by using the relation of Voyvodic and Pickup,[12] which is derived from the Williams theory with the employment of Molière's "γ" factor, rather than for Molière's theory itself.[25] This should make no difference in these comparisons, since Voyvodic and Pickup state that the results of this procedure agree to within 1% with results calculated entirely by Molière's theory. The agreement with theory is generally good. Two facts should be kept in mind in evaluating these results. First, the parameters measured in an emulsion or cloud chamber experiment are not simply connected to the multiple-scattering distribution, and a great amount of interpretation, involving various approximations, must be made before the results can be compared with multiple-scattering theory. Second, errors other than statistical errors are generally present, and are not easily detected. These errors in general cause one to overestimate the scattering.

Finally, we summarize in Fig. 7 the results of this experiment and all other experiments known to us which involve values of $\alpha > 1$. Against α we plot the percent disagreement of the experimental results with those calculated according to Molière's theory:

$$\Delta(\text{percent}) = \frac{V(\text{exptl}) - V(\text{Molière})}{V(\text{Molière})} \times 100,$$

where V stands for the quantity measured in the experiment ($1/e$ width, "scattering constant," etc.).

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[25] There is an error in the presentation of this relation Eq. (17), in Ref. 12. The factor $(1/\beta^2+0.30)^{-1}$ should multiply the argument of the logarithm. This same error occurs in Ref. 15.

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Cross Section for the $Au^{197}(d,p)Au^{198}$ Reaction

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The cross section for the $Au^{197}(d,p)Au^{198}$ reaction was determined experimentally for incident deuterons in the energy range 5.6 to 28 MeV, using the stacked-foil technique. A theoretical confirmation was undertaken. The maximum in the cross section was found to lie between 14 and 15 MeV, with a value of 290 mb.

I. INTRODUCTION

THE cross section for the reaction $Au^{197}(d,p)Au^{198}$ has been determined by Cork and Thornton[1] with deuterons of energy up to 7 MeV. Krishnan and Nahum[2] extended these measurements to 9 MeV. Baron and Cohen[3] reported a value for 20-MeV deuterons. This paper covers the range of deuteron energies from 5.6 to 28 MeV.

II. EXPERIMENTAL

The facilities of the 71-in. synchrocyclotron of the Argentinian Atomic Energy Commission[4,5] were used to irradiate 29 gold foils which had an average thickness of 32.5 mg/cm^2. Fifteen aluminum foils with an average thickness of 4.8 mg/cm^2 were placed between consecutive gold foils. The group of foils was mounted between two metal rings. Range-energy curves[6,7] were used to calculate the energies of the deuterons impinging upon each foil.

To obtain accurate calibrations of the cross sections the well-known $Al^{27}(d,\alpha p)Na^{24}$ cross section was employed.[8,9]

Experimental cross sections were obtained by measuring the specific activities of residual nuclei. Two counting instruments were employed: a Geiger-Müller tube and a 2×2-in. NaI(Tl) scintillator crystal.

