

For easy comparison our corresponding result for electrons may be reproduced here:

$$f(E, r)dEdS = \frac{2dEdS}{\pi K^2} \left\{ \frac{2.8}{1.36} L_{5/6} \left(\frac{2Er}{(1.36)K} \right) - \frac{1.8}{0.71} L_{5/6} \left(\frac{2Er}{(0.71)K} \right) \right\}, \quad (2)$$

with the abbreviation

$$L_p(x) = (\pi/2)(x/2)^{p+1} H_p^{(1)}(ix)/p!$$

[$K \approx 2 \times 10^7$ ev in (1) and (2).] Both formulas are valid for particle energies above the critical one and for big air showers at their maximum development, the normalization being chosen so that the energy spectrum is given by $E^{-2}dE$ for electrons and by $1.29E^{-2}dE$ for photons [as approximately valid for big showers at maximum, apart from a common constant factor in (1) and (2)].

The photon density (1) differs greatly from that of electrons by its more rapid singularity at $r=0$; varying as r^{-1} for photons as compared with r^{-3} for electrons. This means a much stronger concentration of photons within the core and a more rapid variation of photon density in its vicinity than expected from the corresponding behavior of electrons. (The somewhat larger r.m.s.-spread of photons is almost entirely due to the tail of (1) and does not, therefore, contradict the above result.) This seems, at least qualitatively, to agree with the above-mentioned results of Amaldi and also with those recently obtained by Clay⁴ with six- and eightfold coincidences of shielded counters. Our result further suggests that the stars which, according to observations of Blackett,⁵ occur with an abnormally high frequency in the cores of cascade showers and which are evidently produced by some neutral radiation, are eventually due to energetic photons. Processes of this kind could be the source of fast nucleons and of the weak meson component accompanying the extensive air showers according to results of Cocconi and Greisen,¹ Brown and McKay,⁶ and others.

The details of our theory will be published elsewhere.

Note added in proof: The first direct experimental determination of the lateral structure of single extensive air showers has been carried through by R. W. Williams.⁷ His results are consistent with those of the other experimenters quoted (references 1 and 2, below) and with the authors calculations.

¹ Cocconi, Cocconi-Tongiorgi, and Greisen, *Phys. Rev.* **76**, 1020 (1949).

² E. Amaldi, *Como Congress* (September, 1949).

³ G. Molière, *Naturwiss.* **30**, 87 (1942); W. Heisenberg, *Cosmic Radiation* (Dover Publications, New York, 1946). See also *Zeits. f. Physik* **125**, 250 (1948-49).

⁴ J. Clay, *Proc. Konink. Nederland. Akad. Wetenschap.* **52**, No. 4, 2 (1949).

⁵ P. M. S. Blackett, *Como Congress* (September, 1949).

⁶ W. W. Brown and A. S. McKay, *Phys. Rev.* **76**, 1034 (1949).

⁷ R. W. Williams, *Phys. Rev.* **74**, 1689 (1948).

On the Magnetic Moments of Mn⁵⁵, Co⁵⁹, Cl³⁷, N¹⁵, and N¹⁴ *

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USING the nuclear induction radiofrequency spectrometer described earlier,¹ the nuclear magnetic resonances of Mn⁵⁵, Co⁵⁹, Cl³⁷, N¹⁵, and N¹⁴ have been observed. The magnetic

TABLE I. Magnetic moments and diamagnetic corrections.

Nucleus	Nuclear moment in nuclear magnetons	Diamagnetic correction in percent
Mn ⁵⁵	+3.4624 ± 0.0004	0.191
Co ⁵⁹	+4.6399 ± 0.0006	0.214
Cl ³⁷	+0.6835 ± 0.0001	0.113
N ¹⁵	-0.28302 ± 0.00003	0.034
N ¹⁴	+0.40369 ± 0.00004	0.034

moments listed in column 2 of Table I have been computed directly from our measured frequency ratios and the value of the magnetic moment of the nucleus used as a standard. Diamagnetic corrections were not applied; they are listed separately in column 3, and have been determined by linear interpolation from the values for specific atoms given by Lamb, using Hartree fields.² These corrections are to be applied so as to increase the magnitudes of the magnetic moments.

The resonance of Mn⁵⁵ was located near 8.3 Mc, using a field of 7900 gauss and a 2.0-molar solution of LiMnO₄ in water as the sample. Comparing the resonance frequency three times with that of Na²³, from a sample containing 0.25-molar NaCl in 1.0-molar MnSO₄, we found

$$\nu(\text{Mn}^{55})/\nu(\text{Na}^{23}) = 0.9372 \pm 0.0001.$$

The sign of the magnetic moment, and spin, agreed with the h.f.s. data,³ which indicated a spin of 5/2 and a magnetic moment of 3.0 μ_N.

