during counting periods of about ten minutes, running the Tesla coil at 65 sparks per minute, approximately six extra counts per minute were produced through a 1-inch lead absorption-screen, two extra counts per minute through 2 inches of lead, and 28 extra counts per minute through 5/8 inch of lead. The absorption coefficients obtained from the above data are thus of the expected magnitude. The sensitivity of the Geiger counter, which has a residual of about 20 counts per minute, is such that 0.105 mg of radium at a distance of 75 cm produces 26 extra counts per minute through two inches of lead (89 extra counts per minute through 1 inch of lead). The average intensity of the radiation from the tube (at only 66 sparks per minute) is thus very low, but the estimated instantaneous radium equivalent is considerable, and this can be increased by the use of a tube adapted for the production of radiation, the above data being obtained with the tube arranged for the $H\rho$-measurements.

The production of "artificial $\beta$- and $\gamma$-rays" in the region above 1,000 kilovolts has thus been demonstrated. Work is now in progress on the acceleration of protons to radioactive speeds.

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September 11, 1930.

*Note added September 12, 1930.*

By an amusing coincidence the August 29 issue of Die Naturwissenschaften arrived just after the writing of the above note, and it contains a letter by A. Brasch and F. Lange describing the spectacular performance of their high-voltage tube at 2.4 million volts. They are to be congratulated without reserve on the success of their work.

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## Use of the Pierce Acoustic Interferometer for the Determination of Absorption in Gases for High Frequency Sound Waves

In recent articles in this journal, W. H. Pielemeier (Phys. Rev. **34,** 1184, 1929: Phys. Rev. **36,** 1005, 1930) reports determinations of the absorption coefficient in gases for high frequency sound. He employs both the Pierce acoustic interferometer and a torsion vane method. The observations by the first method reveal that as the sound path in the gas is increased the changes in plate current through the tube diminish, and from this rate of diminution Pielemeier attempts to calculate the absorption coefficient. We do not believe this procedure to be entirely justified. The variations in plate current are a function not only of the absorption in the gas but of the circuit constants as well. For we are here dealing with decrements in coupled circuits. The network may be considered as made up of a crystal circuit with a decrement which depends upon the reflector position in the gas; also this crystal is coupled to a plate circuit with its own decrement. Hence, uncorrected observations on changes in plate current through the tube give no information concerning the absolute absorption in the gas. Experiment has shown us that these changes in current depend both on the reactance and the decrement of plate circuit.

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## The Magnetic Moment of the $Li_7$ Nucleus

Using the experimental data on the hyperfine structure of the alkalis, Fermi[1] and Hargreaves have computed approximate values of the magnetic moments of their nucleii. Goudsmit and Young[2] have estimated the magnetic moment of the $Li_7$ nucleus on the simplifying assumption that the coupling to the nucleus takes place entirely through the 1$s$ electron. The apparent inconsistency of their results may be due in part to the experimental difficulty of separating the structure of the ${}^3S_1-P_1$ and ${}^3S_1-P_2$ groups. In part it is probably due to their using $(1/2)(h/2\pi)$ for the nuclear

[1] E. Fermi, Zeits f. Physik **60,** 320 (1930). J. Hargreaves, Roy. Soc. Proc. **124,** 568 (1929); **127,** 141 and 407, (1930).

[2] S. Goudsmit and L. A. Young, Nature **125,** 461 (1930).

spin, their main object being to show that the magnetic moment is of the order of magnitude of the theoretical magnetic moment of the proton.

It has since been shown by Granath[3] that the main reason for using $i=1/2$ for the nuclear spin is absent. The frequency separations between components agree best with $i=3/2$ which is also in agreement with the band spectrum results of Harvey and Jenkins.[4] Goudsmit, Güttinger[5] and ourselves have known for some time that this value of $i$ is fairly consistent with the experimental pattern. The nuclear $g$ factor is on this hypothesis in the neighborhood of 2.3, this value being obtainable directly from Schüler's frequency table and the formula used by Goudsmit and Young.

