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Comparison of Alpha-Particle Energies from Various Po^{210} Sources

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A comparison of the energies of alpha particles from six different Po^{210} sources was made with the same broad-range spectrograph used for a recent comparison of the Po^{210} alpha-particle energy with the $Li^7(p,n)Be^7$ threshold energy. The sources were prepared by different techniques and some were on flat backings whereas others were on cylindrical backings. It is concluded that the discrepancies in the most recent measurements of the alpha energy do not arise from source preparation techniques but the lower values of the older measurements may have been caused by source aging.

RECENT absolute measurements of the energy of alpha particles emitted by Po^{210} and a recent comparison of this energy with the threshold energy of the $Li^7(p,n)Be^7$ reaction are in rather serious disagreement with the older measurements.[1] A very recent absolute measurement gives an intermediate value.[2] One possible cause of the discrepancy is the condition of the polonium source which may depend on its method of preparation and age.

This is a report of part of a project whose goal is to eliminate the variable of source condition. The energy of alpha particles from sources made by one person by one technique were measured in different laboratories and compared with results obtained using sources made by the various techniques used in these laboratories. To this end one of us (T.A.E.) has prepared polonium sources at Notre Dame and at Rice which have then been compared with sources made at those laboratories. This is a report of the comparison made at Notre Dame and the report of the work at Rice will appear soon.[2]

Six polonium sources were made and ten alpha particle groups recorded with the Notre Dame broad-range spectrograph. The following measurements were made: (1) Sources prepared by currentless electro-deposition onto silver by one of us (T.A.E.) using a 2.5 N nitric acid solution of polonium were compared with sources made by the other author (C.P.B.) using the same basic method but with the polonium chloride solution used in earlier work.[1] (2) Sources deposited on cylindrical backings were compared with sources deposited on flat backings. (3) Distributions of particle energies were observed from sources of various ages.

No direct comparison with the $Li^7(p,n)Be^7$ reaction threshold energy was attempted because this would have introduced many more uncertainties and to have equalled the precision of earlier measurements an unwarranted amount of work would have been necessary.

[1] For summary see: C. P. Browne, J. A. Galey, J. R. Erskine, and K. L. Warsh, Phys. Rev. **120**, 905 (1960). Also: C. P. Browne, J. A. Galey, J. A. Erskine, and K. L. Warsh, *Proceedings of the International Conference on Nuclidic Masses, McMaster, 1960* (University of Toronto Press, Toronto, 1960).

[2] E. H. Beckner, R. L. Bramblett, G. C. Phillips, and T. A. Eastwood, Phys. Rev. **123**, 2100 (1961).

Because of the well-known differential hysteresis effects in spectrographs the magnetic field was left on and held constant during all runs in which the first two comparisons listed above were made. The standard procedure for calibrating the spectrograph was used to measure particle energies. This procedure is, first, to clamp the source on a holder which is in turn fastened to the target support rod of the spectrograph. Next the rod is placed in its guides in the target chamber and pressed against the stop which fixes it in a standard position. Then, after evacuating the chamber, the shutter to the spectrograph is opened for a suitable length of time. The position of the source relative to the target rod is set by sliding the holder along the rod while using a microscope to measure the distance from the source to a fiducial mark on the target rod. In this way all sources are put at the same position in the target chamber to within ± 0.003 mm. In comparing flat sources with round sources or sources of different size, the top edge is always placed at the same spot. Particles from the top edge of the source form the edge of the image lying farthest up the nuclear track plate at the focal surface and this is the high-energy side of the group. The usual criterion for the "position" of the group on the plate was used, i.e., the point on the high energy edge at one-third the maximum.

The first comparison, that of sources made by each of the authors, gave the result shown in Fig. 1. Source 1 was made by the standard technique in use at Notre Dame from the polonium chloride solution used for most of the work on comparison of the Po^{210} alpha-particle energy with the $Li^7(p,n)Be^7$ reaction threshold energy. Source 2 was made by the other author (T.A.E.) using a silver wire backing and polonium nitrate solution brought from the Chalk River laboratories. Both sources were deposited on $\frac{1}{4}$-mm diam silver wire. The figure shows that a single curve fits the data points from both sources. Representative statistical uncertainties for points near the maximum of the curve are indicated in the figure. The geometric image size calculated for a $\frac{1}{4}$-mm high source is shown and also the plate distance corresponding to 1-kev energy spread. An energy

