coincidence should be included. At 100–110 Mev for photographic emulsion nuclei this amounts to about 4 percent according to the work of Bernardini, Booth, and Lederman.[2] It is probably higher at higher energies and for lighter nuclei. On the other hand, there is a contribution from the elastic diffraction scattering which should be deducted. This is not large (about 5 percent) for lead but increases for the lighter nuclei and amounts to about 15 percent for carbon. These corrections have been applied in obtaining the absorption+inelastic scattering cross sections which are listed in columns 5 and 6. An appropriate increase in the assigned uncertainty is indicated there. The general result is that the observed total cross sections have the geometric values within the uncertainties (15 percent) of the present technique. Moreover, with the possible exception of carbon, there is no evident energy dependence over the range of energies (85 to 133 Mev) covered thus far.

* Research sponsored by the ONR and AEC.
† AEC Predoctoral Fellow.
[1] Chedester, Isaacs, Sachs, and Steinberger, Phys. Rev. **82**, 958 (1951).
[2] Bernardini, Booth, and Lederman, Phys. Rev. **83**, 1277 (1951).

Spin Paramagnetism of Cr^{+++} at Liquid Helium Temperatures and High Magnetic Fields

WARREN E. HENRY
Naval Research Laboratory, Washington, D. C.
(Received December 6, 1951)

ANALYSIS of measurements of the magnetic moments of suitable paramagnetic salts, in the range where saturation effects are observed, makes possible a determination of the applicability of existing theories of paramagnetism. In particular, one can check ideas relating to magneton numbers and the quenching of orbital angular momentum, as well as examine the use of these ideas in the space-quantized model of the paramagnetic ion.

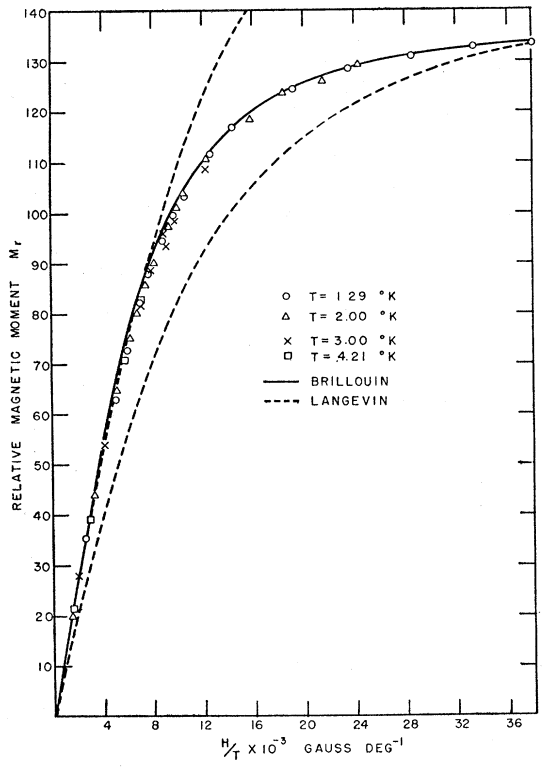

FIG. 1. Relative magnetic moment *vs* H/T for a solid sphere of potassium chromium alum. The Brillouin function (solid curve) is matched to the experimental moment at the largest value of H/T. For comparison, the Langevin function (broken line) is matched at the largest value of H/T to obtain the bottom curve while the slope is matched near the origin to obtain the top curve.

The magnetic moment of potassium chromium alum (which contains the trivalent chromium ion of spin $\frac{3}{2}$) has been previously measured at liquid helium temperatures in fields up to 19 kilogauss.[1] In the present study measurements are extended to 50 kilogauss, making it possible to carry out a more critical study of magnetic behavior near saturation. Relative magnetic moments of a spherical sample of the alum were measured with a double coil system. For fixed values of temperature and magnetic field, the sample was moved with respect to the coils; the resulting deflection of the ballistic galvanometer used being proportional to the magnetic moment of the sample. Relative moments were reproducible to ±0.2 percent and the ratios of magnetic field to absolute temperature were measured to an accuracy of ±1.5 percent. The results are given in Fig. 1.

Analysis of these data consisted of comparison, at given values of H/T, of ratios between calculated and measured moments. Perfect agreement would correspond to constancy of ratios. The Langevin formula did not fit the data (30 percent change in the ratio). However, good agreement (a total spread of about 3 percent over the range) was obtained by comparison with the space-quantized Brillouin model[2] based on the statistical distribution of possible orientations of the magnetic dipoles caused by the spin (the orbital momentum being quenched[3]). This gives for the magnetic moment

$$M=N\mu_B\left[(2S+1)\coth\frac{(2S+1)\mu_B H}{kT}-\coth\frac{\mu_B H}{kT}\right],$$

where N is the total number of ions, μ_B is the Bohr magneton, S is the spin, taken as $\frac{3}{2}$, k is the Boltzmann constant, H is the magnetic field, T is the absolute temperature, and g, the Lande-g factor, has been taken as 2 for $L=0$ instead of $\frac{2}{5}$ for $L=3$.