We have undertaken to make a more accurate calculation for the $g$ factor. Our special reason for doing so is that the electronic configuration of the $^3S_1$ level is especially simple and appears to be favorable for accurate results. We have also been intrigued by the possibility that the $g$ factor might be 2 exactly which would speak in favor of regarding the magnetic moment of $Li_7$ as due to three protons acting independently. It is our purpose to report here briefly on the results of our calculations.

The work of Casimir and of Fermi shows in the case of one electron that it is essential to consider the problem from the point of view of Dirac's electron equation. A non-relativistic equation cannot be expected to give even approximately correct results for $S$ electrons because in the immediate vicinity of the nucleus the electron velocity cannot possibly be regarded as small. There exists at present no satisfactory relativistic treatment of two particles. Nevertheless, for the present purpose, it is possible to form a reasonable extension of the one-electron treatment. In a discussion of light atoms it is possible to treat the one-electron problem also by means of an equation of the Pauli-Darwin type, i.e. employing two rather than four components for $\psi$. Darwin[6] has shown how such an equation can be derived from the original four-component Dirac form. The interaction energy with the nuclear magnetic moment $\mu$ is then to a sufficient approximation

$$\begin{aligned}H' = &(e/mc)[1+(E-mc^2+eA_0)/2mc^2](\boldsymbol{M}\boldsymbol{\mu})r^{-3}\\ &+(hec/2\pi)[2mc^2+eA_0]^{-1}\{-r^{-3}(\boldsymbol{\mu}\boldsymbol{\sigma})+3(\mathbf{r}\boldsymbol{\sigma})(\mathbf{r}\boldsymbol{\mu})\}\\ &+(hec/2\pi)[2mc^2+eA_0]^{-2}(e\mathcal{E})\{r^{-2}(\boldsymbol{\mu}\boldsymbol{\sigma})-r^{-4}(\mathbf{r}\boldsymbol{\sigma})(\mathbf{r}\boldsymbol{\mu})\}\end{aligned} \quad (1)$$

The charge of the electron is taken to be $-e$, $E$ is the total energy, $m$ and $c$ are respectively the mass and the velocity of light, $A_0$ is the electrostatic potential due to the nucleus, $\mathcal{E}$ is the electric intensity due to the nucleus, $\boldsymbol{r}$ is the displacement vector from the nucleus to the electron, $\boldsymbol{M}$ is the angular momentum vector operator, and $\sigma$ is Pauli's spin vector. In the first term the square bracket can be omitted for anything but $s$ terms. For $s$ terms it enforces the convergence of the otherwise divergent integrals for $r^{-3}$. The second term is the closest analogy of the dipole interaction of the nuclear and electronic magnetic moments. On account of the square bracket its effect disappears for $s$ terms. The third term, involving the electric intensity $\mathcal{E}$ is negligible except for $s$ terms. If the square bracket in the second term were absent the result would be indeterminate. In fact it may be shown that if $\mu$ were the limit of a space distribution of magnetization the result of the second term would be $(-1/2)$ of the correct total result.

For two electrons we postulate the interaction energy to be the sum of two terms of the type of (1) one term in each electron. The first order perturbations for the energy of a $^3S$ term come out without further approximations to be given by

$$\begin{aligned}w &= w_1(1, -(1/i), -(i+1)/i)\\ w_1 &= (16\pi/3)\mu\mu_0\int\psi^2(0, q)dq\end{aligned} \quad (2)$$

where $\mu_0$ is the Bohr magneton and $\psi(q_1, q_2)$ is the nonrelativistic Schroedinger wave equation. The letter $q_1$ stands collectively for the Cartesian coordinates of electron 1, and simi-

[3] L. P. Granath, Phys. Rev. **36**, 1018, (1930).

[4] A. Harvey and F. A. Jenkins, Phys. Rev. **58**, 789, (1930).

[5] We should like to express at this point our appreciation to Professor Goudsmit and to Professor Pauli. It is through the courtesy of the latter that we have received proofs of a paper by Güttinger which is in press in the Zeitschrift für Physik and which shows in detail how $i=3/2$ accounts for Schüler's pattern.