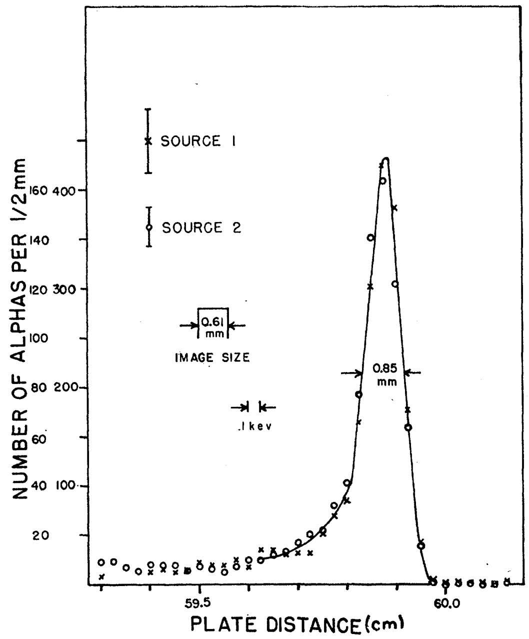

FIG. 1. Alpha-particle groups from two polonium sources. Source 1 made by the standard Notre Dame technique. Source 2 made from polonium nitrate solution (by T.A.E.). The number of alpha particles is plotted as a function of position on the spectrograph plate.

spread of 3 kev when combined with the image size accounts for the observed width of the peak. It is not possible to draw curves through the two sets of points which differ in one-third height position by more than 0.2 kev. Counting and plotting uncertainties are usually considered to amount to at least 0.1 mm or about 0.4 kev in this case. Clearly the two sources give identical results to well within the limits of measurement.

The sources used for the comparison shown in Fig. 1 were on $\frac{1}{4}$-mm diam wire, whereas sources used for most work at Notre Dame have been on $\frac{1}{2}$-mm diam wire. The second set of tests sought a possible effect of source size or shape on the observed particle energy. In earlier work[1] a source had been made on a $\frac{1}{2}$-mm wire which was milled down to a half cylinder to give a flat source. It was felt, however, that the sharp edges thus produced might cause non-uniform deposition of polonium. In the present test sources were deposited on rather wide flat strips of silver and then masked to expose an area of appropriate size to the spectrograph. Positioning on the target rod and masking were done under the microscope.

The result of a comparison of a standard $\frac{1}{2}$-mm diam wire source with a $\frac{1}{2}$-mm wide flat source is shown in Fig. 2. The flat source appears to give an energy value 0.4±0.5 kev higher than the round source. Both these sources were freshly made, the flat one from the Chalk River solution (by T.A.E.) and the round one from the Notre Dame solution (by C.P.B.).

Another comparison was made with a 0.25-mm diam wire and a 0.30-mm flat source. Two runs were made and in each run this flat source gave a slightly higher

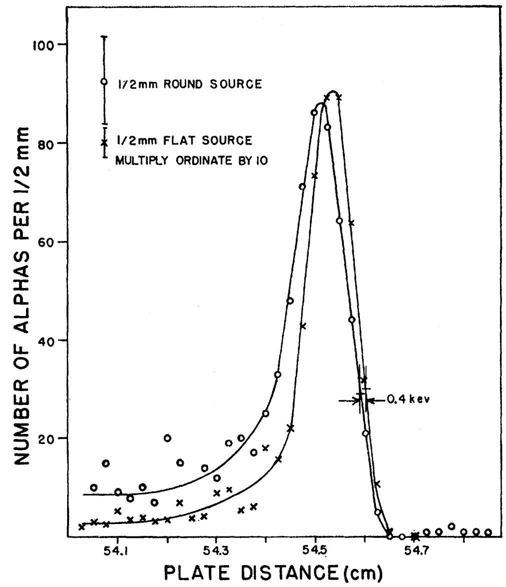

FIG. 2. Comparison of polonium source on a cylindrical backing with a source on a flat backing.

value for the energy than the round source. The average difference for the two runs was 1.5±0.5 kev. Whether this difference was caused by an error in locating the active area of the source under the mask or is inherent in flat vs round sources of $\frac{1}{4}$-mm size was not determined. No difference has previously been found for round wires of different diameter and the Rice work showed no difference for flat sources ranging from 0.1 to 0.8 mm.

