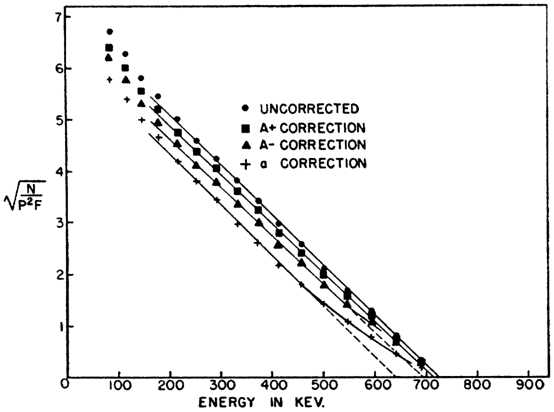

FIG. 1. Fermi plots for Rb^{86} low energy spectrum.

(0.4 mg/cm² and 1.0 mg/cm²) were prepared by evaporation of RbCl in vacuum on mica foils of approximately 2 mg/cm² thickness.

Figure 1 shows the Fermi plot analysis of the low energy Rb^{86} data. Points show the data without forbidden corrections and with first-forbidden corrections[5] a, A_+, and A_-. The $A_\pm'$ and $A_\pm''$ corrections differ insignificantly from the $A_\pm$ corrections, the energy-independent term $(\alpha z/2R)^2$ dominating the energy-dependent terms. A straight line fits best the uncorrected Fermi plot or the A_+ correction, and fits rather poorly the A_- correction; the a correction seems definitely excluded. The corrections yield different extrapolated end points and may also be compared on this basis.

Figure 2 shows the Fermi plot analysis of the high energy beta-spectrum (three percent resolution), and indicates a first-forbidden spectrum with the a correction giving a straight line with end point at 1.80±0.01 Mev. The gamma-ray energy was found to be 1.076±0.003 Mev, as measured by photo-electrons from a U radiator and calibrated with Co^{60}. These results are in agreement with those of Zaffarano, Kern, and Mitchell,[6] although these authors did not attempt to fit a forbidden correction to their data.

A search with a crystal gamma-ray spectrometer[7] failed to show any other gamma-radiation from Rb^{86}, and it is concluded that the end point of the low energy beta-spectrum should be the difference between the high energy end point and the gamma-ray energy, or 724±11 kev. Table I shows the extrapolated end points obtained from the various curves in Fig. 1. Thus on the basis of end points and shapes, type a can be ruled out entirely, and types A_-, A_-' and A_-'' seem quite unlikely. Of the remaining two, the

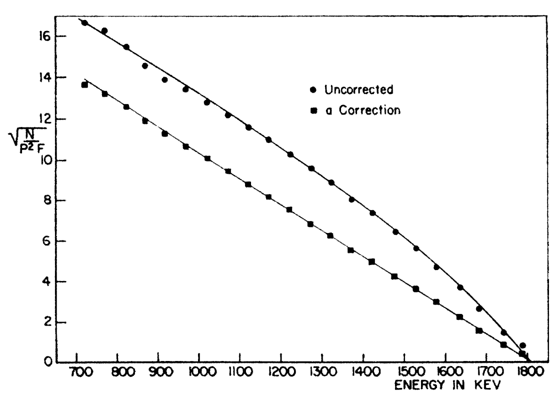

FIG. 2. Fermi plots for Rb^{86} high energy spectrum.

existence of beta-gamma-correlation[1-3] seems to rule out the allowed transition.

Further elimination may be made on the basis of a level scheme with specific spin assignments. Sr^{86} (even-even) should have ground-state spin zero. Selection rules for a first-forbidden transition of type a (such as the Rb^{86} high energy component has been shown to be) allow a transition to spin zero only from spin two. Hence we suggest the level scheme and spin assignments of Fig. 3,

TABLE I. Extrapolated end points.

Correction	Allowed	A_+, A_+', A_+''	A_-, A_-', A_-''	$a=p^2+q^2$
End points	726±10	714±10	696±10	640±10

with change of parity as required for those first-forbidden beta-interactions under discussion.

