The Beta-Ray Spectra of Several Slow Neutron-Activated Substances

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Indium, silver, rhodium, manganese and dysprosium have been rendered radioactive by exposure to slow neutrons from a 200 millicurie radon-beryllium source surrounded by paraffin, and their beta-ray spectra obtained by the cloud-chamber method. The plots of the energy distributions were transformed into straight lines according to the Konopinski-Uhlenbeck formula, and extrapolated to find the upper energy limits. The fit with the K-U theory was found to be good. The extrapolated upper energy limits found were: In (54-minute period), 1.3 MEV; In (13-second period), 3.2 MEV; Ag, 2.8 MEV; Rh, 2.8 MEV; Mn, 2.8 MEV; Dy, 1.4 MEV.

INTRODUCTION

BECAUSE of the wide theoretical interest in the energy distribution of electrons emitted from natural and artificially stimulated radioactive substances, and the relation of their decay[1] periods to the upper energy limits of the electrons, it has become desirable to obtain such data on as wide a variety of beta-ray emitters as possible. The Konopinski-Uhlenbeck modification of the Fermi theory of beta-decay gives us a method of transforming the energy distribution curves onto a scale in which they appear approximately as straight lines and makes it possible to obtain an estimate of the upper energy limit by an extrapolation which is reasonably impersonal and consistent when used to compare various spectra. Estimates of the upper limit without the use of such a transformation become largely guess work, because of the "tailing out" of the upper end of the spectrum.

By means of a 200 millicurie radon-beryllium neutron source we have been able to activate a number of substances and have obtained their beta-ray energy spectra by the cloud-chamber method.

EXPERIMENTAL METHOD

The cloud chamber employed was 15 cm in diameter and 3 cm deep, filled with air and ethyl alcohol vapor at 1 atmosphere pressure, and equipped with a pair of Helmholz coils arranged so as to bend the electron tracks in the plane of the chamber. A collimated beam of parallel light limited the visible part of the chamber to a sheet 1.5 cm deep, located centrally between the top and bottom. A well in which to place the active substances was set into the top glass plate of the chamber near one side, as shown in Fig. 1. This was 2.5 cm in diameter and had a copper wall 0.0025 cm thick. A 2 mm lead lining having a window 1.5 cm high and extending around 90 degrees of the well at the height of the light beam was inserted to define the source of the beta-rays. In the measuring process only those tracks were considered which appeared to originate within this defined window. With this arrangement it was easy to drop activated substances into the well so that they faced the window, and they could be interchanged within about two seconds, which was essential with several of the short lived substances. Non-stereoscopic photographs were taken and later reprojected natural size for measuring, which was accomplished in the usual way, namely, by matching the tracks with circles of known radii drawn on a card. In most of the present work the strength of the magnetic field was 850 gauss, which made the radius of curvature of a 1 MEV track about 5.5 cm and that of a 2 MEV track about 9.5 cm. The tracks were measured and recorded in groups differing by 1/2 cm radius of curvature, which amounts to 10 percent accuracy for 1 MEV and 5 percent for 2 MEV tracks.

Several possible sources of error are recognized to be present in this type of experiment and have been discussed at length by other authors[2, 3] who use essentially the same method, with somewhat varying opinions as to the seriousness of their effects. These may be listed mainly as the following:

[1] Konopinski and Uhlenbeck, Phys. Rev. **48**, 7 (1935).

[2] Kurie, Richardson and Paxton, Phys. Rev. **49**, 368 (1936).

[3] Fowler, Delsasso and Lauritsen, Phys. Rev. **49**, 561 (1936).

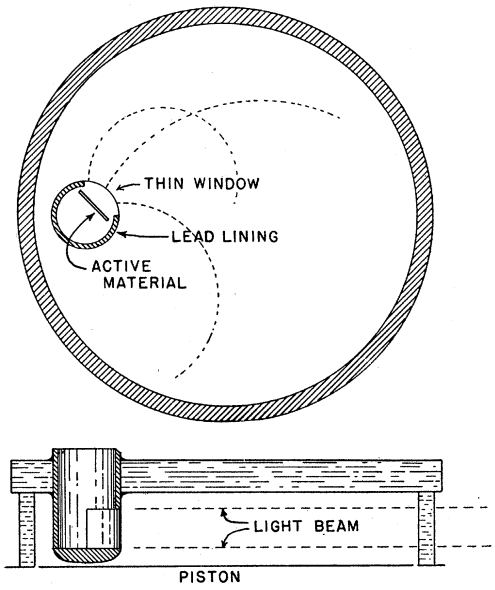


FIG. 1. Horizontal and vertical sections through the cloud chamber, showing the well into which the active substances were introduced.

