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The $H\rho$ of the High Energy Internal Conversion Electrons from Thorium D

WALTER L. BROWN*
Harvard University, Cambridge, Massachusetts†

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The absolute $H\rho$ of the K internal conversion electrons from the 2.6-Mev gamma-ray of ThD has been measured using a 180° magnetic spectrometer whose field was calibrated with the proton magnetic resonance. With a proton resonance frequency, ν_P, of 3.75 megacycles, corresponding to a field of 880 gauss and an electron radius, ρ, of 11.4 cm, the value $\nu_P\rho=42.528\pm0.008$ megacycle cm was obtained for the line. This is equivalent, through the proton gyromagnetic ratio, to an $H\rho=9988._4\pm2$ gauss cm.

I. INTRODUCTION

A BETTER value for the absolute $H\rho$ of the K internal conversion electrons from the high energy gamma-ray of ThD has become of some importance. This line has been used by other workers to calibrate β-ray spectrographs, notably, by Bell and Elliott[1] in their recent work on the deuteron binding energy. The present experiment, utilizing a 180° magnetic spectrometer, is similar to that described by Ellis[2] in 1932. His result, $H\rho=10000\pm15$ gauss cm, was limited in accuracy by uncertainty of the field measurement made with an improved flip coil technique. The present experiment greatly reduces this limitation by utilizing the proton magnetic resonance in mapping the field. More recently than the work of Ellis, Hornyak,[3] and Wolfson[4] with magnetic lens spectrometers calibrated on lower energy lines have given the results 9998 ± 15 and 9988 ± 13 gauss cm, respectively.

II. APPARATUS AND EXPERIMENTAL PROCEDURE

In this experiment the field of approximately 880 gauss was supplied by an Alnico V permanent magnet (Fig. 1) having a working gap of rectangular cross section, one inch high and two inches wide. The flat pole faces produce a field that falls off parabolically for small distances (less than a centimeter) on either side of the mean radius of about 11.4 cm. This shaping of the field gives a partial second-order correction to the semicircular focusing of the spectrometer and thus improves the image intensity.

For exploration of the field in the median plane, the proton magnetic resonance in mineral oil was observed using the negative resistance oscillator circuit developed by Pound and Knight.[5] With a proton sample 2.2 mm in diameter and about 1 cm long, the resonance frequency appropriate to the field at the mean radius could readily be measured to ±50 cycles in 3.75 megacycles. At points on either side of the mean radius the magnetic inhomogeneity across the sample broadens the proton resonance and reduces the precision with which the field can be determined. However, these points are important only as they specify the radial shape of the field and hence the extent of the second-order correction to the ordinary semicircular focusing. In the present case, this shape was found not to depend upon the angular position of the probe in the magnet gap and was given by $H(r)=H_0[1-0.46(r-r_0)^2/r_0^2]$, where H_0 is the field at the mean radius, r_0, and r may differ from r_0 by as much as 8 mm. Unfortunately, H_0 itself was not independent of the angular position and actually varied about 0.1 percent over the 180° sector used and several times this much over the rest of the magnet. This inhomogeneity is small enough so that it does not complicate the focusing, and it can be included as a simple correction to yield the effective H_0 over the complete electron orbit from measurement of H_0 at some specific angular position.

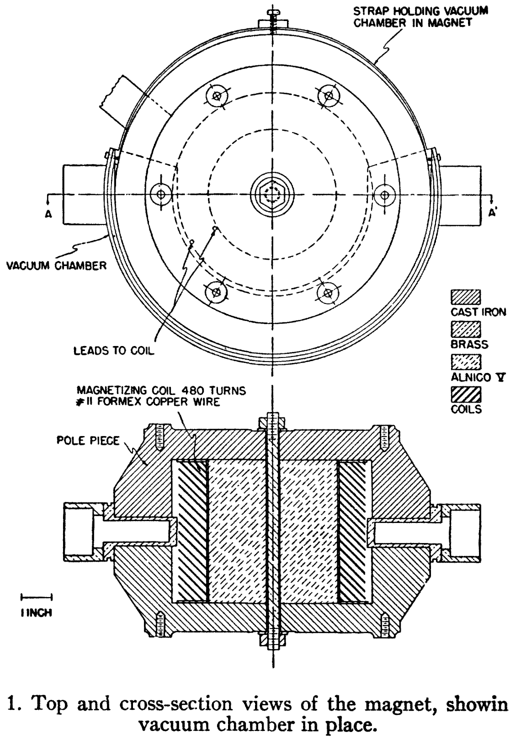

FIG. 1. Top and cross-section views of the magnet, showing the vacuum chamber in place.

