is therefore negative. The magnitude of the observed shift is $(2.7 \pm 0.4)\%$ which is compatible with the linear relation $H_n = H_{n0} - H_{ext}$. A negative shift of about the correct magnitude was also observed in line 4. The multiplet structure in line 4 is symmetrical (Fig. 1) and so does not seriously interfere with the observation of a shift of its central member.

The effective field at the iron nucleus has now been determined both in sign and magnitude. The existence of such a large negative field (-333 koe) was unexpected. Marshall[8] has discussed a number of sources of the effective nuclear field. These consist mainly of direct effects of the $3d$ electrons and indirect effects of polarization of the various s electrons, which then contribute to the field via the Fermi contact interaction. The polarization of inner shells of electrons results in negative contributions to the field. In view of the experimental result these negative terms must completely dominate the other contributions.

We are grateful to S. Raboy for loan of the magnet. We wish also to thank M. R. Perlow for preparation of the source; F. J. Karasek for continuing to supply us with thin rolled iron foils; and E. Kowalski for assistance in taking the data. We have profited from a stimulating discussion with W. Marshall.

†This work was performed under the auspices of the U. S. Atomic Energy Commission.

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RESONANCES IN C^{12} ON CARBON REACTIONS

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(Received March 28, 1960)

The reaction yield from C^{12} on carbon in the laboratory energy range 9-29 Mev has been investigated using C^{12} beams of precisely defined energy from the Chalk River tandem accelerator. The measured excitation curves for all reaction products studied reveal unexpected, sharp, isolated resonances at incident energies just below the Coulomb barrier corresponding to excitations in $Mg^{24} \approx 20$ Mev. At higher energies where strong interference structure was previously observed in the elastic scattering,[1] the reaction resonance structure is considerably less marked. In contrast to these results for the $C^{12} + C$ system, similar measurements for O^{16} ions on oxygen targets show no such resonant behavior; in this case the incident energy required to reach the top of the Coulomb barrier is somewhat higher and corresponds to 27-Mev excitation in S^{32}. It is noted that both reactions are restricted to only those states allowed to a system of two identical spin-zero Bosons.

The various excitation curves for C^{12} on carbon in Fig. 1 show marked similarity; particularly for incident energies below 6.5 Mev (center-of-mass system), sharp resonances appear in all curves at energies of 5.68 Mev, 6.00 Mev, and 6.32 Mev. The observed widths of these peaks are equal to the energy loss in the 40-$\mu g/cm^2$ carbon targets. This amounts to 100 kev in the c.m. system; consequently, in each case the true resonance width is almost certainly less than this. Additional measurements not shown in the figures on alpha particles detected[2] at 27° and 62° and protons detected[2] at 62° in the laboratory and on all gamma radiation of energy greater than 2.8 Mev also show these same sharp resonances below the Coulomb barrier. The fact that these resonance peaks appear at the identical incident energies for all reaction products independently of the angle of observation

