A separate search gave no indication, within statistics, of a yield of protons of energies greater than about five Mev, in agreement with the results of Armstrong and Brolley.

* Work done under the auspices of the U. S. Atomic Energy Commission.

[1] F. L. Ribe and J. D. Seagrave, Phys. Rev. **94**, 934 (1954).

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## Resonances in the Elastic Scattering of Protons*

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THE purpose of this note is to report the existence of nuclear resonances of an unusual type in carbon and oxygen. These resonances were found during a search for anomalies in the elastic scattering of protons using the 32-Mev linear accelerator of this laboratory. The apparatus was that used by Eisberg and Igo.[1] The protons scattered elastically from a thin target (about 20 mg/cm²) were detected by a plastic scintillator and counted after pulse-height analysis. The experimental procedure consisted in fixing the angle of scattering near the first minimum of the diffraction pattern and plotting the counting rate against the energy of the incident proton beam, which was altered by absorption in polystyrene. Smooth variations of the counting rate with the proton energy were found with most targets. These variations correspond to the slow displacement of the maxima and minima of the diffraction pattern. In carbon and in oxygen, however, the smooth curve is interrupted by a sharp peak which rises about 20 percent above the mean counting rate in its immediate vicinity. In carbon, the energy of the peak is 22.5±0.3 Mev; the width at half-maximum is about 1.5 Mev. The results obtained with a polystyrene foil of about 15 mg/cm² are shown in Fig. 1. The effect on the diffraction pattern is shown in Fig. 2; the minimum is filled in near the peak of the resonance and regains its normal shape within 1 Mev on either side of it. The oxygen resonance was first found in a comparison of the elastic scattering of silicon and silica. The data shown in Fig. 3 were obtained with a gaseous target. The peak is at 18.6±0.3 Mev, and the width is about 1.3 Mev. The oxygen resonance is well marked for angles near the minimum of the diffraction pattern but is too small to be detected when the counting rate, at other angles, rises much above this minimum value. In carbon and oxygen no other resonance was found in a proton energy range of 14 to 31.5 Mev. A search for similar resonance in B, N, F, Al, Si, S, Ca, Fe, and Cu, over the same energy range, gave no result. This does not exclude the existence of resonances in these nuclei, for the method is effective only for resonances which are neither too narrow (less than 200 kev) nor too broad (more than 3 Mev). The measured widths are close to the natural widths for they are large compared with both the proton energy loss in the targets—400 kev and 100 kev, for carbon and oxygen, respectively—and the spread in energy of the proton beam—about 100 kev.[2]

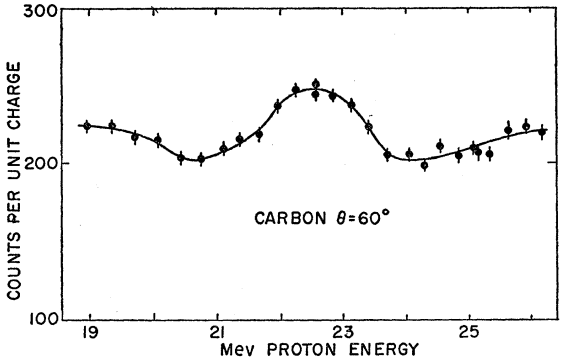


FIG. 1. Resonance in the elastic scattering of protons from carbon at 60°.

It is unlikely that the resonances found in carbon and oxygen are size resonances, because they are much sharper than would be expected theoretically and because no resonance was found in nitrogen, which lies intermediate in atomic weight. Now in carbon there is no anomaly in the cross section[3] of the $C^{12}(p,pn)C^{11}$ reaction near 23 Mev. The observed effect, therefore, demonstrates, in a narrow energy range, an increase in the probability of elastic re-emission of the proton. This is a characteristic to be expected of a single-particle state. It is unlikely, however, that the

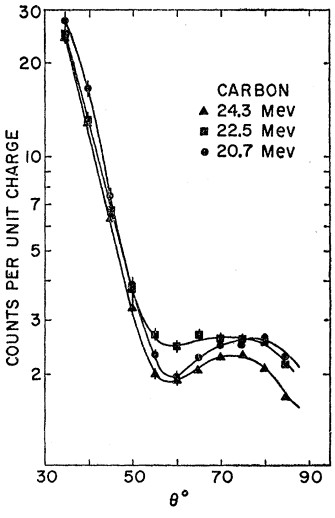


FIG. 2. Angular distribution of protons scattered elastically from carbon, at the peak of the resonance (squares), and above (triangles) and below it (circles).

