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NUCLEAR CROSS SECTIONS FOR 270 MEV NEUTRONS - II

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Nuclear Cross Sections for 270 Mev Neutrons - II

James DeJuren

January 26, 1950

Berkeley, California
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Information Division
Radiation Laboratory
University of California
Berkeley, California
Abstract

The total cross sections of eleven different elements were measured for the neutrons resulting from the bombardment of a 2-in. Be target by the 350 Mev protons of the 184-in. cyclotron. Bismuth fission ionization chambers served as the neutron detectors and had an estimated mean neutron detection energy of 270 Mev for the measurements. The attenuating materials were placed inside the concrete shielding and the monitor was placed to one side of the attenuators. The detector was placed about 30 ft. from the attenuators in line with the target and the attenuators. Collimators in the concrete shielding and a concrete block immediately behind the attenuating materials limited the detection of neutrons scattered through small angles to 20 minutes. "Poor" geometry cross sections of carbon, copper, and lead were measured by placing a shallow fission chamber behind attenuators of large cross sectional area over which the neutron flux was uniform. The inelastic cross section is at least half the total for all three elements.
Nuclear Cross Sections for 270 Mev Neutrons - II  
James DeJuren  
Radiation Laboratory, Department of Physics  
University of California, Berkeley, California  
January 26, 1950

I. Introduction

Nuclear collision cross sections for 95 Mev neutrons\(^1\) have been measured using bismuth fission ionization chambers for neutron detection. Since the chambers have excellent operating characteristics for high-energy neutron detection, they were again employed in attenuation measurements of nuclear cross sections for the neutrons produced by the bombardment of a 2-in. beryllium target with the 350 Mev protons of the 184-in. cyclotron.

Measurements of the ratio of the cross section for bismuth fission relative to the \(n,2n\) cross section for carbon show an increase by a factor of 3.5 in the energy interval between the two sets of measurements. The \(C(n,2n)\) cross section is expected to be fairly flat in this interval decreasing by less than a factor of two; hence the fission chambers are more efficient neutron detectors for the 270 Mev neutrons than for the 90 Mev neutrons of the previous experiments.

These new measurements were undertaken to shed further light on the transparency of nuclei to neutrons of high energy. The model of the transparent nucleus,\(^2\) developed by Fernbach, Serber, and Taylor, for nuclear cross section measurements in the vicinity of 90 Mev gave consistent interpretations for the total cross sections using \(C(n,2n)\)\(^3\) and bismuth fission\(^1\) for detection, which

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have estimated mean detection energies of 84 and 95 Mev, respectively, for the
neutrons produced by "stripping" 190 Mev deuterons with a 0.5-in. Be target.
Both sets of data, when interpreted by this model, gave as the relation of best
fit for the radii: $R = 1.38A^{1/3} \times 10^{-13}$ cm.

Inelastic cross sections of four nuclei were measured in the earlier experi-
ments employing bismuth fission detection at 95 Mev, and the ratios of inelastic
to total cross sections obtained were in approximate agreement with the values
predicted by the transparent model. The nuclear cross sections measured using
"poor" geometry for the 270 Mev neutrons will represent lower limits to the true
inelastic values, since inelastically scattered neutrons can lose large amounts
of energy and still be above the bismuth fission threshold.

II. Average Energy of Detection

The energy distribution of the neutrons knocked out of the 2-in. Be target
by the 350 Mev protons has been measured by Hadley and by Fox, Leith and Wouters.
(Discussed in the preceding article, UCRL-637.) The distribution of neutrons is
peaked around 270 Mev with a width at half maximum of 60 Mev. The ratio of the
bismuth fission cross section to the $n,2n$ cross section of carbon for the 270
Mev neutrons relative to the ratio for the 90 Mev neutrons was measured by plac-
ing an 1/8-in. thick, 1 1/16-in. diameter polystyrene disc in front of a fission
chamber mounted in the collimated neutron flux outside the shielding. The number
of fission pulses in the chamber was recorded for steady, 10 minute bombardments
and the beta-activity resulting from the $n,2n$ reaction of carbon was counted on
a standard Geiger-Mueller counter. Bombardments were also made with brass plugs
in the collimator to eliminate background effects at both energies. The ratio
of the bismuth fission cross section to the $n,2n$ cross section of carbon increased
by $3.56 \pm .11$ when the mean neutron energy was changed from 90 to 270 Mev.

