surface region, the R-matrix theory can account for such processes as pickup and stripping reactions. This procedure requires the explicit use of wave functions and a weak-interaction potential. It does not seem realistic to try to account for the forward peaking in a (d,α) reaction using the customary approximations for the treatment of surface phenomena (i.e., pickup or direct interaction). Nevertheless, it appears that some sort of a direct interaction process holds the only hope as a basis for calculations.

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Anomaly in Energy Level Density Measurements*

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An analysis of nuclear reactions in the intermediate energy range has been made in terms of the statistical theory of nuclear reactions using the Fermi gas level density, const$\times$exp$[(aE)^{\frac{1}{2}}]$, where E is the energy of excitation. The quantity, a, determined from excitation function experiments and from the (α,p) reaction at 40 Mev shows an anomalous behavior when plotted against atomic number, A. On the other hand, the values of a determined from several inelastic scattering and reaction experiments show the correct dependence on A. The effects of noncompound-nucleus processes are discussed.

THE dependence of the density of energy levels on excitation energy can be determined[1] from reaction and inelastic scattering experiments and from a study of excitation functions for reactions in which neutrons are emitted from the compound nucleus produced by bombardment with energetic particles or photons. Data from reaction, inelastic scattering, and excitation function measurements has been analyzed in terms of the statistical model of nuclear reactions employing the Fermi gas level density formula, $\omega(E)=C\exp[(aE)^{\frac{1}{2}}]$. The quantity, $\omega(E)$, is the energy level density; C and a are constants; and E is the nuclear excitation energy. Figure 1 shows a compilation of the values of a obtained from the analysis.

The anomaly is that the values of a obtained from the analysis of γ-ray, neutron, and charged-particle excitation function data[2] and from the 40-Mev (α,p) experiment[3] are reasonably independent of A and abnormally small for large A. These values of a are grouped about the line, $a=8$ Mev^{-1}. This is in disagreement with the Fermi gas prediction of $a=\text{const}\times A$.

On the other hand, values of a obtained from an analysis of some of the available reaction and inelastic scattering data[4] are in agreement with the Fermi gas prediction of $a=\text{const}\times A$.[5] Some experimental data, such as that from the (p,p') experiment at 31 Mev[6] and from the (n,p) reaction at 14 Mev,[7] have not been included in the analysis since they have been interpreted as being predominantly noncompound-nucleus processes.[8] Also, the values of a obtained from the inelastic scattering of 14-Mev neutrons[9] are not included in the present compilation because of the uncertainties which arise in correcting the spectra for the very large contribution of the second neutron from $(n,2n)$ events. This correction has been calculated in several ways,[10] and the values of a which result differ considerably. However, they are in rough agreement with the upper curve in Fig. 1 regardless of how the corrections are made.

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[1] See for instance, J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952), p. 365.

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The effect of noncompound-nucleus processes on this analysis must be considered since cross sections for noncompound-nucleus processes in this energy range are sometimes large.[6,7] In the experimental work of Mrs. Skyrme,[5] materials were bombarded with approximately 150-Mev protons. It was found that there was a strongly peaked forward distribution of high-energy protons, which were interpreted as due to direct collisions (noncompound-nucleus processes). In such a collision the residual nucleus was excited to about 50 Mev. In addition, an isotropic distribution of low-energy protons were observed which were interpreted as the "boil-off" spectrum from the excited nuclei. Lang and LeCouteur[5] have analyzed the energy spectra of the isotropic distribution, only, to obtain the values of a plotted in Fig. 1. In the measurement of (p,n) reactions at 18 Mev, the energy spectra observed have the Maxwellian shape predicted by the statistical theory of nuclear reactions. The high-energy component usually associated with noncompound-nucleus processes, is small. Therefore, no correction was made for noncompound-nucleus processes. In the measurements of the inelastic scattering of 18-Mev protons, noncompound-nucleus processes probably contribute a large part to the high-energy tail of the observed spectrum.[3] Accordingly, only the low-energy component of the proton spectra was used to obtain the quantity, a. The values of a obtained agree with the values obtained from the (p,n) data at 18 Mev and from the 150-Mev proton data as is shown in Fig. 1. However, because a large part of the observed cross section is assumed to be due to noncompound-nucleus processes, the values of a obtained are probably less reliable. The excitation function measurements discussed above involve reactions in which two low-energy neutrons are emitted. Consequently, noncompound-nucleus processes probably contribute very little, since in this energy range, noncompound-nucleus processes are associated with the highest energy component of the spectrum of emitted particles.[6,7] Therefore, no corrections were made for noncompound-nucleus events. In the (α,p) experiment at 40 Mev,[3] the striking agreement of the energy level densities of Cu, Ag, and Au with the predictions of the Fermi gas level, as well as the observation of reasonably flat angular distributions in the backward hemisphere, implies that the statistical model should be valid.[11] The number of high-energy protons, representing a small fraction of the total number emitted in the (α,p) reaction at 40 Mev, did not agree with the number predicted by the Fermi gas calculation. Also, the differential cross section for emission of high-energy protons continued to decrease even at the largest angle of observation. Consequently, they were omitted from the analysis because they are probably due to noncompound-nucleus processes. No further attempt was made to correct the data of this compilation for noncompound-nucleus processes, since no reliable criterion is available.

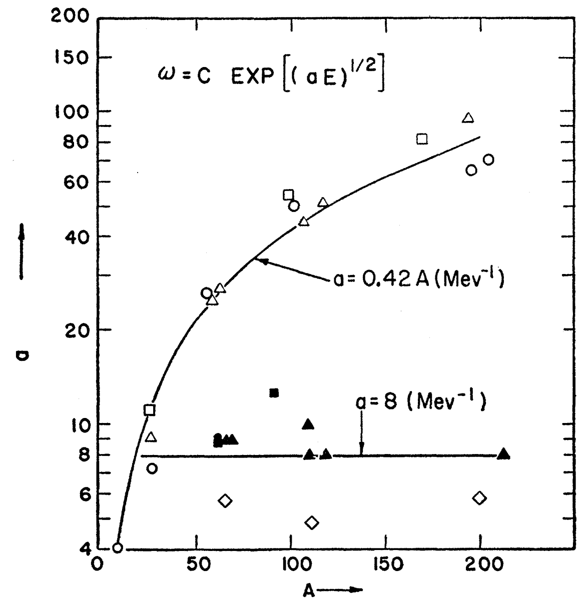

FIG. 1. Compilation of energy level density measurements: (a) Reaction and inelastic scattering: ○ (p,n) at 18 Mev, △ (p,p') at 18 Mev, □ 150-Mev data, and ◇ (α,p) at 40 Mev. (b) Excitation function measurements induced by ● γ rays, ■ neutron and ▲ alpha particles.

A possible explanation for the anomalous values of a obtained from an analysis of excitation function experiments and of the (α,p) experiment at 40 Mev is that the nucleus may be only partially excited in these reactions.[12] For example, the nucleons in some of the nuclear energy shells may not be excited. The result could then be that the nucleus acts like an inert core plus a group of excited nucleons numbering approximately 30 (see Fig. 1). Another possible explanation may be, of course, that although these reactions appear to proceed by compound nucleus formation, noncompound-nucleus events play a large part.[13,14] Additional measurements of the parameter, a, will be needed to clarify the situation.

[11] The angular distribution in the forward hemisphere is peaked forward strongly. Therefore, at forward angles, noncompound-nucleus processes probably predominate.

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