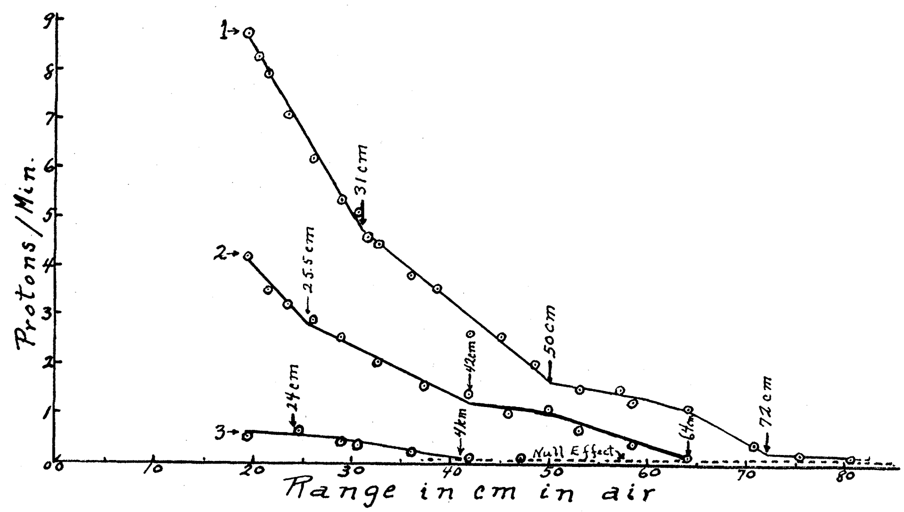

FIG. 2. Phosphorus.

Results surprisingly similar to those for boron are obtained with phosphorus and are summarized graphically in Fig. 2. Three distinct groups are found where only one had been previously observed.[2] The yield of protons was fully as great as that obtained from boron when the phosphorus was bombarded with the 8.6 cm range alpha-particles. But, as comparison of the three curves in the figure will show, the yield decreased rapidly with decreasing energy of bombarding alpha-particle, curve 1 being taken with 8.6 cm range alpha-particles, curve 2 with 7.6 cm alpha-particles, and curve 3 with 5.2 cm ones. In this last curve no trace of the middle group of protons in curve 1 appeared though these protons should be observable in this experiment at a range ending at 24 cm as indicated by the arrow. Values for the Q's for the three proton groups emitted from phosphorus, given in order of decreasing range, are 0; $-1.47\cdot10^6$; $-2.96\cdot10^6$ electron-volts. The single group previously found[2] was reported with a small positive energy but is probably to be identified with the zero energy group here. It should, however, be noted that curve 1 does not fall to the null value of the counter at 72 cm, remaining at approximately twice this value at both 75 and 81 cm. This may mean the presence of a fourth very faint group of larger range. But phosphorus is known to emit neutrons and, while the count observed in this range was from particles which did not penetrate 1 mm of lead, the existence of a group of protons ending somewhere beyond 81 cm can only be established by further experiment.

Much credit for the success of the experiments should be given Professor H. Geiger who suggested the problem and supplied all needed facilities. Dr. O. Haxel also cooperated actively in carrying out the work.

R. F. PATON

University of Illinois,
July 5, 1934.

On the Interpretation of Present Values of Nuclear Moments

Various writers[1, 2, 3, 4, 5, 6, 7] have published speculations on the magnetic moment and the nature of the neutron and proton. In view of the discordant results it appears proper to discuss the reliability of the g values for different nuclei as well as the plausibility of the explanations proposed from the point of view of nuclear structure.