Measurements were made inside the shielding of the ratio of the two cross
sections by varying the radius of the 0.5-in. Be target and therefore the energy of the incident protons. A fission chamber and polystyrene disc were placed near the cyclotron tank wall behind 4 in. of lead which absorbed stray protons but allowed the neutrons to reach the two detectors. The results indicated that the ratio of the bismuth fission to carbon, n,2n cross section increased almost linearly with proton energy and presumably, therefore, linearly with the average energy of the ejected neutrons. Since the carbon (n,2n) cross section is theoretically fairly flat in the interval between 90 and 270 Mev, decreasing by less than a factor of two, the bismuth fission cross section increases slowly over the energy spectrum of the neutrons obtained by bombarding the 2-in. Be target with 350 Mev protons. The energy distribution of neutrons detected by bismuth fission should correspond very closely with the measured distribution which peaks at 270 Mev and the contribution from any low energy tail that may exist in the distribution will be further depressed by the decrease of the fission cross section with lowered neutron energy.

III. Counter Characteristics

The bismuth fission chambers employed in these measurements were used previously and described in the report containing the 95 Mev results and by Wiegand. The counting rates were, in general, between 10 and 20 counts per second using the 270 Mev neutrons, roughly half the rate at 95 Mev. Operation was essentially equivalent at both energies as regards pileups, distribution of fission pulse heights, and stability of counters.

The effect of background on the chambers at 270 Mev was checked by placing brass plugs in the collimator through the concrete shielding. Without the plugs 24,000 fission counts were obtained on the detector, and none with the plugs.

4 Lester Baumphoff. Private communication. Radiation Laboratory.

inserted for steady 10 minute runs. Repeated measurements of cross sections
gave differences that appear to be statistical and the errors assigned to the
cross section values are expressed in standard deviations.

IV. Experimental Arrangement

The diffraction scattering of 270 Mev neutrons by nuclei is peaked so
strongly in the forward direction that considerable distance must be placed
between absorber and detector in order to obtain good geometry with negligible
corrections for the total cross sections measured. Accordingly the monitor and
absorber were placed inside the concrete shielding of the 184-in. cyclotron and
the detector was placed outside the 10-ft. thick shielding in line with the
target (Figure 1). The distance between the absorber and the detector was 30
feet. An 8-ft. thick concrete block, in front of which the attenuating materi-
als were placed, collimated the neutron beam to a 2-in. diameter (equal to the
diameter of the bismuth coated plates inside the fission chamber detector).
Neutrons scattered through an angle greater than 20 minutes could not activate
the detector. The corrections for detection of neutrons diffracted into small
angles, even for the heavy nuclei, are less than one-half of one percent of the
measured cross sections.

The ratios of inelastic to total cross sections were measured with the
"poor" geometry arrangement used at 95 Mev.¹ Slabs of attenuating material were
placed in front of a detector which was centered at the peak of the angular
distribution of neutrons emerging through the cyclotron tank wall, in line with
the collimator in the concrete block mentioned above. The detector placed out-
side the concrete shielding simultaneously measured total cross sections as
described above.

The neutron angular distribution from proton bombardment of the 2-in. Be
target is much broader than the distribution resulting from "stripping" 190 Mev
deuterons; the total angular width at half maximum is about 50° for the 270 Mev neutrons (measured with bismuth fission detection). Thus it was possible to employ absorbers of greater cross-sectional area than in the former experiment and still have uniformity of neutron flux over the faces of the absorbers.