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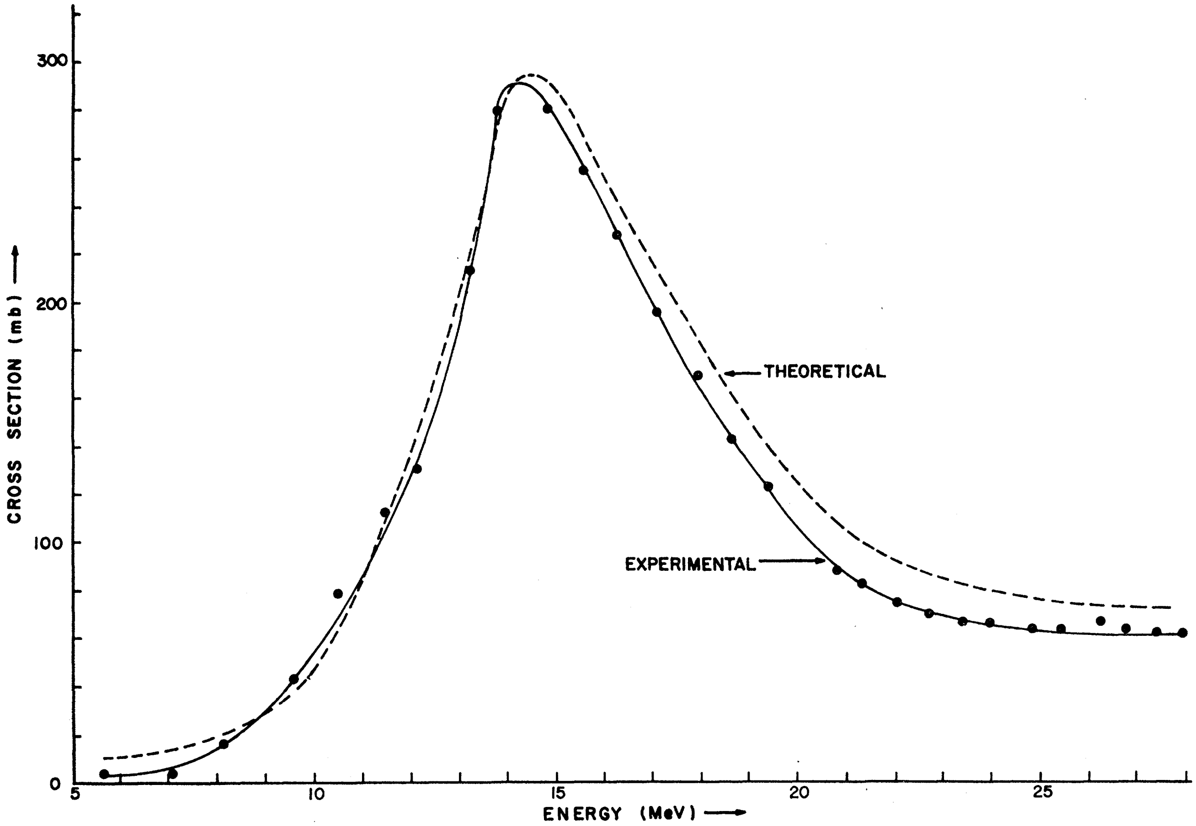

FIG. 1. Cross section for the $Au^{197}(d,p)Au^{198}$ reaction. The experimental points are from this article. The theoretical curve is an evaluation of the expression

$$\sigma_{dp}=\pi R^2\xi_p|\phi_c(R)|^2[1-F_0(R)](\Gamma_p/\Gamma)f_p.$$

III. EXPERIMENTAL RESULTS

The results (Table I) were calculated from the activities as registered by the Geiger and scintillator counters, taking into consideration the proper corrections. The cross sections are plotted in Fig. 1.

IV. THEORETICAL TREATMENT

Peaslee[10] gives for the (d,p) cross section the expression

$$\sigma_{dp}=\sigma_d\Gamma_p(\epsilon)/\Gamma(\epsilon),$$

where σ_d is the cross section for the formation of a compound nucleus by absorption of the entire deuteron, Γ_p is the proton emission width, and Γ is the total emission width at an energy ϵ equivalent to the maximum kinetic energy with which the proton may be emitted.

The formation of a compound nucleus by addition of the entire deuteron can be roughly approximated by

$$\sigma_d=\pi R^2\xi_p|\phi_c(R)|^2[1-F_0(R)],$$

where $R=r_0A^{1/3}\times10^{-13}$ cm is the radius of the nucleus, $\xi_p=0.3$ is the sticking probability of protons for this case,[10] and $|\phi_c(R)|^2$ is the deuteron plane wave in the Coulomb field.