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* Now with Bell Telephone Laboratories, Murray Hill, New Jersey.

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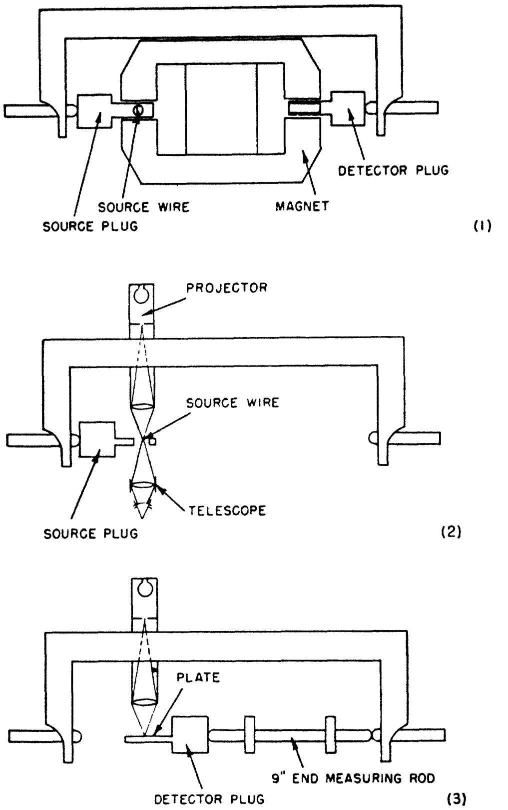

FIG. 2. Schematic diagram of steps in the measurement of ρ.

During a run, field measurements could not be made over the semicircle traversed by electrons. However, H_0 was monitored at an angular position outside the vacuum chamber, and tests had shown that any variation of the field in time occurred uniformly over the whole magnet within ±100 cycles, the accuracy with which such comparisons could be made. Variations during a run did occur, due principally to a reversible temperature dependence of the magnetic field amounting to 1 kilocycle/°C in the total of 3.75 megacycles.

Thorium sources were prepared by electrostatic collection of the thorium active deposit on a 1-mil platinum wire about 8 mm long. A 2-mm slit at the source selected the central section of the wire's length when mounted in the spectrometer. Otherwise, the electron beam was defined only by a single slit placed half-way around the orbit and having a radial opening of 1 cm. Four aluminum baffles were spaced equally around the orbit to prevent electrons scattered from the walls of the vacuum chamber from reaching the photographic detector. These, however, played no part in limiting the beam. The photographic plate was accessible to electrons over a height of about 1 cm and a radial distance of 1 inch.

A calculation of the electron intensity at the detector gives a maximum value of 0.045 electron/cm^2 for every electron emitted from the 2-mm central section of the source wire.[6] If a one-millicurie ThB source can be prepared on the wire, about 10^7 electrons/cm^2 should fall at the position of maximum intensity over a twenty-one hour exposure period. Acceptable image intensities were found to require sources of approximately this magnitude.

Eastman NTB-3 and Ilford G-5 nuclear plates were used as detectors with exposures of about twenty-one hours, two half-lives of ThB, the controlling product in the decay series. There was considerable difficulty with the emulsion of the Eastman plates stripping off the glass backing under these long vacuum exposures. Even in cases where the plates could be processed, the lateral distortion resulting from incomplete adherence of the emulsion was troublesome. Such exposures were sometimes usable because a scale produced on the plate (to be discussed below) allowed the distortion to be estimated. The Ilford plates did not show stripping tendencies and were used exclusively in final exposures.

The measurement of ρ, the radius of the electron orbits, was made by means of a fiducial scale which was projected on the plate before processing and whose lines appeared at known distances from the source. The steps in this procedure are shown schematically in Fig. 2.

(1) At the end of an electron exposure, with the chamber still under vacuum, a large "c"-shaped micrometer made of channel Duraluminum was placed over the magnet. Brass screws in either end of the micrometer were brought into low voltage electrical contact with the plugs supporting the source and detector. The screws were clamped in this position through the remaining steps.