V. Test Materials

Practically the same attenuating materials used at 95 Mev were employed for the present measurements, except that longer lengths of absorber were used (because of the smaller cross sections) at 270 Mev. The hydrogen cross section was measured using pentane-carbon difference and the difference between the deuterium and hydrogen cross sections was measured directly by D2O-H2O difference.

For most of the materials the ratios of detector to monitor were taken for several thicknesses of absorber. For both "good" and "poor" geometry the logarithm of the ratio decreased linearly as a function of absorber thickness, with no transition effects, over several mean free paths of length. Figure 2 contains the experimental data for copper.

VI. Results

Table I contains the experimentally measured total cross sections. Comparison with the 95 Mev values reveals surprising constancy in the ratio of

\[ \frac{\sigma_t(270 \text{ Mev})}{\sigma_t(95 \text{ Mev})} \]

for the elements from deuterium to tin.

Although the "poor" geometry cross sections measured at 270 Mev may not represent true inelastic cross sections since neutrons may lose energy in inelastic collisions and still be above the bismuth fission threshold, the ratios of inelastic to total cross section for the nuclei studied were higher than the ratios obtained at 95 Mev.
Table I

Total Cross Sections for 270 Mev Neutrons
Measured with Bismuth Fission Chambers

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic Number Z</th>
<th>Mass Number A</th>
<th>A(^{1/3})</th>
<th>270 Mev Total Cross Section (\sigma_t\times10^{24}\text{cm}^2)</th>
<th>(\frac{\sigma_t(270 \text{ Mev})}{\sigma_t(95 \text{ Mev})})</th>
<th>Density g/cm(^3)</th>
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<tbody>
<tr>
<td>Hydrogen</td>
<td>1</td>
<td>1</td>
<td>1.00</td>
<td>0.037±0.002, 0.039±0.002, 0.038±0.0015(ave.)</td>
<td>0.52±0.03</td>
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<tr>
<td>Deuterium</td>
<td>1</td>
<td>2</td>
<td>1.26</td>
<td>0.057±0.003</td>
<td>0.55±0.03</td>
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</tr>
<tr>
<td>Beryllium</td>
<td>4</td>
<td>9</td>
<td>2.08</td>
<td>0.229±0.003</td>
<td>0.58±0.01</td>
<td>1.847</td>
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<tr>
<td>Carbon</td>
<td>6</td>
<td>12</td>
<td>2.29</td>
<td>0.287±0.007, 0.293±0.005, 0.277±0.005, 0.290±0.009, 0.288±0.003(ave.)</td>
<td>0.58±0.01</td>
<td>1.580</td>
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<tr>
<td>Oxygen</td>
<td>8</td>
<td>16</td>
<td>2.52</td>
<td>0.372±0.007</td>
<td>0.56±0.01</td>
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<tr>
<td>Aluminum</td>
<td>13</td>
<td>27</td>
<td>3.00</td>
<td>0.555±0.010, 0.552±0.019, 0.561±0.024, 0.555±0.008(ave.)</td>
<td>0.56±0.01</td>
<td>2.714</td>
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<tr>
<td>Copper</td>
<td>29</td>
<td>63.57</td>
<td>3.99</td>
<td>1.14±0.02, 1.15±0.02, 1.145±0.0015(ave.)</td>
<td>0.57±0.01</td>
<td>8.90</td>
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<tr>
<td>Tin</td>
<td>50</td>
<td>118.7</td>
<td>4.92</td>
<td>1.87±0.003</td>
<td>0.59±0.01</td>
<td>7.28</td>
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<tr>
<td>Tungsten</td>
<td>74</td>
<td>183.9</td>
<td>5.69</td>
<td>2.56±0.07, 2.66±0.07, 2.61±0.05(ave.)</td>
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<td>19.3</td>
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<tr>
<td>Lead</td>
<td>82</td>
<td>207.2</td>
<td>5.92</td>
<td>2.83±0.04, 2.81±0.06, 2.91±0.06, 2.84±0.03(ave.)</td>
<td>0.635±0.01</td>
<td>11.34 g/cm(^3)</td>
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<tr>
<td>Uranium</td>
<td>92</td>
<td>238.1</td>
<td>6.20</td>
<td>3.32±0.07, 3.30±0.07, 3.35±0.08, 3.31±0.07, 3.28±0.12, 3.12±0.09, 3.29±0.03(ave.)</td>
<td>0.67±0.01</td>
<td>18.88 g/cm(^3)</td>
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<td>Deuterium-Hydrogen</td>
<td>0</td>
<td>1</td>
<td>1.00</td>
<td>0.019±0.002</td>
<td>0.61±0.10</td>
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Table II