[6] C. G. Darwin, Proc. Roy. Soc. **118**, 654, (1928).

larly $q_2$ for those of 2. The splitting is proportional to the probability of finding an electron in a unit volume at the nucleus. By means of (2) one can calculate a correction factor to be used in the formulas of Goudsmit and Bacher.[7] This factor is

$$f=2\int\psi^2(0,\, q)dq/\int\psi_1 S^2(q)dq.$$

In order to obtain $f$ and hence $\mu$ it is necessary to find a solution of the two-electron nonrelativistic wave equation. In the absence of an analytic solution we have tried a number of wave functions adjusted for the minimum energy by the variational method. Among these the function

$$(r_1-c)\exp\left[-(a/2)r_1-(b/2)r_2\right] -(r_2-c)\exp\left[-(a/2)r_2-(b/2)r_1\right]$$

appears to be best suited for the purpose. It gives when minimized for $a$, $b$, $c$ an Eigenwert which is in excellent agreement with experiment. In terms of the ionization potential of $Li^{++}$ the Eigenwert obtained is $-1.1354$ which may be compared with the spectroscopic value $-1.1358$. The best values of $a$, $b$, $c$ are 0.38, 1.00, 3.18. The correction factor $f$ is for these values of $a$, $b$, $c$, $f=1.063$. Using this factor and making the slight correction in the frequency of Schüler's component,[3] mentioned by Granath,[3] the $g$ factor becomes 2.13 for $i=3/2$. This is closer to 2 than the uncorrected value 2.3. The remaining difference of 6% appears to be too large to be accounted for by experimental error. The accuracy of the theoretical calculation may, of course, be questioned. An estimate of it may be made by the method recently published by Eckart.[8] Such an estimate would lead one to suppose that the result is accurate only to about 7%. In this special case, however, our experience with other trial functions as well as a more detailed consideration of the possible errors indicate that Eckart's accuracy criterion is likely to be too conservative. *The present evidence is, therefore, that* if the nuclear *spin is 3/2, Schüler's observed frequency* separation between *components* (1) *and* (3) *speaks in favor of a nuclear magnetic moment greater than that of three protons by about* 6%.

It should be noted that we base ourselves entirely on Schüler's observed frequency separation between components (1) and (3) because the other components of the pattern are not sufficiently resolved to make definite conclusions possible. It is also not out of place to emphasize here that in our calculation the magnetic field due to the electrons has been supposed to have no effect on the nuclear magnetic moment. An estimate shows this field to be about $4.5\times10^6$ gauss. An exact experimental test of the interval ratio given by (2) may show to what extent the nuclear magnetic moment is affected by this magnetic field.

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September 15, 1930.

[7] S. Goudsmit and R. F. Bacher, Phys. Rev. **34,** 1501 (1929).

[8] Carl Eckart, Phys. Rev. **36,** 878 (1930). Note also Eckart's function for $^3S$ closely resembling ours.

**Wind Mixing and Diffusion in the Upper Atmosphere**

I am glad to see that Professor Chapman (Phys. Rev. **36,** 1014, 1930) agrees with me in thinking that there is no question of Dr. Maris' priority in the development of the subject of wind mixing and diffusion in the upper atmosphere. At the same time Professor Chapman claims that his work was independent of that of Dr. Maris. The internal evidence in his paper (Proc. Roy. Soc. A, **122,** 369, 1929) does not support this claim. To give one example; on page 375 he wrote, "It is here assumed that the mixing ceases at 110 km," with no indication of any calculation which would justify such an exact assumption. Maris had already written (Nature, December 1927) "This 'diffusion' level for hydrogen would move from infinity down to 142 km in one day, at the end of five days it would be at a height of 127 km and in 50 days it would be at 113 km. The corresponding levels for helium would be at 137, 120 and 106 km, respectively." And in Terr. Mag. **33,** 233 (1928) after five printed pages of calculation and close physical reasoning Maris gave (Table 3) the diffusion levels of six atmospheric gases for summer, winter, day and night which "averaged about 110 km."

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September 19, 1930.