1. *Scattering:* The probability of scattering is, according to theory, inversely proportional to the square of the energy of the electron and proportional to the square of the atomic number of the gas in the chamber. Also, the probability of small angle scattering is greater than that of large angle scattering. In the present work most of the reprojected tracks were sharp enough so that single scattering of as much as 2° could be recognized, and also appreciable departure of the track from circularity could be recognized; the latter taking care to a large extent of the effect of multiple small angle scattering. In most cases where scattering was recognized in one part of a track, the remaining circular part of the track could be measured with the required accuracy. In a typical run of pictures, only about one otherwise measurable track out of 15 had to be discarded completely on account of scattering. Scattering which is not recognized but large enough to shift the measured radius of curvature of the track by 1/2 cm (the interval used in measuring) is not believed to be frequent and it is estimated that the ordinates of the curves obtained are not influenced to more than a few percent from this cause.

2. *Dependence upon curvature of* (a) the length of track required for accurate measurement of curvature and (b) the chance of a measurable portion of the track lying within the visible part of the chamber. Both these effects are in the direction of favoring the tracks of small curvature.

3. *Effect of thickness of source.* The thicknesses of the substances activated, in terms of stopping power for 1 MEV electrons, were estimated to be as follows: In, 0.2 MEV; Ag, 0.2 MEV; Rh, 0.25 MEV; Mn, 0.35 MEV; Dy, 0.25 MEV. The effect of this is to distort the curve slightly toward the low energy.

4. *Material between the source and the chamber* (copper foils): The stopping power of this material was taken into account in plotting the curves. It varies somewhat with the energy of the electron. For 1 MEV electrons it was estimated to be as follows: In the set-up used for the Ag, In and Rh sources, 0.035 MEV; in that used for the Dy and Mn sources, 0.07 MEV.

5. *Relation between the $H\rho$ interval and the energy interval:* The ratio between the $H\rho$ and the corresponding energy interval is a varying factor in the region of low energies, and consequently in plotting the data on an energy scale as in Figs. 2 to 7, it was necessary to apply a small correction to the ordinates obtained for the 1/2 cm curvature intervals.

6. *Magnetic field strength:* The strength of the magnetic field was calculated from the geometry of the windings and the current, and, as a check, about 1000 recoil electron tracks from the gamma-rays of Th C″ were measured and found to give a cut-off which was in exact agreement with the known energy.

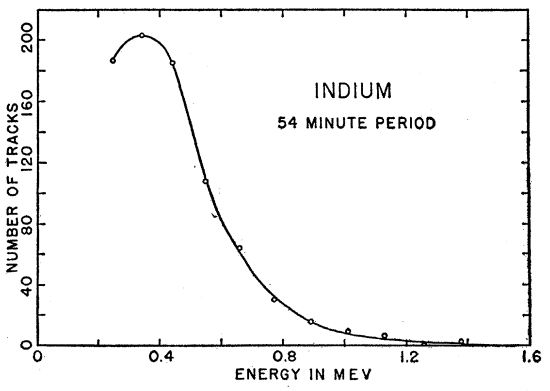


FIG. 2.

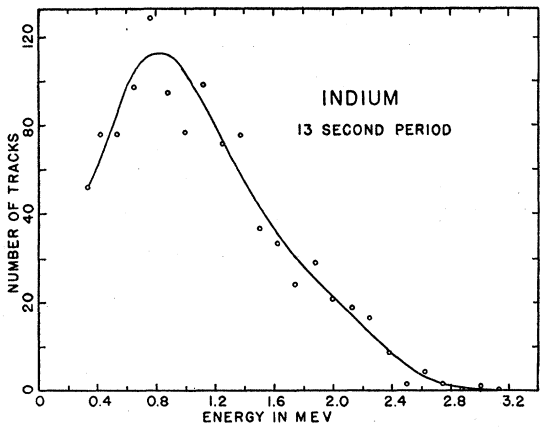


FIG. 3.