Ratios of "Poor" Geometry to Total Cross Section
Measured with Bismuth Fission Chambers

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<tr>
<th>Element</th>
<th>$\frac{\sigma_i(270 \text{ Mev})}{\sigma_t}$</th>
<th>$\frac{\sigma_i(95 \text{ Mev})}{\sigma_t}$</th>
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<tr>
<td>Carbon</td>
<td>0.505 ± 0.02</td>
<td>0.46 ± 0.015</td>
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<tr>
<td>Copper</td>
<td>0.50 ± 0.02</td>
<td>0.39 ± 0.005</td>
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<tr>
<td>Lead</td>
<td>0.51 ± 0.01</td>
<td>0.40 ± 0.01</td>
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The values of $\frac{\sigma_i}{\sigma_t}$ at 270 Mev indicate that the inelastic cross sections are at least half the total cross sections.

Secondary or inelastic neutrons resulting from the interaction of an incident neutron with a nucleus would have lower energies and presumably a greater attenuation in matter than the primary neutrons. Consequently the logarithm of the attenuation should not be linear as a function of absorber thickness if neutrons degraded in energy comprise a large fraction of the detected neutrons. For lead the logarithm of the attenuation was linear through 3.5 mean free paths of absorber, but since the measured inelastic cross section is a slowly varying function of neutron energy this evidence is not a conclusive argument for calling the "poor" geometry measurement the inelastic collision cross section. But it is possible to state for lead that at 270 Mev the inelastic cross section is at least 80 percent of its value at 95 Mev. This is a smaller reduction than that observed for the total cross section.

VII. Conclusions

The total neutron collision cross sections measured by scintillation counters and bismuth fission chambers in the neighborhood of 270 Mev agree well with each other from beryllium to lead. To obtain a reasonable fit with the data in terms of the transparent model of the nucleus, the potential change experienced
by the bombarding neutron when entering a nucleus must be dropped to zero. New
measurements, to be published later, indicate the total cross sections for these
elements are flat in the vicinity of 270 Mev.

The experimentally measured value of the total n-p cross section for the
270 Mev neutrons is $38 \pm 1.5 \times 10^{-27}$ cm$^2$. The value predicted$^6$ by the model
proposed by Christian and Hart, in which tensor forces are combined with a
Yukawa potential, is $37 \times 10^{-27}$ cm$^2$ at 280 Mev (the value published in Phys. Rev.
77, 441 (1950) is erroneous).

VIII. Acknowledgments

The author wishes to express his appreciation to Dr. Burton J. Moyer, who
sponsored the work; to Messrs. N. Knable and W. Knox, who assisted with the
measurements involving beta counting; and to the cyclotron crew for their coop-
eration in performing the experiments. This work was carried out under the
auspices of the Atomic Energy Commission.

$^6$ R. Christian. Private communication. Radiation Laboratory.
FIG. 1

1\(^{st}\) MONITOR

1\(^{st}\) DETECTOR

ABSORBERS

190 MEV DEUTERONS

1/2 BE TARGET

CYCLOTRON TANK

2\(^{nd}\) DETECTOR

CONCRETE SHIELDING

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FEET
26.5° GEOMETRY
ATTENUATION OF 270 MEV NEUTRONS IN COPPER MEASURED WITH BISMUTH FISSION CHAMBERS