According to Konopinski and Bethe,[11]

$$|\phi_c(R)|^2=l_c^2/l_0^2.$$

Using the approximations given in Ref. 11, we have

$$l_c^2=g/(2-x) \quad \text{for} \quad x<1,$$
$$l_c^2=g^2(x-1)+0.744g^{4/3}(2x-1)^{2/3} \quad \text{for} \quad x>1,$$
$$l_0^2=R^2/\lambda\!\!\!^{-2},$$

where

$$x=E/B'.$$

Here E is the kinetic energy of the particle, B' its effective Coulomb barrier, g its "characteristic orbital momentum," $\lambda\!\!\!^{-}$ its wavelength, and $F_0(R)$ the fraction of deuterons whose neutrons lie outside the nucleus when the proton arrives at the surface.

According to Weisskopf and Ewing,[12] the emission probability can be written

$$\Gamma_b=f_b(E-E_b)/w_c(E),$$

[10] D. C. Peaslee, Phys. Rev. 74, 1001 (1948).

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TABLE I. Experimental cross sections for the $Au^{197}(d,p)Au^{198}$ reaction.

Energy (MeV)	Cross section (mb)
5.6	6
7.12	10
8.25	16
9.54	46
10.50	81
11.50	115
12.15	132
13.25	214
13.90	284
14.85	283
15.60	259
16.45	216
17.15	199
18.00	171
18.65	145
19.45	134
20.05	96
20.85	90
21.45	85
22.10	76
22.70	72
23.45	68
24.05	67
24.85	64
25.50	64
26.30	67
26.85	65
27.45	62
28.00	62

where $w_c(E)$ is the level density of the compound nucleus at the excitation energy E, and

$$f_b = \frac{m}{f^2\pi^2}(2s+1)\int_0^{E-E_b} \epsilon S_b(\epsilon)\xi_p w_R(E-E_b-\epsilon)d\epsilon .$$

Here s is the spin of the escaping particle, m its mass, ϵ its energy as given by Hamburger *et al.*,[13] and S_b and ξ_b its penetration function and sticking probability.

It may happen that the residual nucleus emits a particle if its excitation energy is sufficient to do so. The relative probability of single proton emission can be approximated, if the first emitted particle is a neutron, by the expression given by Blatt and Weisskopf[14]:

$$f_p = (1+\epsilon_{\rm sec}/\Theta)\exp(-\epsilon_{\rm sec}/\Theta) .$$

[13] E. W. Hamburger, B. L. Cohen, and R. E. Price, Phys. Rev. **121**, 1143 (1961).

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Here Θ is the temperature governing the emission of neutrons, $\epsilon_{\rm sec}=\epsilon_\alpha-\epsilon_{\rm th}$, ϵ_α being the incident energy and $\epsilon_{\rm th}$ the threshold energy of the secondary reaction.

Then the direct (d,p) cross section is

$$\sigma_{d,p} = \pi R^2 \xi_p |\phi_c(R)|^2[1-F_0(R)](\Gamma_p/\Gamma)f_p .$$

The results obtained from these calculations are plotted in Fig. 1. The theoretical curve has been arbitrarily normalized to the experimental one at 28 MeV.

V. DISCUSSION

The maximum experimental and theoretical values for the cross sections were found to lie between 14 and 15 MeV, just above the potential barrier.

Several curves were computed for different values of r_0; r_0 was taken equal to 1.8, 1.65, and 1.5. The computed curves were sensitive to variation in r_0 and the best fit was obtained for $r_0=1.5$.

As predicted by Peaslee,[10] the agreement in shape of the theoretical and observed curves is quite good, considering that the accuracy of the curves is not better than a few percent. The percentage increases at high energies may be due to the need for considering single-proton emission.

As expected, the stripping mechanism is largely responsible for the (d,p) cross section in this reaction. In the regions above the potential barrier, low cross sections can be attributed to the competition of different reactions such as d-$2n$, d-$3n$, d-$p\alpha$, d-p,$2n$.

The values obtained were compared with those found by Krishnan and Nahum[2] and by Baron and Cohen.[3] In the range studied by Krishnan and Nahum the values are higher than those given in this paper, but recently Baron and Cohen have reported for this reaction a value in good agreement with that reported here.

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