(a) It is believed by Inglis and Landé[3] that the disagreement between Landé's[1] assumed value $g_s=4$ for the proton g factor, the molecular beam value[8] 5.0 ± 10 percent, and the atomic beam value[9] 6.4 ± 10 percent is to be attributed to the crudities of the theory used in all three cases. As far as we know this objection cannot apply to the R. K. Z. value. The only essential points presupposed in the theory of the experiment are: (1) the possibility of describing the interaction of the electron and the nucleus by assuming a nuclear magnetic moment, (2) the sufficient validity of Dirac's equation for a single electron as applied to hydrogen. It is possible that one or both of these suppositions are incorrect, but it seems impossible to discuss the problem definitely without either. The agreement between the S. E. F. and the R. K. Z. value may be regarded as a support of both. It should be remembered that the S. E. F. value is obtained by a direct measurement of the force on the magnetic moment of the proton and does not depend on interactions between electrons and protons a short distance apart. The corrections for the rotational magnetic moment of the molecule were made experimentally by using

[1] A. Landé, Phys. Rev. **44**, 1028 (1933).
[2] B. Venkataschar and T. Subbaraya, Zeits. f. Physik **85**, 264 (1933).
[3] D. R. Inglis and A. Landé, Phys. Rev. **45**, 842 (1934).
[4] H. Kallmann and A. Schueler, Zeits. f. Physik **88**, 210 (1934).
[5] H. Schueler, Zeits. f. Physik **88**, 323 (1934).
[6] H. Schueler and H. Westmeyer, Naturwiss. **21**, 674 (1933).
[7] T. Tamm and S. Altschuler, Comptes Rendus de L' Academie des Sciences de l' U.R.S.S. **1**, 458 (1934).
[8] Stern, Estermann and Frisch, Zeits. f. Physik **85**, 4, 17 (1933).
[9] Rabi, Kellogg and Zacharias, Phys. Rev. **45**, 761 (1934).

parahydrogen. The only vital assumption involved is that of the constancy of this magnetic moment to the corresponding mechanical angular momentum. We see no reason for seriously questioning this.

On the other hand, the nuclear g values used by Landé are questionable. With the exception of $g=2.19$ for Li^7 they are all obtained on the supposition that the many electron problem presented by an atom is approximated with sufficient accuracy by replacing the effect of all but the valence electrons by a suitable central field. In some cases corrections for perturbations have been made. In no case has a complete calculation been carried out. The magnitude of the error introduced by this assumption is at present unknown and there appears to be no valid reason for supposing it to be small.

It is possible to eliminate our lack of knowledge of absolute nuclear g values by paying attention to the ratios of the g factors of isotopes. The atomic wave functions cancel out in such a calculation. It is of interest to discuss such ratios for Z odd and M odd by using Landé's picture of i and μ as due to proton having a definite orbital angular momentum l. For Rb the only reasonable assignment of l is $l=1$ for Rb^{87} and $l=3$ for Rb^{85}. Other assignments lead to impossible ratios of $g(87)/g(85)$ or else to wrong signs of $g(87)$ or $g(85)$. Using the experimental value $g(87)/g(85)=3.46$ one obtains $g_s=3.97$ which is in excellent agreement with Landé's $g_s=4$ but disagrees violently with S. E. F.'s $g_s=5$ or R. K. Z.'s $g_s=6$, these values of g_s would require $g(87)/g(85)=5.4$, 9.3, respectively. Both of these values are excluded by the high accuracy of Kopfermann's experiments. For Sb the experimental value $g(121)/g(123)=1.80$ may be accounted for either by $g_s=3$ with $l=2$ for Sb^{121} $(i=5/2)$ and $l=4$ for Sb^{123} $(i=7/2)$ or else by $g_s=-3$, $l=3$ for Sb^{121} and Sb^{123}. The latter choice is in disagreement with Rb and so is $g_s=3$ because $g_s=4$ gives $g(121)/g(123)=2.4$ which can hardly be mistaken for 1.80. For Ga there appears to be no reasonable way of accounting for $g(71)/g(69)=1.27$, on Landé's picture.[1]