The coefficient R/Q in the beta-gamma-correlation function $1+(R/Q)\cos^2\theta$ is observed[1-3] to be positive. It is interesting to note that, on the basis of reference (4), this sign is consistent with the proposed level scheme only for types $A_\pm'$ of all thoses cited in

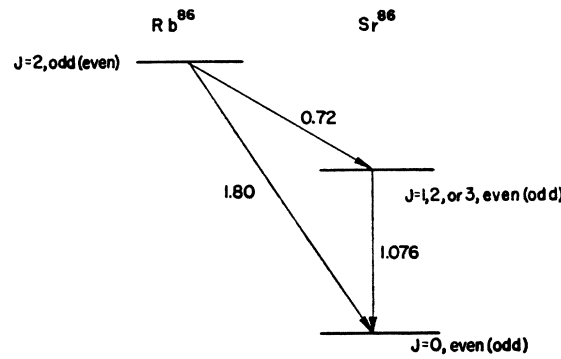

FIG. 3. Decay scheme of Rb^{86}.

Table I, except possibly for the intermediate state $J=3$, for which there are no angular correlation calculations. These A_+' and A_-' corrections arise from matrix elements $\int \boldsymbol{\sigma}\times\mathbf{r}$ in the first-forbidden tensor and axial vector interactions, respectively. The former of these is somewhat more likely on the basis of our data.

The authors are deeply indebted to Professor R. Sherr for his interest and helpful suggestions during the course of this experiment and to Professor D. R. Hamilton for his extensive assistance in the interpretation of the results.

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[1] D. J. Stevenson and M. Deutsch, Phys. Rev. **78**, 640 (1950).
[2] T. B. Novey, Phys. Rev. **78**, 66 (1950).
[3] R. Stump and S. Frankel, Phys. Rev. **79**, 243 (1950).
[4] D. L. Falkoff and G. E. Uhlenbeck, Phys. Rev. **79**, 334 (1950).
[5] E. J. Konopinski, Rev. Mod. Phys. **15**, 209 (1943). (Our notation is the same as that introduced by Konopinski on page 227.)
[6] Zaffarano, Kern, and Mitchell, Phys. Rev. **74**, 682 (1948).
[7] R. Hofstadter and J. A. McIntyre, Phys. Rev. **79**, 389 (1950).

On the Deviations of Nuclear Magnetic Moments from the Schmidt Limits*

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ASSUMING that magnetic moments of odd nuclei arise solely from the orbital and spin magnetic moments of the odd nucleon, one easily finds that the magnetic moment of an odd proton or odd neutron nucleus of spin I should have one of two values (the Schmidt limits) depending on the relative orientation of the orbital and spin angular moments.[1] Experimentally determined moments partially corroborate the above model in that almost without exception they lie between the Schmidt limits and