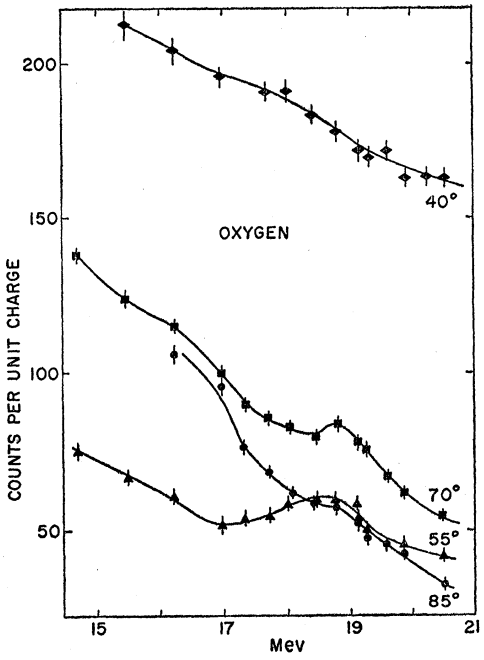


FIG. 3. Resonance in the elastic scattering of protons from oxygen at various angles.

resonance is caused by a state with an independent existence at this high excitation energy; it is more probable that its characteristics are distributed over many levels of the usual kind.

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## Systematics of Neutron Capture Cross Sections*

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THERE appears to exist a rough correlation between the neutron cross sections of heavy (*trans*-lead) nuclei and the binding energy of the captured neutron. In Fig. 1 the sum of capture and fission cross section (where fission occurs) for each nuclide is plotted against the neutron binding energy.[1]

The correlation is best for the even-even nuclides. Odd-even nuclei, forming odd-odd compound nuclei, have larger cross sections for a given binding energy than even-evens which form even-odd compound nuclei. Conversely, even-odd nuclei, which form even-even compound nuclei, appear to have smaller cross sections than might be expected. The cross sections of $Pb^{208}$ and $Bi^{209}$ are unusually low, which is presumably a consequence of their closed-shell configurations. The singular position of both $Bk^{249}$ and $Cf^{250}$ might be connected in some unexplained way with the minor closed shell at 152 neutrons.[2]

To a rough approximation, the thermal capture cross section is given by $\sigma_{th}=(\zeta^2\Gamma_{rad}/D)\times 1100$ barns[3,4] where $\zeta^2\approx 1$, and $D$ is the level distance in ev in the compound nucleus. For heavy nuclei, $\Gamma_{rad}$ is always close to 0.1 ev. Very roughly, therefore, $\sigma_{th}=110/D$.

For nuclei of comparable type, $D$, and therefore $\sigma_{th}$, will be determined mainly by the excitation of the compound nucleus, and hence by the neutron binding energy. The separation of different nuclear types in Fig. 1 suggests that the level density of the compound nucleus decreases in the order odd-odd nuclei > even-odd > even-even, which is not unexpected.

However, the rate of increase of $\sigma$ with binding energy $E$ is much greater than expected from a semiempirical

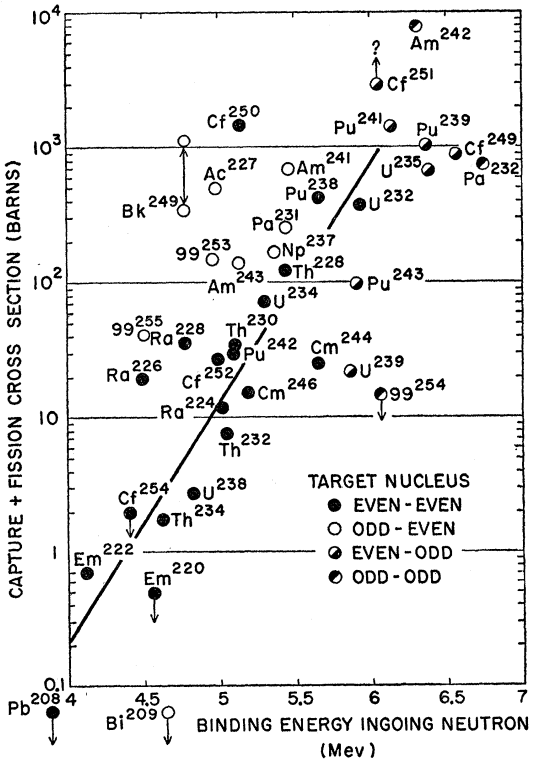


FIG. 1. Neutron cross sections of the *trans*-lead nuclides.