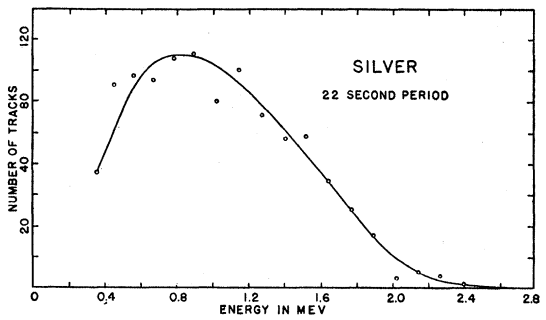
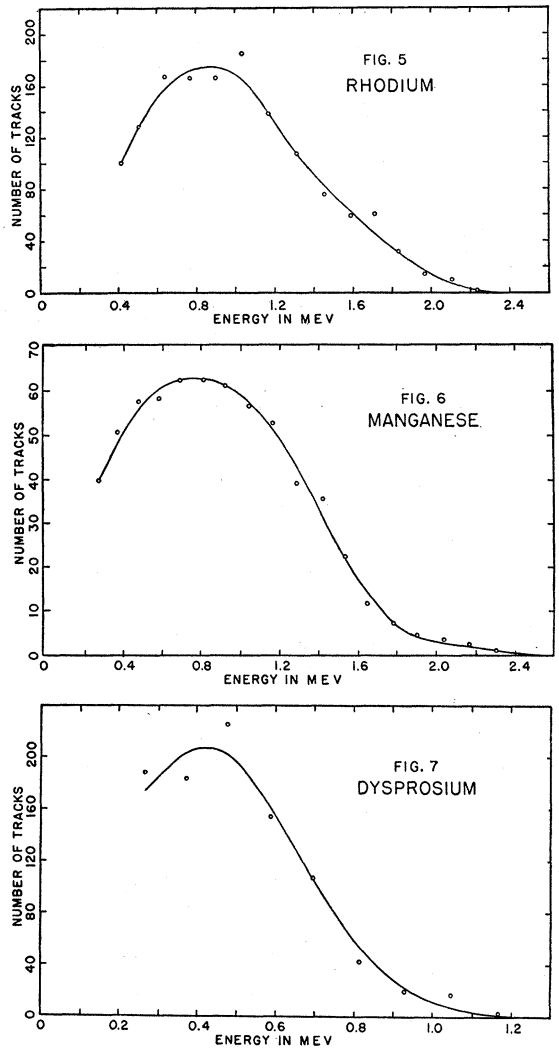


FIG. 4.



FIGS. 5, 6 and 7.

RESULTS

Indium

Indium emits two groups of negative electrons with half-lives 54 minutes and 13 seconds,[4] respectively. It seems reasonable to assume that these result from two separate isotopes. The spectrum of electrons of the 54-minute period was obtained by exposing the indium for several hours, then waiting about 5 minutes before beginning the measurements, which should have reduced the activity of the 13-second period by a factor of 10^7. In measuring the short period activity, five foils were activated in rotation, each for about 15 seconds before being placed in the cloud chamber. A freshly activated foil was used for each expansion. A consideration of the times involved in this procedure indicated that less than 2 percent of the tracks obtained should have been due to the long period, and these cannot affect the upper end of the 13-second spectrum, as is seen by comparing the energies of the two spectra. Figs. 2 and 3 show the distribution in energy of the tracks for the two periods.

Gamma-rays were detected from the 54-minute period and a few recoil electron tracks were obtained from a thin sheet of glass placed across the center of the chamber. A gamma-ray in the neighborhood of 1 MEV was indicated, with a few tracks also extending to higher energies, indicating the possible presence of an additional weaker and somewhat higher energy line. The small number of tracks makes an estimate of the gamma-ray energy extremely

[4] Amaldi, d'Agostino, Fermi, Pontecorvo, Rasetti and Segrè, Proc. Roy. Soc. **A149**, 522 (1935).

hazardous. No attempt was made to detect gamma-rays from the 13-second period.