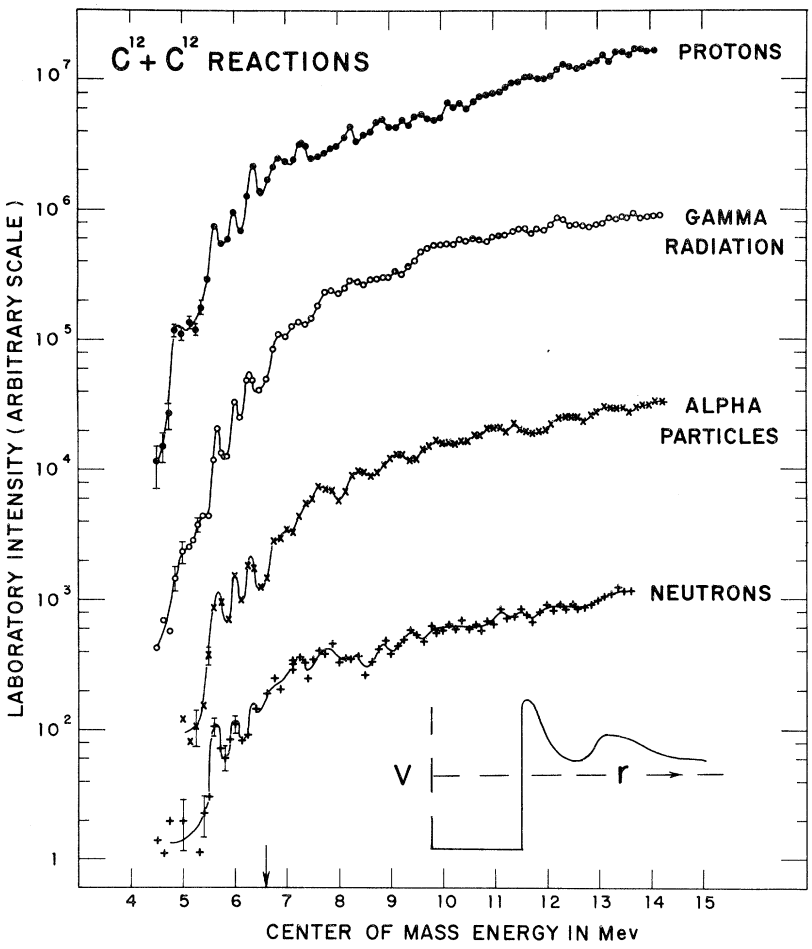

FIG. 1. Excitation curves for C^{12} on carbon reactions: protons at 27°, alpha particles at 42°, neutrons at 30°, and gamma radiation at 90°. The magnitudes of the corresponding differential cross sections (laboratory system) at 10 Mev (c.m. system) incident energy are: protons—15 mb/sr, alpha particles—34 mb/sr, and neutrons—3 mb/sr. These cross sections refer to protons >6 Mev laboratory energy, alpha particles >7.5 Mev, and all neutrons. Detectors were, respectively: Si p-n junctions (reference 2) covered by 0.007 inch of Al for protons, Au-Si surface barrier detectors (reference 2) covered by 0.001-inch Al for alpha particles, long counter of Hanson-McKibbon type for neutrons, and NaI crystal detectors biassed to detect gamma radiation >2.8 Mev energy. Target was a self-supporting ~40-μg/cm^2 C foil. Statistical errors are indicated where they are significantly larger than the points. The classical Coulomb barrier is indicated at 6.6 Mev. The inset shows the quasi-molecular potential envisaged.

precludes interference phenomena and suggests that isolated states of small total widths are involved. The measured separation of adjacent states for the three best defined resonances is nearly constant at 320 kev. There is some evidence that the regular structure persists but with increasing peak widths as the energy is raised above the Coulomb barrier. At still higher energies, the differential cross sections show similar but not identical excitation curves at different angles, suggestive of interference phenomena involving overlapping states in accord with the elastic scattering data.[1] The magnitudes of the differential cross sections (lab system) at 20 Mev are given in the figure captions for the reaction products studied and can be extrapolated to other energies using the excitation curves.

In marked contrast, the data in Fig. 2 for O^{16} on oxygen show yield curves that rise smoothly with energy. It does not appear tenable to attribute this smooth behavior solely to greater level density and widths of the compound system caused by the somewhat greater mass and excitation achieved in the O+O system relative to the C+C system. The top of the Coulomb barrier corresponds to an excitation of ~27 Mev in S^{32} for the former as compared with ~20 Mev in Mg^{24} for the latter. Rather it appears necessary to invoke a reaction mechanism which in the $C^{12}+C^{12}$ case, particularly below the Coulomb barrier, results in the formation of a few sharp, well-separated, states superimposed on the continuum arising from any broad overlapping levels of the compound nucleus. In addition, any such postulated mechanism must include an explanation of the absence of sharp structure in the $O^{16}+O^{16}$ data and in similar measurements on the O+C system.