(2) The micrometer was removed from the magnet and placed on a separate stand. A small projector containing a scale ruled on a black photographic plate was inserted through the back of the "c." The vacuum chamber was brought to atmospheric pressure and the source plug removed. With this plug in electrical contact with one micrometer screw, the projector was moved until a line of the fiducial scale was brought into coincidence with the source wire, this operation being observed through a telescope.

(3) A 9-inch end measuring rod was placed in contact with the other micrometer screw, and the detector plug in contact with the rod. Turning on the projector then cast the image of the fiducial scale on the photographic plate.

The result of this procedure was to produce a scale on the plate so that a particular line of the scale lay a known distance from the source wire, as the source and detector were held during exposure. The determination of the diameter of the electron orbits was thus reduced

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[6] The portion of the plate which received any electrons was only 1 cm high by 0.02 cm in radial width, and the intensity is much less than its maximum value over most of this area. The solid angle at the source contributing to the image is actually 10^{-4} of a sphere.

to the measurement of the short distance on the processed plate from the electron line to the fiducial line.

III. THE RESULTS

Figure 3 shows the radial dependence of the photographic image as traced with a microphotometer which scanned a swath 1 mm in height across the center of the plate. The evenly spaced vertical lines are 0.1 mm apart and are made by the microphotometer. The three similar peaks are lines of the fiducial scale, one of which lies at a known distance from the source. The principal peak is the K internal conversion electron distribution, with its sharper rise on the side of large radius in the spectrometer.

A detailed second-order calculation similar to that of Beiduk and Konopinski[7] has been made under the present conditions of focusing, and it is found that ideally the sharper rise of the line would have a width insignificantly greater than 1 mil, the width of the source. The distance measurement should, under this condition, be made to the center of the rise, since this position lies just the diameter of the electron orbits from the center of the source and the fiducial line in step (2) was made to coincide with the center of the source. Actually, the rise is about three times as broad as its theoretical minimum value. There are a number of factors which can contribute to this broadening: (1) Variations in the permanent magnet field during an exposure generally amounted to 300 or 400 cycles in 3.75 megacycles, corresponding to a radial shift of the whole electron distribution at the detector of about 1 mil. (2) The source wire may not be aligned exactly parallel to the axis of the magnet. From observations made of the mounting, it is not unlikely that this gives the source an apparent width 50 percent greater than the diameter of the wire. (3) The emulsions used were thick, 100 to 200 microns, in order to get as dense a photographic image as possible. A calculation of multiple scattering shows that the electron beam will suffer a mean square lateral displacement of the order of a mil in traversing even the thinnest of these. (4) The width of the microphotometer trace used in scanning the processed plates is not at all negligible. In a typical case it will be between one and two mils.

These four factors together can easily account for the observed broadening of the rise of the electron line, With the exception of the improper vertical alignment of the source, they will not, however, broaden the rise symmetrically about its center. A reasonably uniform change in magnetic field during exposure as well as the other two effects will tend to shift the toe of the rise more in one direction than they shift the peak in the other. This would require that the distance measurement be made to some point higher on the rise than its center. However, since the details of broadening are not known, the measurements have been made to the center in all cases and an uncertainty included in the measurements covering two-thirds of the total rise. The proper point will almost certainly lie within this range.

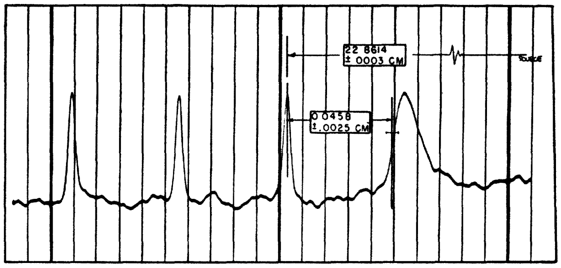

FIG. 3. Microphotometer trace of the K-internal conversion electron line.

The uncertainty in selection of the proper point on the electron line is the predominate one in the value of ρ. The actual measurement of the distance on the microphotometer trace from the center of the fiducial mark to the center of the rise of the electron line contributes no significant error. The length of the 9-inch end measuring rod has been calibrated by the National Bureau of Standards to five parts in a million. The temperature correction to be applied to this length introduces an uncertainty of about one part in a hundred-thousand.

The proton resonance frequency appropriate to the magnetic field seen by the electrons fluctuates during an exposure, as previously mentioned. The maximum extent of the variation measured at the monitoring point added to the ±100 cycle limit, within which the field seen by the electrons is known to vary in the same way as the field at the monitoring point, determines the uncertainty ascribed to the frequency measurement.