Silver

Silver emits negative electrons with half-lives 22 seconds and 2.3 minutes,[4] which have been reported to be of roughly equal intensity and both water sensitive. By placing the silver in the cloud chamber immediately after activation for several minutes, a number of tracks were obtained on the first one or two expansions (the expansion interval was 30 seconds), but tracks on later expansions, which were expected to be present due to the 2.3-minute period were found to be comparatively rare. In obtaining the data in Fig. 4, six silver samples were used; each was activated for only 30 seconds, prior to the expansion, to safeguard further against the possibility of getting any tracks belonging to the 2.3-minute period.

Rhodium

Two periods have been reported for rhodium: 44 seconds and 3.9 minutes.[4] We have measured the energy spectrum of the 44-second period only. A freshly activated foil was used for every two expansions. Fig. 5 shows the energy distribution of negative electrons obtained.

Manganese[4] and dysprosium[5, 6]

These substances emit negative electrons, each with a half-life of approximately 2.5 hours. Photographs were taken over a period of about 2 hours after activation. The results are shown in Figs. 6 and 7. The upper energy limit for dysprosium is in agreement with that reported by Hevesy and Levi.[5]

Comparison with the Konopinski-Uhlenbeck Theory

In Figs. 8, 9 and 10 are plotted the data of the 6 spectra on scales whose ordinates are $[N(\rho)/(H\rho)^2]^{\frac{1}{4}}$ ($N(\rho)$ is the number of tracks in a 1/2 cm interval) and whose abscissa are the total energy of the electrons, including the rest mass, in mc^2 units. Agreement of the experimental data with the K−U theory is indicated if the points fall on straight lines when plotted on this scale. Statistical fluctuations in the ponts near the high energy end of the curves render the last few points untrustworthy, but it is seen that, with the exception of the extreme ends, the points fall reasonably well on straight lines. The upper energy limits of the spectra obtained by extrapolation are: In (54-minute period), 1.3 MEV; In (13-second period), 3.2 MEV; Ag, 2.8 MEV; Rh, 2.8 MEV; Mn, 2.8 MEV; Dy, 1.4 MEV.

According to the Konopinski-Uhlenbeck modification of the Fermi theory the shape of the beta-ray curves depends to some extent upon the nuclear charge especially for elements of high atomic number. In calculating the points for all the K-U plots shown, however, the atomic number was taken equal to zero. As a justifica-

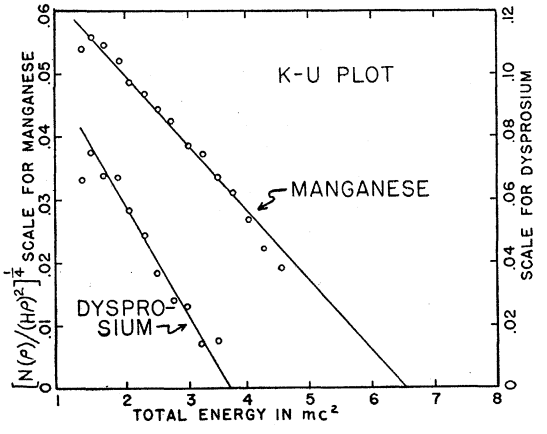


FIG. 8.

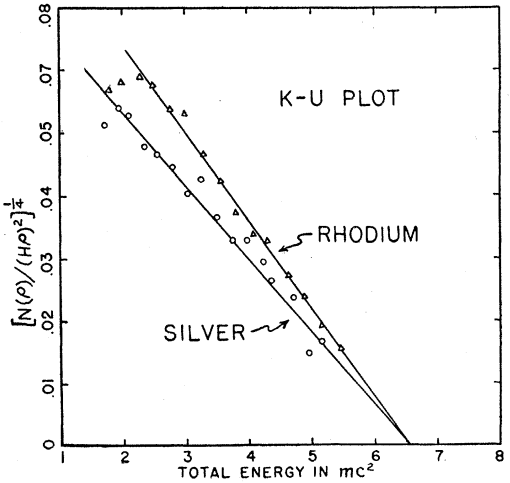


FIG. 9.

[5] Hevesy and Levi, Nature **136**, 102 (1935).
[6] Marsh and Sugden, Nature **136**, 102 (1935).

