Nonelastic Cross Sections of Pb^{206} and Pb^{208} for 14-MeV Neutrons*†

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Measurements of the nonelastic cross sections of Pb^{206}, Pb^{208}, Cu, and Bi for 14-MeV neutrons by the sphere transmission technique are reported. The results are as follows: Pb^{206}, 2.50±0.05 b; Pb^{208}, 2.58±0.09 b; Bi, 2.53±0.05 b; Cu, 1.44±0.03 b. The values for Pb^{206} and Pb^{208} were computed from the measured nonelastic cross sections of ordinary lead, 2.53±0.05 b, and of radiogenic lead, 2.50±0.04 b. The difference in the cross sections of Pb^{206} and Pb^{208} is much less than that predicted from the one-body alpha decay theory.

I. INTRODUCTION

THE half-lives for alpha decay of Po^{212} and Po^{210} differ by 14 orders of magnitude; this difference has been attributed[1] to a difference in the nuclear radii of the daughter isotopes, Pb^{208} and Pb^{206}. On the basis of the one-body theory of alpha decay, Asaro[2] and Devaney[3] calculated the difference in the effective nuclear radii of Pb^{208} and Pb^{206} to be 8 to 9%. The corresponding difference in the cross sections would be about 18%. Since other even-even nuclei (not in the region of 82 protons and 126 neutrons) agree rather well with the one-body theory, we might expect the one-body theory to be applicable for Po^{212} and Po^{210}. However, a great deal of evidence supports the conclusion that the nuclear volume is essentially proportional to the number of nucleons in the nucleus, i.e., the constant-density theory. Constant density requires that the difference in the cross sections of Pb^{208} and Pb^{206} be less than 1%. Further, calculations by Mang,[4] with the shell-model theory, explains the difference in alpha decay half-lives of Po^{212} and Po^{210} without requiring a difference in the radii of the Pb isotopes.

A direct measurement of the radii or cross sections of the two lead isotopes, Pb^{208} and Pb^{206}, was made by Kerlee, Reynolds, and Goldberg[5] by the scattering of ions. The quantities thus measured relate to the charge radii rather than the nuclear-potential radii which enter in the one-body alpha decay theory. The present experiment employed neutron scattering to measure quantities related to the nuclear-potential radii. These measurements corroborate the results of the ion scattering measurements, namely, that there is no appreciable difference in the nuclear radii of Pb^{208} and Pb^{206}.

The details of the experiment are discussed in Sec. II, and the results presented in Sec. III.

II. EXPERIMENTAL DETAILS

Since measurement by the sphere transmission technique requires a rather large quantity of the sample material, the isotope Pb^{206} used was in the form of radiogenic lead; the isotope Pb^{208}, ordinary lead. The radiolead was obtained from Atomic Energy of Canada, Limited; the spectrographic analysis given by the vendor was Pb^{204}—0.08%, Pb^{206}—88.25%, Pb^{207}—8.78% and Pb^{208}—2.92%. The natural lead was obtained in the form of a "chemical brick" (99.9% lead) from the American Smelting and Refining Company; its composition was taken to be that of the natural abundance of lead isotopes, namely, Pb^{204}—1.4%, Pb^{206}—25.2%, Pb^{207}—21.7% and Pb^{208}—51.7%.

The shell thickness was chosen to be approximately $\frac{1}{4}$ of a mean free path or $\frac{1}{8}$ of a nonelastic mean free path for 14-MeV neutrons. In the actual experiment, the sphere enclosed the detector rather than the neutron source because this configuration gave a neutron beam which was more nearly monoenergetic at the sphere and almost uniform in intensity over the dimension of the sphere.