The mean of a total of seven usable exposures gives the value

$$\nu_P\rho = 42.528 \pm 0.008 \text{ megacycle cm},$$

where ν_P is the frequency of the proton resonance in mineral oil, and ρ is the radius of the electron orbits. Among the seven cases, the maximum deviation from the mean is 0.006, and the mean deviation 0.003. The ±0.008 megacycle cm represents the sum of the limits of error assigned to the independent measurements of ν_P and ρ, as described above.

Combining this result with the Thomas, Driscoll, and Hipple[8] value of the gyromagnetic ratio of the proton in mineral oil, the K conversion electrons are found to have

$$H\rho = 9988._4 \pm 2 \text{ gauss cm}.$$

The values given by other observers, previously quoted, all easily agree with this result within their stated errors.

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In finding the electron energy,

$$E_e = mc^2\{[1+(He\rho/mc^2)^2]^{\frac{1}{2}}-1\},$$

it is desirable to use Gardner and Purcell's[9] ratio of the electron cyclotron frequency to the proton resonance frequency, $\omega_e/\omega_P = 657.475 \pm 0.008$. In terms of it, $He\rho/mc^2 = (2\pi/c)(\omega_e/\omega_P)\nu_P\rho$. Thomas'[10] value of $e/mc = (1.75891 \pm 0.00005)\times 10^7$ and Hansen and Bol's value of $c = (2.99790 \pm 0.000007)\times 10^{10}$ (discussed by Bearden[11]) give an electron rest energy $mc^2 = 0.51096 \pm 0.00002$ Mev. Using these constants, the internal conversion electrons are found to have an energy

$$E_e = 2.5267 \pm 0.0006 \text{ Mev.}$$

Adding the K-shell absorption limit of Pb which Compton and Allison[12] give as 0.0880 Mev, the energy of the original ThD gamma-ray is found to be

$$E_\gamma = 2.6147 \pm 0.0006 \text{ Mev.}$$

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Proton-Proton Scattering at 105 Mev and 75 Mev*

Robert W. Birge,† Ulrich E. Kruse, and Norman F. Ramsey
Harvard University, Cambridge, Massachusetts

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The proton-proton differential scattering cross section has been measured at 105 Mev and at 75 Mev by using the internal beam of the Harvard cyclotron. Scintillation counters detected the scattered and recoil protons in coincidence while the beam current was monitored by measuring the absolute activity of C^{11} formed in the polyethylene scattering foil. The cross section as a function of angle in the center-of-mass system appears to be isotropic within statistical deviation. It has the values 5.4×10^{-27} cm^2 and 6.6×10^{-27} cm^2 at 105 Mev and 75 Mev respectively, with an estimated error of twenty percent.

I. INTRODUCTION

The scattering of protons by protons provides an important method for studying the nature of nuclear forces. At low energies, less than five Mev, the de Broglie wavelength $\lambdabar$ of a proton is large compared to the range of nuclear forces, and the interaction is effective only in states of zero orbital angular momentum (S states). Recent proton-proton scattering experiments at energies as high as thirty Mev[1] have failed to show any appreciable contribution to the cross section from higher angular momentum states, but it is necessary to bring in tensor forces to explain the magnitude of the observed cross section.[2]

Further experiments now in progress at Berkeley,[3] in the 350-Mev region, indicate spherical symmetry, but with twice the cross section that can be explained theoretically by the use of central force scattering theory. Because of these unusual results at high energies, the 100-Mev region is of particular interest.

The experiment described here used the internal beam of 115-Mev protons made available by the operation of the Harvard 95-inch frequency-modulated cyclotron. A brief description of the equipment and some of the results has already appeared,[4] hence the chief purpose of this paper is to give in somewhat more detail the techniques used and problems encountered in the experiment.

II. DESCRIPTION OF EQUIPMENT

A. Target

The internal proton beam is intercepted by a ten-mil polyethylene, $(CH_2)_n$, target and the recoil and scattered protons in the vertical plane are detected in coincidence as in the method of Wilson and Creutz[5] and as in the scattering experiments of Oxley[6] which use an internal cyclotron beam. This method effectively eliminates the background due to protons scattered from the carbon in the target. The polyethylene foil is

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* Assisted by the joint program of the ONR and AEC.

† Now at the Radiation Laboratory, University of California, Berkeley, California.

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