As can be seen from a comparison of experimental points and the Brillouin curve in Fig. 1, there is agreement for all temperatures used and for fields up to 50 kilogauss, where, for the lowest temperature used, a 99.5 percent saturation was achieved. The ideas of quenching and space quantization are not incompatible with the experimental results here obtained. A more detailed report of this study will be made later.

[1] Gorter, de Haas, and van den Handel, Amsterdam Acad. Sci. **36**, 158 (1933).
[2] L. Brillouin, J. Phys. **8**, 74 (1927); K. F. Niessen, Phys. Rev. **34**, 253 (1929); R. H. Fowler and E. A. Guggenheim, *Statistical Thermodynamics* (Cambridge University Press, London, 1939), p. 629.
[3] H. A. Kramers, Proc. K. Ned. Akad. Wet. **33**, 959 (1930); H. A. Jahn and E. Teller, Proc. Roy. Soc. (London) **A161**, 220 (1937).

Beta-Spectra of Cerium 144 and Praseodymium 144

CHENG LIN-SHENG, G. JOHN, AND J. D. KURBATOV
Ohio State University, Columbus, Ohio
(Received December 7, 1951)

IN previous investigations of Ce^{144} and its daughter product Pr^{144} two beta-spectra were reported: one spectrum of Ce^{144} with upper energy limit 348 kev and a second of Pr^{144} with upper energy limit 3.07 Mev. In addition three monochromatic electron groups were observed.[1]

Recently the transitions in Pr^{144} were reinvestigated with a permanent magnet spectrograph, and gamma-rays of 80.0 kev, 134.0 kev, and some other less definite gamma-rays were observed.[2]

In the present work the beta-spectra of Ce^{144} and Pr^{144} in equilibrium were studied. The Ce^{144} was obtained from Oak Ridge National Laboratory as carrier-free aged fission product. Part of this material was purified without carrier and a second part purified with carrier cerium added. In both cases the procedure used was precipitation of Ce IV at pH 3.5.

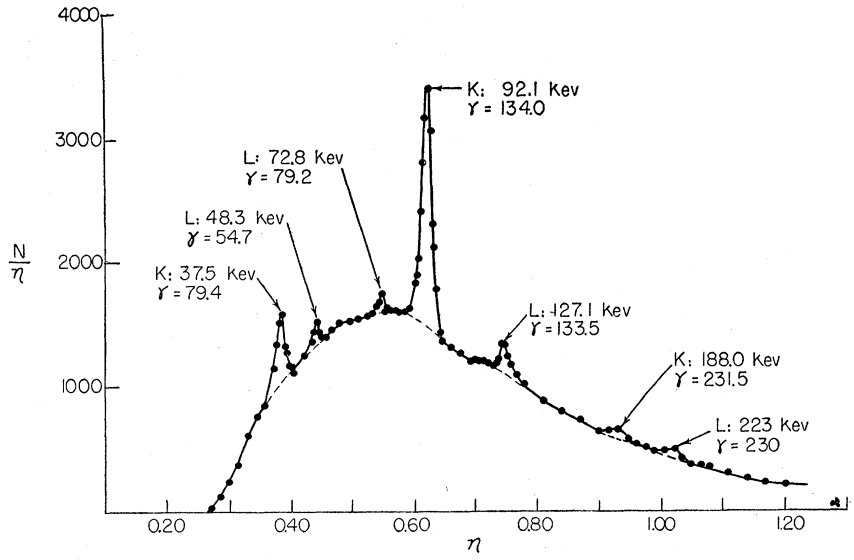

FIG. 1. Low energy part of electron spectrum of Ce^{144} and Pr^{144} (thin sample).

Both the carrier-free, very thin source of Ce^{144}, and the Ce^{144} with a few mg of common cerium added were studied with a solenoidal spectrometer equipped with a G. M. tube of 0.57 mg/cm² rubber hydrochloride window. The spectrometer was calibrated with I^{133}, Cs^{137}, and S^{35}. It gave undistorted spectra down to at least 50 kev with thin sources.

Figure 1 shows a plot of part of the electron spectrum from 25 kev to 250 kev. In this plot peaks can be seen for the conversion lines of gamma-rays of 54.7±0.5 kev, 79.4±0.8 kev, 134±1 kev, and 231±2 kev. The K-conversion line of the 54.7-kev gamma-ray has too low an energy to be observed with the instrument used. The K/L ratios of the 79.4-kev, 134-kev, and 231-kev gamma-rays are 6.3±0.7, 8.3±0.6, and 1.7±0.3, respectively.