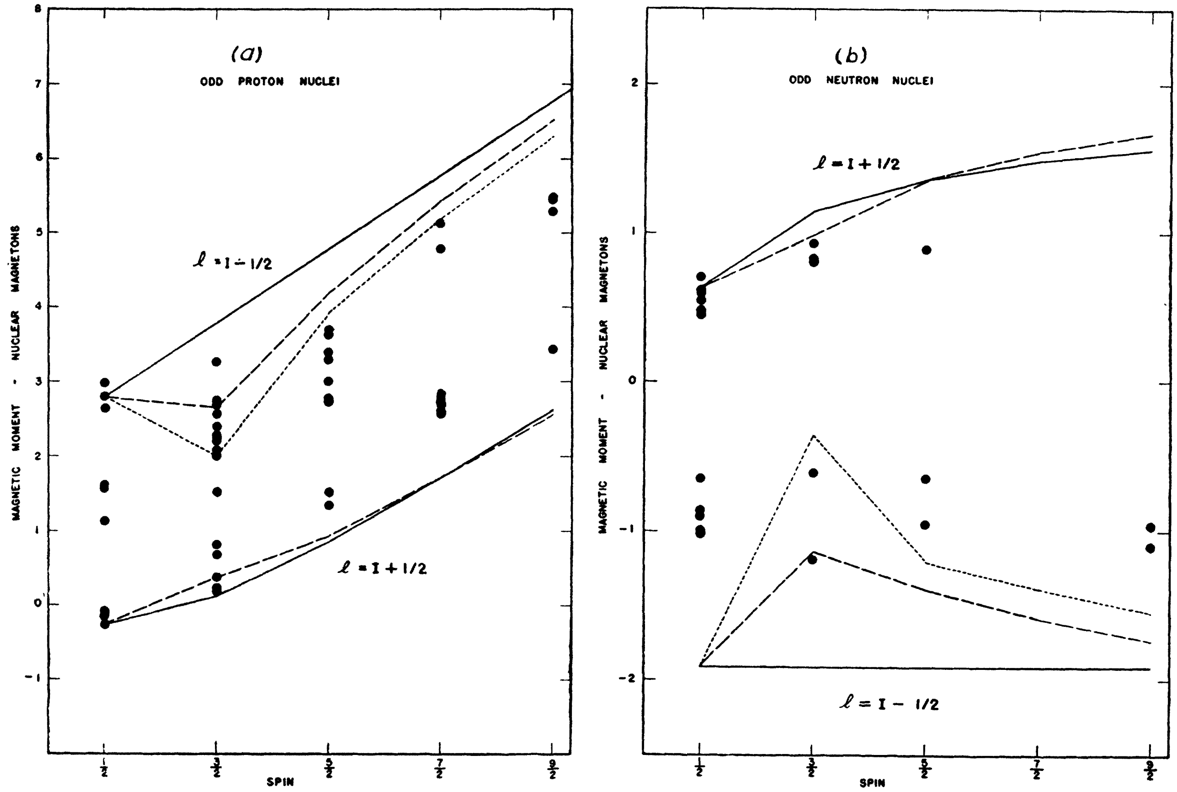

FIG. 1. Magnetic moments of odd proton (a) and odd neutron (b) nuclei as a function of nuclear spin. Circles represent observed values for various nuclei. Full lines represent the Schmidt limits. Dashed and dotted lines represent, respectively, values calculated taking into account excitations of one surface wave phonon and two surface wave phonons of the Y_2 mode of the core.

appear to form two bands roughly paralleling the Schmidt limits when plotted against nuclear spin.[2] This fact, together with other evidences from shell structure in nuclei, isomerism, and beta-decay probabilities, has led to the proposal of nuclear models[3] in which the nucleons are assumed to have single particle orbits. The particular model characterized by strong spin-orbit coupling which has been proposed by M. G. Mayer has been very successful in correlating many of the features of nuclear structure, but in its strict form it unambiguously predicts the Schmidt limits for the magnetic moments of odd nuclei. Hence, before it can be accepted seriously, it must be possible to explain deviations from the Schmidt limits by a modification of this model which does not destroy its salient features bearing on nuclear structure. The features which must be preserved are the assignments of total and orbital angular momentum to the odd nucleon. This communication presents a preliminary account of some results bearing on this question.

While the simplest explanation of the deviations consists in assuming that the state of the odd nucleon is a mixture of states with orbital angular momentum $l=I-\frac{1}{2}$ and $l=I+\frac{1}{2}$, this explanation encounters the two serious difficulties that the two states which must be mixed differ widely in energy according to the Mayer assignments and that an ambivalence in the parity of the core is required. We, therefore, feel that this is not the correct explanation and propose instead that there is an exchange of angular momentum between the odd nucleon and the core.[4] In this exchange both the total and orbital angular momentum of the odd nucleon are assumed to remain constant in magnitude (as a consequence of the strong spin-orbit coupling) and to suffer only changes in direction. Hence the angular momentum assignments to the odd nucleon are unchanged in this modification of the Mayer model. If the odd nucleon is the only nucleon in its angular momentum state, there is no difficulty with the exclusion principle involved in a change of its magnetic quantum number and probably no difficulty arises when other paired nucleons are present in the same angular momentum state. The features of our model may be summarized precisely as follows: If l, s, j, and m_j and L, S, J, and M_J are the orbital, spin and total angular momentum, and magnetic quantum number of the odd nucleon and the core, respectively, and I is the total angular momentum of the nucleus, then l, $s(=\frac{1}{2})$, j, $S(=0)$, and I are constants of the motion, but the state of the nucleus is a mixture of states of different m_j, L, J, and M_j.