The effect of source age is shown in Fig. 3. As the magnetic field was cycled between the runs shown here,

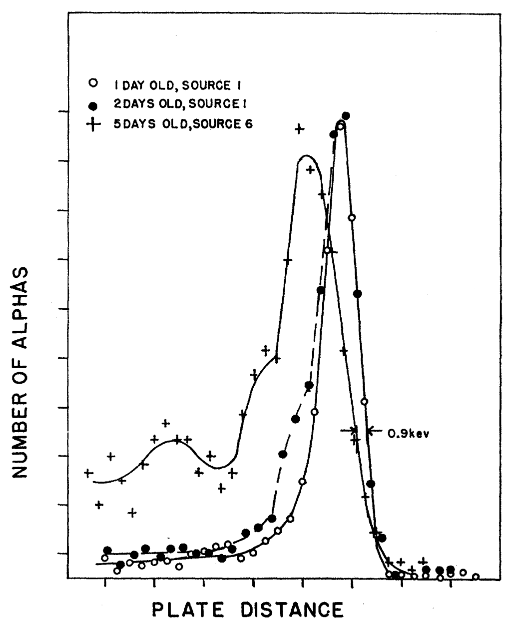

FIG. 3. Effect of source age on the distribution of alpha particles.

the actual position of the group on each plate was not exactly the same. To illustrate the aging effect the groups have been displaced to roughly line up the extrapolated high-energy edges. The vertical scales were adjusted to give approximately equal peak heights. It is seen that in two days the low-energy "tail" increased noticeably and by five days the slope of the high-energy edge changed. Similar results were obtained at Rice.[2]

If the spectrograph calibration curve is used to calculate the energy of the alpha particles from each of the sources it is found that the maximum deviation from the average is 1.8 kev and the average deviation is 1.1 kev. The average of these energies is 0.047% below the value used to obtain the calibration curve; well within the uncertainties in the calibration. It can only be said from this that the sources used in the present work give the same energy as sources prepared previously, within the limits of reproducibility of the spectrograph field.

The conclusion may be drawn that for fresh sources of $\frac{1}{2}$-mm height the different source solutions, methods of preparation and shape of backing used here give no measurable difference in alpha-particle energy. For a $\frac{1}{4}$-mm source a small difference was observed which may be caused by the backing shape. This difference, however, is much smaller than the discrepancies in the various measurements.[2] Source age has an appreciable effect on the alpha-particle energy and may be an important cause of the discrepancies of some of the older measurements, as has been discussed before.[1]

The difference between the Notre Dame and the Rice values is 4.4 kev when the Rice value for the $Li^7(p,n)Be^7$ threshold is used with the Notre Dame data. The standard deviations in the two measurements are about 1.5 to 2.0 kev. It is concluded that the difference does not depend on the characteristics of the polonium sources. It should be pointed out that the Notre Dame value is the highest and the Rice value one of the lowest of the recent measurements.

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Distortion Effects in Deuteron Stripping Reactions with Low Q Values*

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A series of numerical calculations have been carried out to verify the hypothesis that distortion effects become small for deuteron stripping reactions with low bombarding energy when the Q value is sufficiently small. Our results do not support this hypothesis.

It has been observed[1] that the angular distributions of protons from (d,p) reactions at low bombarding energy and low Q value correspond very closely to the predictions of the Butler theory[2] when the cutoff radius is adjusted appropriately. This result is at first glance rather surprising since the Butler theory is expected to work best when the bombarding energy is well above the Coulomb barrier. When the bombarding energy is not well above the Coulomb barrier, the Butler theory usually gives a poor fit to the observed deuteron stripping angular distribution.

The good fit to Butler theory at low bombarding energy and low Q value has been interpreted[1,3] as being the result of a diminution of distortion effects. When the Q value is equal to

$$Q_0=\left(\frac{M_I}{M_D+M_I}\right)\left(\frac{M_FM_P}{M_DM_I}-1\right)E_D\approx-\tfrac{1}{2}E_D$$

(where E_D is the incident energy, M_I is the mass of the target nucleus, M_F is the mass of the residual nucleus, M_D is the deuteron mass, and M_P is the proton mass), the situation is most favorable for the stripping to occur with the proton remaining a long distance from the target nucleus. This condition, $Q=Q_0$, is therefore regarded by some authors as the optimum condition for the validity of the Butler theory. Since the Q values for stripping reactions are seldom less than -1 Mev, these optimum conditions can only be achieved when the bombarding energy is low.

By resorting to numerical computation with high-speed digital computers, it has been possible to introduce into direct-reaction theory calculations for deuteron

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[1] D. H. Wilkinson, Phil. Mag. 3, 1185 (1958); J. P. F. Sellschop, Phys. Rev. Letters 3, 346 (1959); Phys. Rev. 119, 251 (1960).

[2] S. T. Butler, Proc. Roy. Soc. (London) A208, 559 (1951); F. L. Friedman and W. Tobocman, Phys. Rev. 92, 93 (1953).

[3] E. K. Warburton and L. F. Chase, Jr., Phys. Rev. 120, 2095 (1960).