The neutron source for the cross section measurements was the $T(d,n)He^4$ reaction; the deuteron source was a 1 MeV Van de Graaff accelerator. The detector enclosed by the sphere was located 30 in. from the tritium target at an angle of 98° with respect to the deuteron beam. The angle of 98° gave neutrons of energy 13.98±0.05 MeV with minimum dependence on the deuteron energy definition.[6]

The detector consisted of a $\frac{1}{2}$-in.-diam, $\frac{1}{2}$-in.-long cylindrical plastic scintillator, coupled by a Lucite light pipe to an RCA 6342 photomultiplier. The output from the photomultiplier passed through a preamplifier into a multichannel analyzer. Two additional detectors monitored the neutron intensity; one of these fed a counter which gated the multichannel analyzer for a fixed

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number of counts (in the monitor counter). The counter of the second monitor detector was also gated by the first monitor and served as a check on the monitor system.

In order to minimize the effects of system fluctuations on the transmission, the transmission measurements for the ordinary lead and radiolead were alternated. Ten runs on each of the leads were taken during one day. This procedure was repeated on two different days. In addition, 14 consecutive runs on the radiolead were made during a single day.

To check for possible systematic errors, spheres of copper and bismuth were constructed and the nonelastic cross sections of these materials measured. These results checked well with the values reported in the literature; see Table I.

III. RESULTS

Nonelastic cross sections are measured conventionally by the sphere-transmission technique.[7–9] The theoretical analysis of the sphere-transmission measurement is due to Bethe, Beyster, and Carter.[10] The relatively thin shell approximation (that is, multiple scattering effects included) was used; the thickness of the transmission spheres used, of the order of $\frac{1}{8}$ of a nonelastic mean free path, justified this approximation. Corrections were included for the effect of detector efficiency, finite source to detector distance, the effect of a nonmonoenergetic, anisotropic source, finite detector size, and analyzer dead time. The experimental conditions were chosen to minimize the magnitude of these corrections as much as possible. The total correction was less than 5%.

TABLE I. Comparison of 14-MeV neutron nonelastic cross sections.[a]

Element	Present	MacGregor[b]	Graves[c]	Bonner[d]
Copper	1.44±0.03	1.49±0.03	1.42±0.02	1.44±0.04
Radiolead	2.50±0.04			
Ordinary lead	2.53±0.05	2.56±0.03	2.49±0.02	2.52±0.09
Bismuth	2.53±0.05	2.56±0.03	2.53±0.02	2.52±0.09

[a] All cross sections in b.
[b] Ref. 7.
[c] Ref. 8.
[d] Ref. 9.

TABLE II. Comparison of 14-MeV neutron total cross sections.[a]

Element	Present	Coon[b]	Vervier[c]	Conner[d]	Lasday[e]
Ordinary lead	5.27±0.07	5.48±0.11	5.33±0.1	5.40±0.08	4.97±0.27
Radiolead	5.18±0.04				

[a] Cross sections in b.
[b] Ref. 11.
[c] Ref. 12.
[d] Ref. 13.
[e] Ref. 14.

The nonelastic cross sections measured in this experiment, along with those of others, are given in Table I. As can be seen, the values for the nonelastic cross sections obtained compare well with those of others.

If the nuclei are assumed spherical and the volume of Pb^{207} a mean between that of Pb^{206} and Pb^{208}, then the cross sections of Pb^{206} and Pb^{208} can be calculated from the values for the ordinary and radiolead. The calculated values are, respectively, 2.50±0.05 and 2.58±0.09 b. The percentage difference between these two cross sections is 3.2±4.0%.

The total cross sections used in the calculations of the nonelastic cross sections were measured by standard transmission techniques. These values are given in Table II along with those of others. These total cross sections have been corrected for multiple scattering.

IV. CONCLUSION

As determined from the measurements of the nonelastic cross sections of Pb^{206} and Pb^{208}, the percentage difference between these two cross sections is much less (approximately $\frac{1}{6}$) than that predicted from the one-body theory of alpha decay. This result agrees with those of Kerlee, Reynolds, and Goldberg[5] and the theory of Mang.[4] The conclusion is that there exists no anomalous variation of nuclear radii from Pb^{206} to Pb^{208}.

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