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DIRECT INTERACTION NEUTRONS FROM 14-Mev INELASTIC  
NEUTRON SCATTERING

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## Direct Interaction Neutrons from 14-Mev Inelastic Neutron Scattering\*

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## ABSTRACT

Neutron nonelastic cross sections measured at different detector biases have been used to determine the cross sections for inelastically scattering 14 Mev neutrons into 9- to 14-Mev energy range. The cross section for producing these high energy neutrons, which may be attributed to direct interaction processes, is roughly 10% of the nonelastic cross section, for all elements. A comparison is made with data of Coon and co workers, who measured angular distributions for the same high-energy inelastically scattered neutron group.

When the inelastic neutron spectra resulting from bombardment of various nuclei by 14-Mev neutrons are observed, it is found that most of the inelastically scattered neutrons are of very low energy, <5 Mev. These neutrons are characteristic of the boil-off spectrum resulting from compound nucleus formation. However, a certain number of high energy neutrons are also observed, and these are attributed to direct interaction processes<sup>1</sup> in which no compound nucleus is formed. Coon and co workers<sup>2</sup> have measured cross sections for inelastically scattering 14.5-Mev neutrons into the energy band from 9 to 14 Mev. (The 9-Mev cutoff is for experimental convenience and has no particular theoretical significance.) Their data consisted of differential cross section measurements over the angular range from 40° to 150°. An integration over angles gives a lower limit, with an accuracy of about  $\pm 30\%$ , to the total cross section for inelastic scattering into the 9- to 14-Mev energy region. The same integrated cross section can be obtained from a comparison of the nonelastic cross sections at 14 Mev obtained, after

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corrections, at detector biases of 9 and 14 Mev.<sup>3</sup> Table III of reference 3 gives the results of nonelastic cross section measurements on a series of elements for detector biases of 9, 4 and 12, 6 Mev, which, within the accuracies we are discussing, are close enough to the range 9 to 14 Mev to permit a direct comparison with the results mentioned above.<sup>2</sup> Corrections must be made for the facts that inelastically scattered neutrons are detected with lower efficiency than elastically scattered neutrons, and that the multiple scattering corrections are different in the two cases. Taking these corrections to the nonelastic measurements into account, Table I gives the cross sections for inelastic neutron scattering into the energy region above 9.4 Mev, for a neutron bombarding energy of 14.2 Mev. The cross sections obtained by an integration of the data of Coon *et al.*,<sup>2</sup> over the angular range from 40° to 180° are also presented for comparison.

Table I shows that the "direct-interaction cross sections" as inferred above are remarkably similar for all elements. Since nonelastic cross section values at 14 Mev<sup>3</sup> range from about 1 barn for aluminum to 2.5 barns for bismuth, direct-interaction processes in which a 9- to 14-Mev neutron is emitted constitute roughly 10% of the nonelastic events. The data of Coon *et al.*,<sup>2</sup> consist of differential cross section measurements in the angular range from 40° to 180°. Hence the sphere measurements, which represent an integration over the entire angular range, are expected to yield larger cross sections. As Table I shows, this is in fact the case. The difference between the two sets of measurements can be used to infer the shape of the angular distribution of 9- to 14-Mev neutrons in the 0 to 40° angular range. A subtraction indicates a rather sharp forward peaking, in agreement with predictions of the direct interaction hypothesis,<sup>1</sup> although the magnitude of the errors precludes quantitative comparison.

#### REFERENCES

- <sup>1</sup> R. M. Eisberg and G. Igo, *Phys. Rev.* **93**, 1039 (1954); S. T. Butler, *Phys. Rev.* **106**, 272 (1957); G. Brown and H. Muirhead, *Phil. Mag., Ser. 8*, **2**, 473 (1957).
- <sup>2</sup> Coon, Davis, Felthouser, and Nicodemus, Los Alamos (to be published).
- <sup>3</sup> MacGregor, Ball, and Booth, *Phys. Rev.* **108**, 726 (1957).



Table I. Cross sections in millibarns for neutron inelastic scattering to the 9- to 14 Mev energy region, with a neutron bombarding energy of 14 Mev.

Element	MacGregor et al. <sup>3</sup>	Coon et al. <sup>2</sup>
B <sub>9</sub>	50 ± 20	
B <sub>10</sub>	140 ± 50	
C	100 ± 40	
F	170 ± 50	
Mg	170 ± 50	
Al	100 ± 40	
S	70 ± 30	
Ti	140 ± 50	
Fe	100 ± 40	76 ± 30
Co	100 ± 40	
Ni	100 ± 40	
Cu	120 ± 40	72 ± 30
Zn	170 ± 50	
Zr	150 ± 45	
Ag	140 ± 50	
Cd	100 ± 40	
Sn	140 ± 50	91 ± 30
Sb	190 ± 55	
W	170 ± 50	
Au	200 ± 50	
Hg	150 ± 45	
Pb	170 ± 50	88 ± 30
Bi	140 ± 50	

END