The frequency of the Co⁵⁹ resonance was measured, by use of a 1.0-molar aqueous solution of the diamagnetic compound K₃Co(CN)₆ at a field of 6600 gauss and a radiofrequency near 6.6 Mc. Comparing this frequency to that of Na²³ five times, we found

$$\nu(\text{Co}^{59})/\nu(\text{Na}^{23}) = 0.89709 \pm 0.00009.$$

Verifying that the spin is 7/2 and that the magnetic moment is positive,⁴ we find this frequency ratio leads directly to a magnetic moment of (4.6399 ± 0.0006) μ_N, which is much larger than the value 2.0 to 3.0 nuclear magnetons obtained by More.⁴ The new value indicates that the odd-proton is in an $f_{7/2}$ orbit, as proposed by Mayer;⁵ this nucleus has hitherto been regarded as an exception to her single-particle model of the nucleus.

The frequencies of resonance of the chlorine isotopes were compared four times, using concentrated HCl and a field of 9400 gauss, with the result that

$$\nu(\text{Cl}^{35})/\nu(\text{Cl}^{37}) = 1.2014 \pm 0.0001.$$

Omitting the negligible correction from the reduced electron mass ratios, this differs by about 0.1 percent from the ratio $a_{35}/a_{37} = 1.20272 \pm 0.00008$ of the magnetic dipole interaction constants as determined by Davis, Feld, Zabel, and Zacharias⁶ by the atomic beam method. In computing μ(Cl³⁷) we have made use of the frequency ratio $\nu(\text{Cl}^{35})/\nu(\text{H}^1) = 0.09799 \pm 0.00007$ as determined by Chambers and Williams.⁷

The resonance frequency of N¹⁵ at a field of 11,000 gauss was compared with that of deuterium, the sample being 5 ml of liquid ammonia together with 1.18 grams of NH₄NO₃ and 1.25 grams of Cr(NO₃)₃ · 9H₂O in a sealed tube. The N¹⁵ in the ammonia was enriched to about 7.5 percent; the deuterium was from a 1.8-molar aqueous solution of MnSO₄ containing 25 percent D₂O. We found

$$\nu(\text{N}^{15})/\nu(\text{D}^2) = 0.66004 \pm 0.00006.$$

The sign of the magnetic moment, which was previously unknown, has been determined to be negative; its value is in good agreement with the molecular beam value.⁸

The frequencies of the resonance of N¹⁴ and D², from samples of concentrated HNO₃ and 0.6-molar MnSO₄ in 85 percent D₂O, respectively, were compared at 11,000 gauss with a General Radio Model 271 frequency meter, with the result that

$$\nu(\text{N}^{14})/\nu(\text{D}^2) = 0.47070 \pm 0.00005.$$

The magnetic moment is in good agreement with the molecular beam value.⁹ Since we have observed that the frequency of resonance of N¹⁴ in liquid samples depends strongly upon the compound in which it is contained (see the following letter), we have felt that it is important to state carefully what compounds have been used as our samples.

The magnetic moment of Na²³ has been computed by taking μ(H¹) = 2.79348 ± 0.00014 nuclear magnetons,¹⁰ and $\nu(\text{Na}^{23})/\nu(\text{H}^1) = 0.26450 \pm 0.00003$;¹¹ the magnetic moment of D² was similarly computed using $\mu(\text{D}^2)/\mu(\text{H}^1) = 0.307013$.¹²

We would like to express our appreciation to Professor Felix Bloch for his continued interest in our work. Thanks are also due Mr. William S. Gorton Jr. of the Department of Chemistry for preparing the liquid ammonia sample.

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²W. E. Lamb, Jr., *Phys. Rev.* **60**, 817 (1941).
³R. A. Fisher and E. R. Peck, *Phys. Rev.* **55**, 270 (1939).
⁴K. R. More, *Phys. Rev.* **46**, 570 (1934); *Phys. Rev.* **47**, 256 (1935).
⁵M. G. Mayer, *Phys. Rev.* **75**, 1969 (1949).
⁶Davis, Feld, Zabel, and Zacharias, *Phys. Rev.* **76**, 1076 (1949).
⁷William H. Chambers and Dudley Williams, *Phys. Rev.* **76**, 638 (1949).
⁸J. R. Zacharias and J. M. B. Kellogg, *Phys. Rev.* **57**, 570 (1940).
⁹S. Millman and P. Kusch, *Phys. Rev.* **60**, 91 (1941).
¹⁰H. Taub and P. Kusch, *Phys. Rev.* **75**, 1481 (1949).
¹¹F. Bitter, *Phys. Rev.* **75**, 1326 (1949).
¹²This figure is that given by Bloch, Levinthal, and Packard, *Phys. Rev.* **72**, 1125 (1947), rounded to six places.

The Dependence of a Nuclear Magnetic Resonance Frequency upon Chemical Compound*

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IN the course of measurements on N^{14} , mentioned in the previous letter, we made the surprising observation that its frequency of resonance, in liquid samples, depended strongly upon the chemical compound in which it was contained.^{1,2} This effect is strikingly demonstrated by the appearance of two resonances, separated by 1.6 kc in the neighborhood of 3300 kc, corresponding to a field of 10,500 gauss, using a solution of NH_4NO_3 in 2.0-molar $MnSO_4$ as a sample. These resonances presumably arise from the NH_4^+ and NO_3^- complexes, since samples of $NH_4C_2H_3O_2$ and HNO_3 separately give rise to two different resonances whose frequencies approximate those from the above sample. The separation is four times greater than the line widths measured between points of maximum slope.

