are appreciably populated. Gallium 66 and 67 resonances have been observed in both levels. Because of a coincidence between the Zeeman frequencies for spin $\frac{3}{2}$ in the ${}^2P_{\frac{3}{2}}$ state and spin 0 in the ${}^2P_{\frac{1}{2}}$ state, exposures taken at this position show a compound decay. Two special runs were therefore made, one for which the 9.4-hr component was allowed to decay before the run was begun, the other for which the 9.4-hr component was selectively produced by differential bombardment. In each case the appropriate resonances were considerably enhanced.

Gross results of spin searches are shown in Fig. 2.

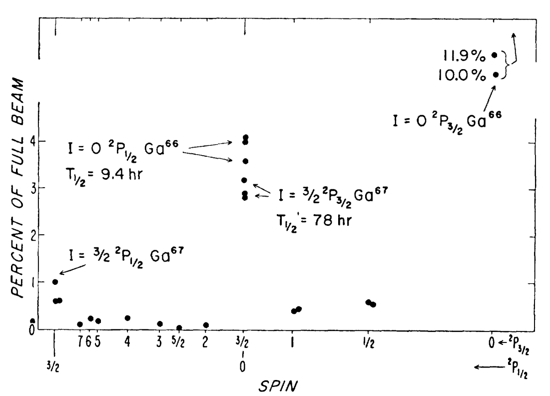

FIG. 2. Comparison of spin samples of Ga^{66} and Ga^{67}. Results of spin searches are indicated by points at various values of frequencies corresponding to specific spins. The experimental points are extrapolated to a time shortly after cyclotron bombardment, and the observed resonances are normalized by the component of the appropriate isotope in the full beam. All possible resonances corresponding to an even-A isotope, $I=0$, and an odd-A isotope, $I=\frac{3}{2}$, were observed.

The atomic-beam method is unfortunately incapable of giving an unequivocal spin-zero assignment, because interactions between the electronic and nuclear systems may be too small for observation. It can, however, give an upper limit to the interaction. Observations on the Ga^{66} resonance in the ${}^2P_{\frac{1}{2}}$ state have been made at three values of magnetic field and from the observed data one can set a conservative upper limit to the magnetic dipole moment of 10^{-3} nuclear magnetons. It is therefore highly probable that the spin of Ga^{66} is zero.

Work on gallium is continuing; a new upper limit to the magnetic moment of Ga^{66} and the hyperfine structure of Ga^{67} will be published later.

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Magnetic Moment and Spin of ${}_{40}Zr_{51}{}^{91}$

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THE optical hyperfine structure of Zr I which was studied by Arroe and Mack[1] yielded a nuclear spin of 5/2 for Zr^{91}. Suwa,[2] using the same method, determined the magnetic moment to be $\mu(Zr^{91})=-1.3$ ± 0.3 nm. Murakawa[3] corrected the result of Suwa and determined the magnetic moment to be $\mu(Zr^{91})=-1.9$ ± 0.2 nm.

Using a Bloch-type nuclear resonance spectrometer, a nuclear induction signal of Zr^{91} has been observed in a saturated solution of $(NH_4)_2ZrF_6$ in D_2O. A comparison of the signal with the corresponding one of O^{17} indicates a negative magnetic moment. The ratio of resonance frequencies of Zr^{91} and D^2 in the same magnetic field and the same sample was measured as

$$\nu(Zr^{91})/\nu(D^2)=0.60557\pm 0.00001.$$

In order to determine the spin of Zr^{91}, differentiated u-mode signals of Cl^{35} (abundance $f=75.4\%$, $I=3/2$, $\mu=0.8209$) and Zr^{91} (abundance $f=11.2\%$) in appropriate solutions of well-defined molarities ($m=1.97$ and 0.7, respectively) were compared at the same resonance frequency and consequently nearly the same magnetic field. The height of these signals was measured as a function of the amplitude H_m of the modulating magnetic field. The ratio of signals S with maximum height was determined to be

$$S(Cl^{35})/S(Zr^{91})=0.93\pm 0.04.$$

Assuming spins of 3/2, 5/2, 7/2 for Zr^{91}, the expected ratios are 2.3 ± 0.2, 1.00 ± 0.07, 0.56 ± 0.04, respectively, according to the formula

$$\frac{S_1}{S_2}=\frac{[mfI(I+1)\gamma H_1]_1[H_m]_2}{[mfI(I+1)\gamma H_1]_2[H_m]_1},$$

where H_1 is the amplitude of the rf field, m the concentration of the nuclei, and γ the gyromagnetic ratio. The experimentally determined ratio of the signals is therefore compatible with a spin 5/2 for Zr^{91} as measured by Arroe and Mack.