Figure 2 shows a Fermi plot of the total spectrum. The highest beta-spectrum of energy 3.00±0.06 Mev, gives a straight line in an uncorrected Fermi plot as low as 1.30 Mev. After subtraction of the 3.0-Mev component from the total spectrum another component of 1.30±0.02 Mev is revealed, showing a straight line from 1.30 Mev down to 645 kev. The "hump" at about 640 kev may be the result of the conversion electrons of ~700-kev gamma-ray reported by Alburger *et al.*[3] Further subtractions from the Fermi plots show two groups of beta-spectra with upper energy limits of 605±8 kev and 446±8 kev. They show concave curves in the uncorrected Fermi plots. Considering the several subtractions in the Fermi plots, it may be mentioned here that if a correction factor of D_2-type is applied, the result is a straight line for the 605-kev and 446-kev groups. The α-type correction factor fails to yield straight lines. The remaining group of the beta-spectrum has an end-point energy of 307±6 kev. Its uncorrected Fermi plot is a straight line from 307 kev down to ~150 kev; below the latter energy the conversion electrons and back scattering produce distortion.

The authors wish to express their appreciation for a grant received from the Ohio State University Development Fund. This work was supported in part from funds granted by the Ohio

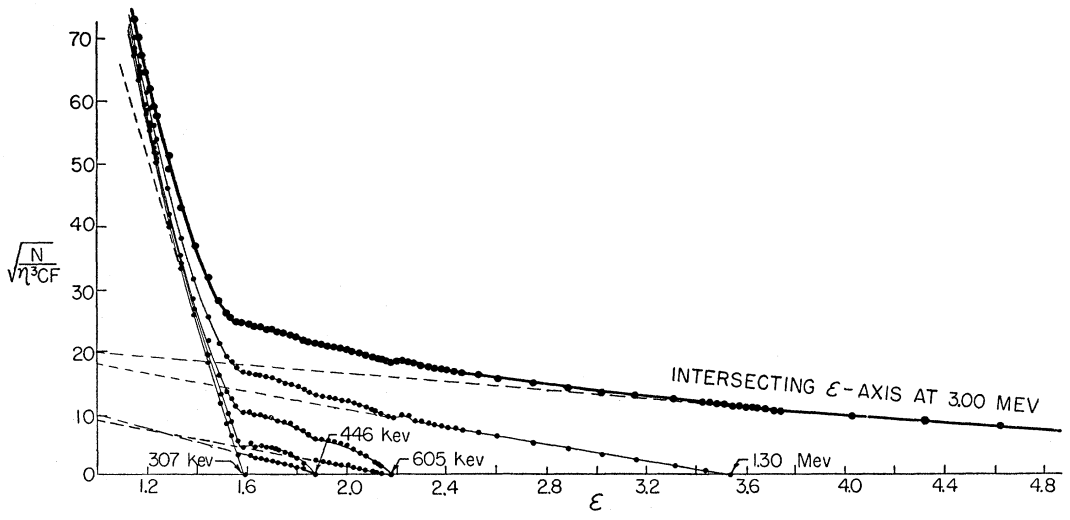

FIG. 2. Fermi plot of Ce^{144} and Pr^{144}.

State University Research Foundation to the University for aid in fundamental research.

Note added in proof.—The low relative intensity of some beta-components allows large variation in upper energy limits. The presence of beta-ray of energy 2.3 Mev of 5 percent abundance was recently reported by D. E. Alburger *et al.* at the 1952 Annual Meeting of the American Physical Society in New York. The existence of this beta-ray would clearly modify the foregoing analysis of the Fermi plot of Ce^{144} and Pr^{144}.

[1] V. A. Nedzel, National Nuclear Energy Series, Plutonium Project Record, Vol. 9, *Radiochemical Studies: The Fission Products*, Paper No. 187 (McGraw-Hill Book Company, Inc., New York, 1950).
[2] Emmerich, John, and Kurbatov, Phys. Rev. **82**, 968 (1951).
[3] Alburger, der Mateosian, Goldhaber, and Katcoff, Phys. Rev. **82**, 332 (1951).

The Formation of Triplet Positronium in Gases*

T. A. Pond†
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey
(Received December 6, 1951)

POSITRONS stopped in a gas annihilate with the emission of one, two, or three photons. One-photon annihilation has been calculated to occur less than 0.01 percent of the time in light gases.[1] Three-photon annihilation can occur in substantial amounts only for the positron and electron of a positronium atom[2] in a triplet state.[3] In the experiment to be described, the probability of three-photon decay from positronium is measured by comparing two-photon coincidence rates under circumstances which are identical except that in one case triplet positronium is allowed to annihilate, and in the other substantially all the positrons are forced to decay with two photons.

