neutrons, while no such discrepancy occurs between the ρ value of the germanium isotopes, Ge^{70} ($\rho=0.09$)[20] and Ge^{72} ($\rho=0.11$).[21] ρ depends mainly on the mean life of the 0^+ state and the conversion coefficient α. If there is no large error in either of these terms, the difference in the value of the two matrix elements may reflect a structural difference in the two nuclei.

ACKNOWLEDGMENTS

We wish to express our appreciation to Professor C. S. Wu for stimulating discussions. We also thank Mr. E. Hadjimichael for his help in the early stages of this experiment.

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PHYSICAL REVIEW VOLUME 123, NUMBER 1 JULY 1, 1961

Coulomb Barrier in a Highly Excited Nucleus

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(Received February 9, 1961)

Experiments involving alpha emission spectra from nickel and rhodium bombarded with protons are analyzed using the statistical model. It is shown, using values calculated by Igo for the cross sections for alpha absorption, that the experimental data are consistent with a constant value for the potential barrier.

EXPERIMENTS by Fulmer and Goodman[1] in which the alpha emission spectrum of a nucleus, formed by bombardment with high-energy protons, have been interpreted by these authors as showing that the Coulomb barrier in a highly excited nucleus is lower than in a ground state. This result is in apparent conflict with the theoretical work of Lane and Parker[2] on this topic, and will be shown, using values of the alpha-particle capture cross section calculated by Igo,[3] to be unnecessary.

According to Weisskopf,[4] the number of particles in an energy range dE of the emission spectrum of a compound nucleus should be $N(E)dE=\omega(U-Q-E)E\sigma_c(E,U-Q-E)dE$ where E is the energy of the emitted particle, Q its binding energy, U the excitation energy of the compound nucleus, ω the level density as a function of the excitation energy in the residual nucleus, and σ_c the cross section for the inverse reaction [i.e., capture of an α particle with energy E by the residual nucleus at an initial excitation energy $(U-Q-E)$]. The assumption under question, which is implicit in Igo's work, is that σ_c is a function of E only and not of the residual excitation energy $(U-Q-E)$.

The experimental data for various values of the bombardment energy were plotted by Fulmer and Goodman in the form $N(E)$ against E. Using Igo's σ_c, these data, replotted in the form $\log[N(E)/E\sigma_c(E)]$ against E, are shown in Fig. 1 for rhodium and nickel. If the level density function had the form $\omega(U-Q-E)=\omega(U-Q)\exp(-E/\tau)$, and if no alpha particle which followed any other emission were included, then the plots should yield straight lines. If the plots are approximately straight lines, then a value for τ may be derived from each, using points near the maximum value of $N(E)$ in each case. The relation $U=a\tau^2-2.5\tau$ may then be used as in Le Couteur and Lang[5] to derive a value of the parameter a. Values of τ and a are listed in Table I.

Examination of Fig. 1 reveals that the plots are not in fact straight lines. In the case of rhodium, a straight

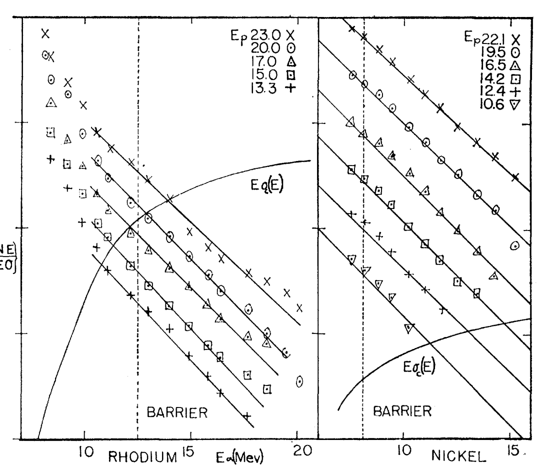

FIG. 1. Alpha-particle spectrum from Fulmer and Goodman[1] for (p,α) in (a) rhodium and (b) nickel, plotted in the form $\log_{10}\{N(E)/[E\sigma_c(E)]\}$ versus E using values for $\sigma_c(E)$ from Igo.[3] A plot of $\log_{10}\{E\sigma_c(E)\}$ versus E is also given. The vertical scale interval is 2.0.