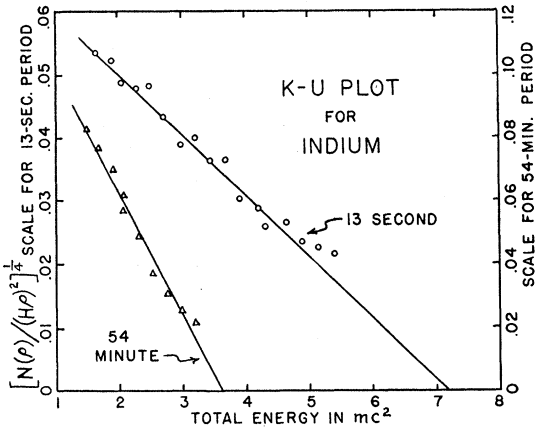


FIG. 10.

tion of this we applied the atomic number correction to the plot of dysprosium (66) and, rhodium (45), and found that it made no significant change either in their form or their end points, insofar as the accuracy of the present data is concerned.

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Note: Since completing these experiments a paper has appeared by R. Naidu and R. E. Siday (Proc. Phys. Soc. **48**, 332 (1936)) in which they describe measurements of the energy spectra of Ag, Rh, and Dy. Their upper energy limits, obtained by inspection of the energy distribution plots, are 3.8, 3.6, and 1.9 MEV, respectively. These are about 30 percent higher than the values we obtain by inspection. Also, the limits they give for Si and F are very much higher than previous measurements on the same substances by Kurie, Richardson and Paxton (Phys. Rev. **48**, 167 (1935)) and by Crane, Delsasso, Fowler and Lauritsen (Phys. Rev. **47**, 971 (1935)). Alichanow, Alichanian and Dzelepow (Nature **136**, 257 (1935)) have reported energy limits for Rh, Ag and Mn, which are in fair agreement with our values.

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The Emission Spectrum of D_2 in the Extreme Ultraviolet

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The emission spectrum of the D_2 molecule has been photographed in the extreme ultraviolet region by use of a grazing incidence vacuum spectrograph with 2-meter grating In the $2p\,^1\Sigma - 1s\,^1\Sigma$ system 37 bands have been analyzed. In the $2p^1\,\Pi - 1s\,^1\Sigma$ system 29 bands were obtained. Constants of the three observed electronic states of the D_2 molecule are given and the data are compared with that of the H_2 molecule. Electronic shifts of 4 cm^{-1} and 23 cm^{-1} are observed for the $2p\,^1\Sigma - 1s\,^1\Sigma$ and $2p\,^1\Pi - 1s\,^1\Sigma$ systems, respectively.

INTRODUCTION

THE following paper is concerned with a description of the $2p\,^1\Sigma - 1s\,^1\Sigma$ $(B-A)$ and $2p\,^1\Pi_{cd} - 1s\,^1\Sigma$ $(C-A)$ band systems in the extreme ultraviolet spectrum of the D_2 molecule. Considerable study has been applied to these systems in the spectra of the H_2[1] and HD[2, 3, 4] molecules and in the present work a comparison is made between the H_2 and D_2 spectra.

EXPERIMENTAL PROCEDURE

For excitation of the D_2 bands in the extreme ultraviolet the methods used previously[1] for the study of H_2 are in general applicable. The chief difficulty in the production of the D_2 spectrum is the problem of outgassing the discharge tube so completely that the remaining amount of H_2 in the electrodes and the glass is negligible. In our case this is somewhat complicated by the fact that no window can be used between the discharge tube and the slit of the spectrograph. It is therefore necessary either to use a stopcock between the source and slit or to admit air into the discharge tube before attaching it to the spectrograph and after each exposure. It is found that by taking suitable precautions the latter method

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[1] See C. R. Jeppesen, Phys. Rev. **44**, 165 (1933) and references given there.

[2] C. R. Jeppesen, Phys. Rev. **45**, 480 (1934).

[3] Kurt Mie, Zeits. f. Physik **91**, 475 (1934).

[4] Y. Fujioka and T. Wada, Scientific Papers of the Institute of Physical and Chemical Research, Komagome, H ongo, Tokyo, **27**, 210 (1935).