The apparatus is shown in Fig. 1. The magnetic field along the axis roughly doubles in the $\frac{5}{8}$ in. from the center to either pole tip. Because of the radial inhomogeneity, positrons from the $\frac{1}{2}$-mC Na^{22} source,[4] whose velocities lie in the central plane, move in helical orbits [Fig. 1 (B)]. A fraction of the positrons which have a component of velocity along the axis are trapped back into the central region by the axial inhomogeneity, which transfers energy of axial translation into rotation as the positrons adiabatically enter the stronger field. This greatly increases the annihilation rate around the central plane. The NaI(Tl) scintillation counters look for 180° coincidences in a portion of this region defined by the holes in the lead collimators. The lead shields the counters from the direct radiations of the source.

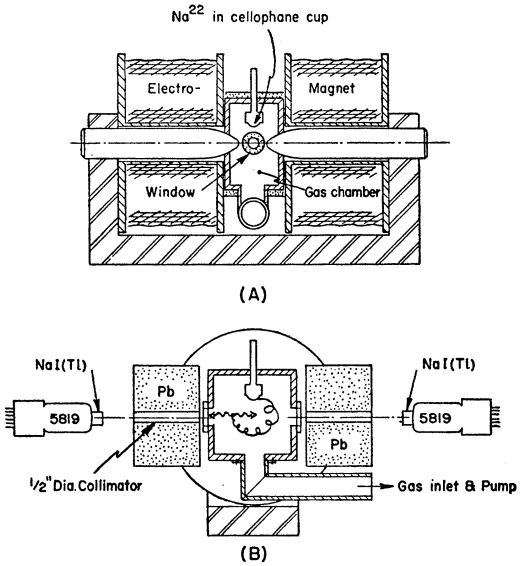

FIG. 1. Apparatus for studying positron annihilation in gases.

TABLE I. Fraction of positrons stopped in various gases in mean field of 5.62 kgauss, which decay from triplet state of positronium by three-photon emission.

Gas	H_2	N_2	A	He
Three-photon fraction	0.188	0.114	0.166	0.169
Standard deviation (percent)	7.5	4.4	8.5	8.8

A measure of the total number of positrons annihilating in view of the counters is obtained by adding a small amount of NO to the gas. The NO, because of its unpaired electron, gives rise to electron exchanges which can convert triplet to singlet positronium and vice versa.[2] Since the latter's lifetime is much the shorter, the annihilations will be with two photons. We find that adding NO increases the coincidence counting rate by a constant amount for concentrations greater than 0.6 percent. In a typical measurement, the coincidence counting rate is measured first in the gas (e.g., argon) with 3 percent NO added for a total pressure of 760 mm, and then in argon with 3 percent N_2 at the same total pressure. The difference between the two rates divided by the former is interpreted as the fraction of positrons that annihilate with three photons from the triplet state. The nitrogen is added in the latter case in order to ensure that the moderation conditions are as similar as possible.

Current and pressure controls are adequate to reduce counting rate variations caused by fluctuations in these quantities to less than 0.5 percent. The geometry and electronics are frequently tested by inserting a Na^{22} source into one of the collimating holes. All data are normalized to a standard counting rate under this condition. The gas mixtures were frequently changed to prevent changes in composition during the measurements as a result of reactions on the chamber walls. The chamber was filled with air after each exposure to NO, to eliminate an apparent evolution of NO in the subsequent run. Experiment shows that, at the field used, no positrons annihilate on the collimator windows in sight of both counters. Spurious coincidences caused by other effects are less than 1 percent of the total counting rate.

Preliminary data on the relative number of positrons stopped in various gases which decay from the triplet state of positronium with emission of three photons are shown in Table I. These measurements were made in a mean field of 5.62 kgauss. The determination of this field, as well as the correction necessary to reduce these data to zero field values, is discussed in reference 5.

It is a pleasure to thank Professor R. H. Dicke for suggesting this investigation and for his continued advice.

* Supported by the AEC and the Higgins Scientific Trust Fund.
† AEC Predoctoral Fellow, 1949–1951. This material is part of a thesis to be submitted to Princeton University.
[1] H. A. Bethe, Proc. Roy. Soc. (London) **150**, 129 (1935).
[2] M. Deutsch, Phys. Rev. **83**, 866 (1951).
[3] A. Ore, University of Bergen Yearbook **12** (1949).
[4] D. B. Cowie of the Carnegie Institution of Washington kindly prepared this source.
[5] T. A. Pond and R. H. Dicke, Phys. Rev. **85**, 489 (1952).

Fine Structure Splitting in the Ground State of Positronium*

T. A. Pond† and R. H. Dicke
Palmer Physical Laboratory, Princeton University, Princeton, New Jersey
(Received December 6, 1951)

IF a positronium atom in the 1^3S state is perturbed by a magnetic field, 1^1S wave function is mixed into the $m_j=0$ substate, while the $m_j=\pm 1$ substates are unaffected. Hence two-