Using the ratio of the magnetic moments of H^1 and D^2 as determined by Smaller,[4]

$$\mu(H^1)/\mu(D^2)=3.2571999\pm0.0000012,$$

and the value of the proton magnetic moment,[5]

$$\mu(H^1)=2.79275\pm0.00003 \text{ nm},$$

the diamagnetically uncorrected value of the magnetic moment of Zr^{91} can be calculated as

$$\mu(Zr^{91})=-1.29802\pm0.00002 \text{ nm},$$

or, diamagnetically corrected, as

$$\mu(Zr^{91})=-1.30284\pm0.00002 \text{ nm}.$$

When one considers the proton number $Z=40$ and the neutron number $N=51$ (magic plus one), the spin and sign of the magnetic moment are in agreement with the predictions of the simple single-particle model which places the neutron in a $d_{5/2}$ state. The deviation of the magnetic moment of 32% from the Schmidt value $\mu(\text{Sch})=-1.913$ nm, however, is rather large. For this reason one may consider configurations which also include protons, particularly the last two protons outside the closed shell $Z=28$. In terms of the independent-particle model, the two protons would couple their individual spins j_p to a total proton spin $J_p=0$, 2, or 4, whereas J_p would couple with the odd-neutron spin $j_n=5/2$, to the total angular momentum $I(Zr^{91})=5/2$. Possible configurations consistent with the exclusion principle are

$$[\pi(p_{1/2})^2{}_{J_p=0};\,\nu d_{5/2}]_{5/2},\quad [\pi(g_{9/2})^2{}_{J_p=0};\,\nu d_{5/2}]_{5/2},$$
$$[\pi(g_{9/2})^2{}_{J_p=2};\,\nu d_{5/2}]_{5/2},\quad \text{and}\quad [\pi(g_{9/2})^2{}_{J_p=4};\,\nu d_{5/2}]_{5/2},$$

which yield the magnetic moments in nuclear magnetons of -1.913, -1.913, $+0.037$, and $+4.04$, respectively. This shows clearly that the ground state of Zr^{91} cannot be described by one single configuration of the type mentioned.

The observed relaxation time T_1 of Zr^{91} in aqueous solution of $(ZrF_6)^{--}$ is of the order of 10^{-3} sec and indicates an appreciable electric quadrupole moment.

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Magnetic Moment of the Mu Meson

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It is the purpose of this note to consider radiative corrections to the magnetic moment of the mu meson, under the assumption that the mu meson is a Dirac particle of spin $\frac{1}{2}$, coupled to the electromagnetic field in exactly the same way as the electron is, and not directly coupled to the electron-positron field.

We write the g factor in the form

$$g=2(1+\delta_1+\delta_2)+O(\alpha^3). \tag{1}$$

Here δ_1 represents the correction to the magnetic moment obtained by ignoring the effect of the electron-positron field, and δ_2 arises from the fact that the virtual photons emitted by the mu meson can give rise to a virtual electron-positron pair. This last effect is of order α^2, and the corresponding Feynman diagram is shown in Fig. 1.

From the work of Schwinger[1] and of Karplus and Kroll[2] on the radiative corrections to the magnetic moment of the electron we get δ_1, by noting that this correction is independent of the mass of the pair field. The correction δ_2 can be obtained most directly from formula (53), p. 546 in Karplus and Kroll[2] by a minor modification. The result is

$$\delta_1\cong\frac{\alpha}{2\pi}-\left(\frac{\alpha}{\pi}\right)^2(2.973), \tag{2}$$

$$\begin{aligned}\delta_2&=\left(\frac{\alpha}{\pi}\right)^2\int_0^1 dx\int_0^1 dy\, x^2(1-x)y^2(1-\tfrac{1}{3}y^2)\\&\qquad\times\left[x^2(1-y^2)+\frac{4m_0^2}{m_\mu^2}(1-x)\right]^{-1}\\&=\left(\frac{\alpha}{\pi}\right)^2\left[\tfrac{1}{3}\ln\left(\frac{m_\mu}{m_0}\right)-\frac{25}{36}\right]+\alpha^2 O\left(\frac{m_0}{m_\mu}\right),\end{aligned} \tag{3}$$

$$\delta_2\cong\left(\frac{\alpha}{\pi}\right)^2(1.08),$$

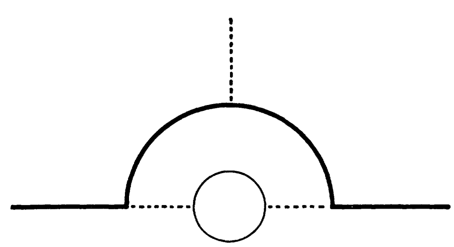

FIG. 1. Feynman diagram for the correction δ_2 to the magnetic moment of a mu meson. The heavy solid lines refer to mu mesons, the thin solid lines to electrons, and the dotted lines to photons.