We propose as the mechanism for the exchange of angular momentum between the nucleon and the core the "tidal" forces (polarization effects) which the latter would be expected to exert on the former. To determine whether this effect is of sufficient magnitude to explain the observed deviations we have calculated it assuming that the core can be represented as a liquid drop and that a point (delta-function) interaction (of magnitude to give about the correct binding energy for the odd nucleon) exists between the nucleon and each element of fluid of the core. The effect of the odd nucleon is to excite surface waves which carry angular momentum on the liquid-drop core. We have considered only the excitation of the surface wave of lowest energy (corresponding to a spheroidal deformation of the core and represented by the second-order spherical harmonics Y_2) and have found that the interaction energy is actually large compared to the excitation energy of this mode; consequently, large angular momentum transfers between the nucleon and the core take place. Because of the complicated nature of the "strong coupling" problem involved in this calculation we have limited ourselves to taking into account only the excitation of one and two surface wave phonons of type Y_2. The gyromagnetic ratio of the core was assumed to be $\frac{1}{2}$.

The results are shown in Fig. 1. It will be noted that in a majority of cases the theoretically derived deviations are in the right direction and of the proper order of magnitude to accord with the observed moments. The results are not sensitive to the strength of the interaction provided it is large compared with the core level spacing. It would be of interest to continue the calculations further by taking account of higher order excitation of the Y_2 modes as well as other modes which can be excited, but the labor involved appears prohibitive at present.

Before taking the proposed model too seriously, however, one should observe certain of its limitations. First, the model predicts that spin $\frac{1}{2}$ nuclei have magnetic moments coinciding with the Schmidt limits; there are a considerable number of observed exceptions. Secondly, the model predicts (small) deviations in the wrong direction for nuclei with $1=I+\frac{1}{2}$ for $I>5/2$ resulting in additional discrepancies particularly for the compact group of odd proton nuclei with $I=7/2$. To just what extent and in what direction the model must be modified to explain these discrepancies is not clear.

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[1] T. Schmidt, Zeits. f. Physik **106**, 358 (1937).

[2] H. H. Goldsmith and D. R. Inglis, *The Properties of Atomic Nuclei I* (Information and Publications Division, Brookhaven National Laboratory, Upton, New York, October 1, 1948).

[3] L. W. Nordheim, Phys. Rev. **75**, 1894 (1949); M. G. Mayer, Phys. Rev. **75**, 1969 (1949); **78**, 16 (1950); Haxel, Jensen, and Suess, Phys. Rev. **75**, 1766 (1949); E. Feenberg and K. C. Hammack, Phys. Rev. **75**, 1877 (1949); E. Feenberg, Phys. Rev. **77**, 771 (1950).

[4] In this connection, see J. Rainwater, Phys. Rev. **79**, 432 (1950).

Cascade Processes Recorded in an Emulsion Chamber Exposed in the Stratosphere

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A LUCITE frame supporting 5 disks of emulsion (5 cm diameter, cast between 1200 and 2400 microns thick) was exposed in the stratosphere at λ 55°N for 6.8 hr. at an average elevation of 90,000 ft. The disks developed uniformly and the tracks of singly charged particles at the minimum of ionization exhibited 23 grains per 100 microns.[1] Intensity measurements on the number of low energy mesons created in one of the 1200 micron disks have been made, a phenomenon particularly suited to the emulsion chamber owing to the greater probability of the ejected particles terminating their range within the thick recording medium. In a volume of 1.5 ml a total of 8 events were observed in which either Π^+- or Π^--mesons were created, the range of the ejected particles residing between 213 and 9150 microns. This corresponds to an observational intensity of 19 ± 7 per cc per day, which is about 8 times greater than that observed in plates of comparable sensitivity coated 300 microns thick.[2]

One of these events exhibiting the termination and decay of a Π^+-meson (Fig. 1) is of particular interest as this track is the wide angle member of a 17-particle shower initiated by a relativistic alpha-particle. With the exception of track 10, which produces a small star, the remaining shower particles leave the disk after traversing 14 to 20 mm of emulsion[3] without appreciable increase in grain density. The emission of the slow Π^+ at a large angle with the shower axis provides further evidence for the Bethe mechanism of plural-multiple meson production.[4]

In this preliminary survey no attempt was made to count or identify all the incident heavy primaries, but a large number were observed to stop within the disk either by ionization or nuclear capture processes. An exceptionally heavy track (maximum core diameter 8 microns, total diameter including delta-rays measuring up to 30 microns) came to rest after traversing 15 mm of the disk. On the basis of a thin down length of 700 microns its charge[5] is estimated at 49 ± 3. The track may possibly have been produced by a tin nucleus, as this element has the greatest astrophysical abundance of the elements with atomic numbers[6] between 45 and 55.