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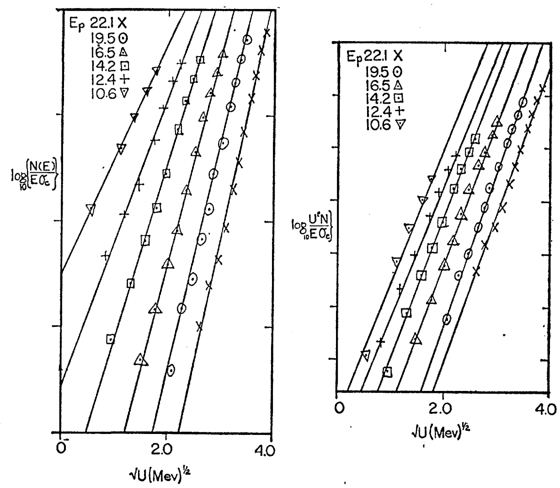

FIG. 2. Plots of the alpha-particle spectra from Fulmer and Goodman for (p,α) on nickel in the forms (a) $\log_{10}\{N(E)/[E\sigma_c(E)]\}$ versus $\sqrt{U}$, and (b) $\log_{10}\{U^2N(E)/[E\sigma_c(E)]\}$ versus $\sqrt{U}$, where U is the remaining excitation energy of the nucleus after the emission of an alpha particle of energy E. The vertical scale interval is 1.0.

line drawn to fit points near the maximum value of $N(E)$ in the original data gives an underestimate of the emission at both the low- and the high-energy ends of the spectrum. The high-energy discrepancy, which is smaller, may be attributed to direct interaction. The low-energy spectra, if interpreted simply, suggest that the cross section has been underestimated in the energy region below the barrier by as much as a factor of ten. This factor does not, however, increase with the energy of the residual nucleus. A lowering of even 1 Mev in the energy of the barrier would represent an additional factor of five in the apparent underestimate. The cause of the discrepancy is *not* therefore to be found in dependence of σ_c on the energy of the target nucleus.

It is more reasonable that not all of the spectrum arises from the primary emission of an alpha. The reaction $Rh^{103}(p,\alpha)Ru^{100}$ has a Q value of 6.3 Mev. The (p,n) reaction has a Q value of -1.5 Mev. There is thus in several neighboring nuclei an energy commonly reached toward the end of a cascade, in which alpha emission is feasible, but not proton or neutron emission. This is similar to the situation found by Allan[6] for proton emission from copper and could produce the observed excess emission of low-energy alpha particles. For nickel, the plots in Fig. 1(b) exhibit a slight curvature but in the opposite direction from that in the rhodium plots. Such a curvature is associated with the usual forms of the level density function but would be smothered by the other effects in Fig. 1(a). The difference is consistent with the explanation suggested above, since the nickel (p,α) reaction has a Q of -0.7 Mev. These results make it improbable that the departures from straight lines in the rhodium results are due to a wrong form for the quantity $\sigma_c(E)$.

[6] D. L. Allan, Nuclear Phys. 6, 464 (1958).

TABLE I. Values of τ and first approximations to a for rhodium and nickel, derived from (p,α) experiments.

	E_p (Mev)	τ (Mev)	a (Mev^{-1})
Rhodium	23.0	0.975	20.8
	20.0	0.985	18.2
	17.0	1.06	12.2
	15.0	0.94	13.2
	13.3	0.97	10.6
Nickel	22.8	1.36	9.4
	20.2	1.46	6.90
	17.2	1.51	5.20
	14.9	1.35	5.00
	13.1	1.27	4.38
	11.3	1.28	3.24

The apparent success of the statistical model in this case suggests trying a more exact form of the level density function. In the absence of experimental evidence for the multiple emission suggested for rhodium, this can only check consistency.

In Fig. 2(a), the data from Fulmer and Goodman are plotted in the form $\log_{10}[N(E)/E\sigma_c(E)]$ against $\sqrt{U}$, where U is the excitation energy of the residual nucleus in Mev. If the level density were of the form $\omega(U)=K\exp[2(aU)^{\frac{1}{2}}]$, then the plot should be a set of parallel straight lines. The lines are straight but are obviously not parallel.

In Fig. 2(b), the data are plotted in the form $\log_{10}\{[N(E)U^2]/[E\sigma_c(E)]\}$ against $\sqrt{U}$. If the level density were of the form $\omega(U)=KU^{-2}\exp[2(aU)^{\frac{1}{2}}]$ appropriate to a Fermi gas model with most emitted particles having low orbital angular momentum, the plots should be straight parallel lines. This condition is close to being realized, with the actual slopes corresponding to values of a varying from 9.4 to 11.8 Mev^{-1}. Such values are in agreement with other measurements of a.[5]

It is apparent that with analysis as precise as it is reasonable to apply to the data, there is no conflict with the assumption of a constant Coulomb barrier and a Fermi gas model of the level density.