We have observed, within a resolution of 0.1 kc, that the N^{14} resonances from the ion NH_4^+ from the compounds NH_4NO_3 , $NH_4C_2H_3O_2$, and MH_4Cl coincide at one frequency, while those from the ion NO_3^- from the compounds NH_4NO_3 , HNO_3 , and $Cu(NO_3)_2$ coincide at another frequency. Measuring the N^{14} resonances from other molecules relative to that arising from the ion NO_3^- from HNO_3 or NH_4NO_3 , we have obtained the results given in Table I. All such frequency shifts have been in the direction of lower frequency.

The separations of resonances from four pairs of compounds were also measured at 6700 gauss, corresponding to a frequency of 2100 kc, to determine whether or not the frequency separations were independent of the field intensity. They are apparently proportional to it, for the ratios of the separations are in agreement

TABLE I. Frequency shifts relative to the resonance from the ion NO_3^- at 10,500 gauss.

Compound observed	Frequency shift (kc)
NH_4^+ from NH_4NO_3 , $NH_4C_2H_3O_2$, NH_4Cl	-1.0
Liquid NH_3 , containing 0.6-molar $Cr(NO_3)_3$; NH_4OH	-1.2
$(NH_2)_2CO$	-1.0
KCN	-0.2

TABLE II. Resonance frequency separations with different compounds and field intensities.

Compounds compared	Separation (kc) at		Ratio
	10,500 gauss	6700 gauss	
NH_4^+ and NO_3^- from 7.5-molar NH_4NO_3 in 2.0-molar $MnSO_4$	1.6	0.9	0.58
HNO_3 and $NH_4C_2H_3O_2$	1.0	0.7	0.70
HNO_3 and $(NH_2)_2CO$	1.0	0.6	0.60
NH_3 , containing 0.6-molar $Cr(NO_3)_3$ and NO_3^- , from NH_4NO_3	1.2	0.7	0.58

with the ratio $6700/10,500=0.64$, within our experimental resolution. (See Table II.)

We further made the observation that the separation of the two resonances arising from NH_4NO_3 was dependent on the concentration of the paramagnetic salt $MnCl_2$ added to it. A 7.5-molar solution of this salt without $MnCl_2$ shows two resonances separated by 1.0 kc, as given in Table I, but with 1.0- and 2.0-molar concentrations of $MnCl_2$ the separations become 1.4 kc and 1.6 kc, respectively.

We shall continue to investigate this phenomenon because of its direct significance for the interpretation of nuclear magnetic resonance frequencies in terms of nuclear moments, as well as to obtain an insight into its origin. With the largest observed line shift amounting to about 5 parts in 10^4 , this effect is almost twice as large as the total diamagnetic correction calculated for the atom. These calculations, however, do not hold for the polyatomic molecules which we have studied and appreciable modification of the diamagnetism, as well as terms due to induced paramagnetism (high frequency matrix elements) can be expected, particularly in cases where three out of seven electrons may be strongly influenced by the chemical bond. The fact that the shifts are of the same order of magnitude as the diamagnetic correction and exhibit likewise proportionality to the applied field suggests a similar origin, although we have not been able to explain satisfactorily the observed magnitude of the effect. Until it is clearly understood, the accuracy of magnetic moments determined under certain chemical conditions remains somewhat in doubt.

We should like to express our appreciation to Professor Felix Bloch for stimulating discussions about this work.

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¹W. C. Dickinson, at M. I. T., has also observed similar shifts for F^{19} in different compounds. We are grateful to Professor F. Bitter for communicating this information to us.

²W. D. Knight, *Phys. Rev.* **76**, 1259 (1949), has observed a large frequency difference between the nuclear magnetic resonance frequency of a metal and its salt. The satisfactory explanation which he has given for this difference does not apply, however, to our case.

Spallation Products of Arsenic with 190-Mev Deuterons*

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RECENT investigations¹ of the nuclei formed when arsenic is bombarded with 190-Mev deuterons in the 184-in. cyclotron have been extended.

The target material consisted of twice sublimed arsenic. Spectrographic analysis² showed no impurity in sufficient quantity to account for the formation of any of the isotopes reported here with the observed yield.

The use of improved chemical separations and counting techniques has enabled the identification of 38 nuclear species among the elements from chromium through selenium. Table I lists the isotopes identified, the observed and the "nominal" half-lives as reported in the literature,³ and the yields relative to that of As^{72} taken as 1.00.

In calculating yields, the extent of electron capture has been taken from the data collected in reference 3. For Se^{73} , Ge^{69} , and Ga^{66} , crude absorption measurements indicated that approximately two-thirds of the decays are by electron capture. The yield of As^{72} is based on the count of beta-particles, as no x-rays were observed (< 50 percent of the disintegrations). The yields reported here should all be accurate to within a factor of two and many accurate to within 20 percent, depending on the certainty with which electron-capturing ratios and counting efficiencies of x-rays are known.

Table I contains two changes in isotope assignment differing from those previously reported.¹ The 44-min. selenium and 52-min.