A cascade initiated by a heavy primary of charge 18.1 ± 1.3 as estimated by delta-ray counts is described in Fig. 2. At point C the incident particle produces a nuclear disruption constituted of six shower particles $C_1\cdots C_6$, and 15 evaporated nucleons, and a heavy residual fragment emerges co-linear with the primary. This residual fragment has a charge of 10.2 ± 0.7, continues for a distance of 8.9 mm and while still moving at relativistic speed produces a narrow angle shower (tracks $N_1\cdots N_6$) without any associated slow nucleons. In the second shower particles N_1 and N_3 have a recorded range of 7 mm at the points of emergence from the disk and both show a continuous grain density of 4×minimum, and hence are probably relativistic alpha-particles. Tracks N_2, N_4, N_5, and N_6 have minimum ionization grain density and are probably a mixture of fast mesons and protons.

The charge of the incident primary and that of the co-linear heavy fragment indicate that the particles are very probably argon and neon nuclei respectively. While the masses of the particular isotopes are not determinate, A^{36} and Ne^{20} are distinct possibilities. These isotopes have a particularly stable nuclear shell-structure, and if tracks ZC and CN were produced by them, the event suggests that in the interaction of heavy primaries with nuclei in the emulsion a preferential shearing may occur such that units constituted of integral multiples of the helium structure may emerge as sub-units of the interacting nuclei. This implies that the incident argon nucleus also originated from a more complex

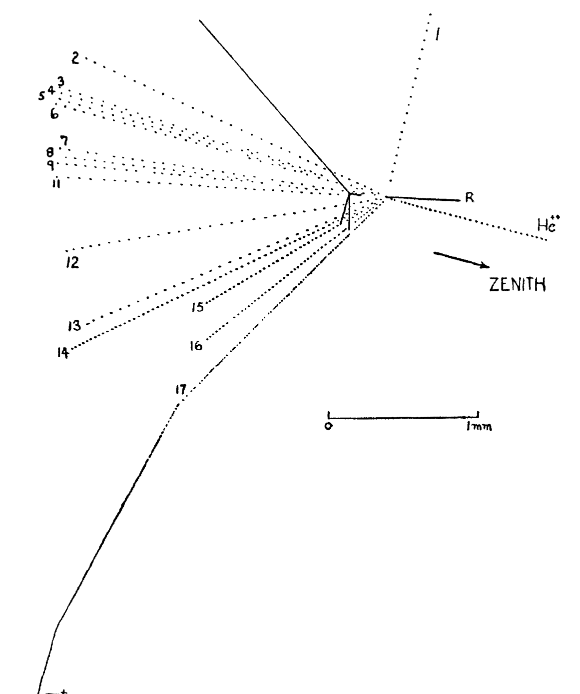

FIG. 1. Wide-angle shower initiated by a relativistic alpha-particle. This event is noteworthy in that only a single slow nucleon, track R, is associated with the star. Tracks 3–6 and 7–11 are produced by singly charged minimum ionization particles and constitute narrow angle showers of 0.05 and 0.04 radians, respectively. Particle 10 is captured in flight and forms a 4-pronged star 240 microns distant from the origin. Tracks 14, 15, and 16 have a grain density close to 4×minimum. Track 14 was followed for a distance of 14.2 mm until it escaped from the recording medium, without exhibiting an increase in grain count. Track 17 terminates in the emulsion with a range of 4800 microns, and is identified as a Π^+-meson by the decay track of the μ^+-meson which has a range of 520 microns (corrected for dip). The center of the shower occurred at a depth of 890 microns and the μ^+-particle terminated 10 microns below the upper surface of the 1200-micron disk.