The theoretical values given in Table III of Tamm and Altschuler appear to satisfy the isotope ratio for Sb very accurately giving $g(121)/g(123)=1.79$ as compared with the experimental value 1.80. This agreement is due, however, to a numerical error present in this table and in the corresponding table of Landé. For Sb^{123} one cannot use $l_p=3$ because $i=7/2$ was used to obtain $g=0.60$ and for g (proton spin) $=g_{sp}=4$ one would have $g(123)=10/7=1.43$ as compared with the observed 0.60. On the other hand, using $l_p=4$, one gets $g(123)=0.67$. In order to obtain reasonable agreement with the observed $g(121)$ one has to use $l_p=4$ in Sb^{121} coupled to s_p to give $j_p=7/2$ which is then coupled to $j_n=1$ to give $i=5/2$. One obtains a theoretical $g=1.00$ and a theoretical $g(121)/g(123)=1.50$ which is in poor agreement with the observed 1.80. For Ga the table of Tamm and Altschuler gives for $g(71)/g(69)$ the values 1.50 theoretically which compares poorly with the experimental 1.28. Kallmann and Schueler obtain satisfactory ratios for Rb and Sb but for Ga the theoretical 1.36 is too large. Even if this discrepency were removed the value $g_{sp}=4$ used by K. S. is in definite contradiction with S. E. F. and R. K. Z. as well as with the g factor for Li^7.

It should be emphasized that in the above comparison the uncertain features of theoretical calculations have been eliminated. Thus the data available at present appear to indicate a variable g_s according to all the schemes proposed. None of the above values are in agreement with $g=2.2$ for Li^7 which leads to either $g_s=4.6$ or $g_s=-5.0$. Either of these values agrees with the measurements of S. E. F. and of R. K. Z. since the sign of g_s is left undetermined by them. On the other hand, adjusting $g(Li^7)$ to be 2 as is desired by Landé, implies an accuracy of only 10 percent in the theoretical calculations. The relative simplicity of the electronic configurations dealt with suggests a much higher accuracy.

(b) The attempt at a conclusion that the neutron is not an elementary particle from the sign of its g factor appears to be premature. It is well known that interaction terms of Pauli's type can describe a particle with an arbitrary magnetic moment so that either sign of the g factor is in agreement with the view that the neutron is an elementary particle. Further, either sign can be explained by supposing that the neutron is composite: a negative value can be explained by saying neutron = proton + electron, a positive value one could explain by saying neutron = neutron′ + electron + positron.

The sense in which electrons or positrons may be said to exist in a nucleus is very obscure. We doubt whether much meaning may be ascribed to theories making detailed pictures of the composition of the neutron or proton.

(c) According to the usual ideas of nuclear structure the constitution of a nucleus resembles that of a polyatomic molecule or else of a liquid. It is questionable whether there is much meaning to a central field which one must necessarily assume in order to assign an orbital quantum number to a particle under these conditions. Even if the central field picture applies it is questionable whether the core may be considered as having a constant g factor as is done by Kallmann and Schueler. It is also questionable whether the coupling order $p(nn)$ used by Tamm and Altschuler is consistent with the generally supposed importance of the pn bond. One would rather suppose that $(pn)n$ is a more probable coupling possibility.

In the table of Landé for nuclei with odd Z and odd M some nuclei have $l_p>j_p$ and others $l_p<j_p$. Presumably one of these possibilities corresponds to a lower energy level than the other. The energy difference between $j_p=l_p+\frac{1}{2}$ and $j_p=l_p-\frac{1}{2}$ may be supposed to be of the order of the magnetic interaction energy of two nuclear magnetons located at a distance of 10^{-13} from each other. Its order of magnitude is several hundred volts. The probability of magnetic dipole radiation from the higher to the lower of these levels is such that the mean life would be $\sim 1/50$ sec. if $\Delta W=200$ volts. It is thus difficult to reconcile the known stability of a number of nuclei with the above theories of nuclear moments.

G. Breit
New York University
I. I. Rabi
Columbia University

July 21, 1934.