The formation by two low-energy carbon nuclei of quasi-molecular states with a lifetime of ~10^{-20} second terminated either by the collapse of the

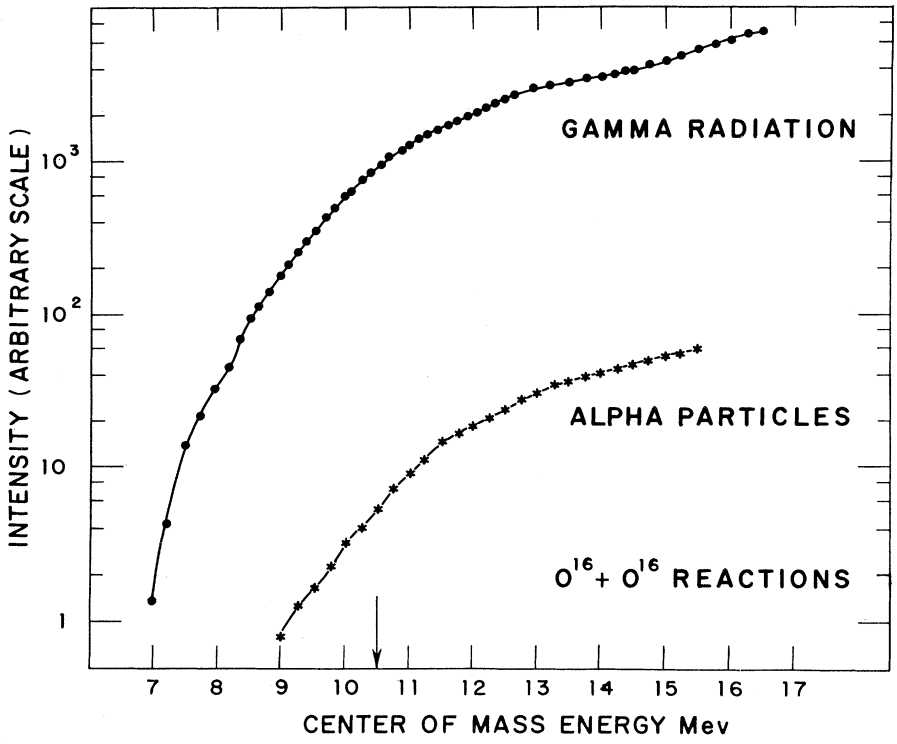

FIG. 2. Excitation curves for O^{16} on oxygen. The alpha particles were detected at 27° and the gamma radiation at 90° in the laboratory. The cross section for alpha-particle production at 10 Mev (c.m. system) incident energy is 4.5 mb/sr (laboratory system). The target was ~ 25 $\mu g/cm^2$ SiO. In the energy range covered, the reaction yield from Si is negligible. The classical Coulomb barrier is indicated at 10.5 Mev.

system into a compound state which de-excites by light-particle emission or by the re-emission of the carbon nuclei through the Coulomb barrier would, if it occurs, be in accord with the observation of resonances of $\lesssim$100-kev width both in the reaction and elastic scattering data. The possibility of forming such states at energies below the Coulomb barrier may arise from a minimum in the interaction potential caused by neutron interactions made possible by deformability of the reaction particles at a range where Coulomb and angular momentum forces are still effective in preventing immediate coalescence into a compound nucleus. The potential shape envisaged is shown in the inset in Fig. 1 with the resonances in question corresponding to states in the well of larger radius. At high energies, hence high angular momenta, as encountered in the elastic scattering, the centrifugal barrier is expected to modify the well shape to favor re-emission of the incident particles, i.e., compound elastic scattering, while at lower energies the lower orbital momenta are expected to favor coalescence leading to other reactions. The absence of such quasi-molecular states in O^{16} interactions may well arise from the closed shell structure of this nucleus. In this case nucleon transfer involves an exchange from p to d shells; furthermore, the greater rigidity of the closed shell structure will make less likely the distortion necessary to have neutron interactions at a range where Coulomb and angular momentum forces are still effective in causing repulsion. It is of interest to note that the Wigner limit to the reduced width and the level spacings in a square well appropriate to two carbon nuclei ($r \approx 10$ fermis) are in qualitative accord with the experimental data. The physical basis of the above potential is discussed more fully by Vogt and McManus.[3]

In view of the above results it is planned to examine interactions among other light nuclei to see if the lack of resonance structure is peculiar to interactions involving closed shell nuclei. In particular the C^{12} on Ne^{20} interaction which leads to the same excitation in S^{32} as O^{16} on O^{16} is being investigated.

We are indebted to Dr. E. Vogt and Dr. H. McManus for illuminating discussions regarding the nature of the reaction mechanisms involved.

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