Total nuclear reaction probabilities and average cross sections for 27 to 92 MeV α particles in silicon

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The total nuclear reaction probabilities for 27–92 MeV α particles stopping in Si were measured in coincidence studies of α-d elastic scattering. These probabilities are proportional to α-particle range and extrapolate to 2.07% at 100 MeV. They are adequately described both by calculations using Satchler's optical model parameters and by the assumption of an energy-independent reaction cross section of 1170±55 mb. They are less well fitted by the Rebel optical model parameters and by predictions of semiclassical theory.

I. INTRODUCTION

Here we report measurements of the total probability for 27–92 MeV α particles, incident upon silicon, to undergo nuclear reactions before being brought to rest by ionization processes resulting from their electromagnetic interactions. These data also determine the average nuclear reaction cross section σ_R for the same energy range.

Reaction cross section data may be used to test models of the nucleus-nucleus interaction, including the optical model. They also help to determine nuclear radii. There is, however, a shortage of directly measured σ_R's, particularly for complex projectiles at low bombarding energy. More often they are deduced from the optical model analysis of elastic scattering data.

Reaction cross sections have a dual importance for nuclei such as Si, Ge, Na, Cs, and I, which are present in detectors. The data are useful for both nuclear model studies and detector efficiency evaluations. Detector efficiency corrections are required since some detected particles undergo nuclear reactions before stopping. These produce anomalous pulses (either too large or too small, for reactions of positive or negative Q), compared with other particles of the same energy which lose all their energy by ionization.

Reaction probabilities are obtained by measuring the spectra of monoenergetic projectiles injected into scintillation and semiconductor detectors. Early studies[1,2] were used primarily to measure detector efficiency. In a subsequent experiment,[3] large enough apertures and Si detectors were used in the measuring telescope that both slit scattering and elastic scattering of projectiles out of the telescope could be neglected. The average σ_R's for-low-energy deuterons and ^{3}He in Si were then determined. The present experiment is closely patterned after this latter study.

Our data for the reaction probability of 27–92 MeV α particles in Si are consistent with an energy-independent σ_R of 1170±55 mb. The quality of fit thus obtained (χ^2 per degree of freedom equals 1.15) was nearly identical to that of our best fit with cross sections computed from the optical model. These calculations, which used Satchler's[4] parameters, predict σ_R's that fall with increasing energy. Those predicted by the semiclassical formula of Renberg *et al.*[5] rise with increasing energy and give a somewhat poorer fit ($\chi^2/d=2.8$, when the fit is optimized with an α particle radius of 1.83 fm).

II. EXPERIMENTAL PROCEDURE

Our method for measuring nuclear reaction probabilities utilizes coincidence detection of elastic scattering events. Spectra of scattered projectiles are recorded in a "measuring telescope" containing a detector in which reactions are to be observed. The associated particles are detected in a "recoil telescope" with a much smaller aperture, which consequently determines the effective coincidence solid angle.

In this experiment, a primary 120 MeV α-particle beam from the KVI cyclotron initiated α-d elastic scattering in a 7 μm CD_2 target. The energies of the secondary α particles being studied were varied from 27 to 92 MeV by changing the c.m. scattering angle from 121° to 49°.

The α-particle (measuring) telescope employed a 100 μm transmission detector and a 5-mm thick stopping detector. Small signals in the latter detector denote α particles which undergo reactions in it. The ratio of small signals to normal signals (due to particles losing all their energy by ionization processes) determines the nuclear reaction probability. It is essential that the secondary α particles be monoenergetic and, in particular, that none of them scatter from the aperture of the measuring telescope. These requirements are enforced by the design of the deuteron (recoil) telescope.

The recoil telescope utilized a Si transmission detector of 300 μm thickness, a NaI(Tl) stopping detector, and an aperture subtending 1.15 msr. The kinematics of $\alpha+d$

elastic scattering are such that when deuterons are observed in a given solid angle, the associated α particles emerge in a solid angle about half as large (here, well under 1 msr). Since the measuring telescope had 3.9 msr aperture, there was a large margin of safety against the observation of slit scattering in the measuring telescope. The adequacy of clearance was verified by measurements showing that the elastic coincidence detection rate remained constant when the recoil telescope was held fixed and the measuring telescope was moved within the expected angular range.

Conventional fast-slow electronics were used. Events were accepted after a fast coincidence between both elements of the deuteron telescope and the transmission (but not the stopping) α detector. Pileup rejection was used in the α telescope; these circuits improve the quality of the spectra but, as we show later, do not reject all pileup events. Pulse heights, timing data, and the pileup flags from the detectors were recorded in event mode on magnetic tape. Random coincidence rates, subtracted in the usual manner, were always less than 1% of total rates.

Several measurements were made with CH_2 targets to test for possible background from the carbon in the CD_2 target. The only events in these runs which satisfied our selection criteria were a very few *α-deuteron* elastic coincidence events from the deuterium "contamination" in the CH_2 target. The number of these events was statistically consistent with the expected yield from the deuterium present at natural abundance (0.014%); all such events produced α-particle pulses of normal size in the measuring telescope. The CD_2 target contains about 1% hydrogen, but $\alpha+p$ coincidences were neither seen nor expected, since the measuring telescope was always at too large an angle to detect the α particles.

Background might arise from α particles which undergo no reaction but give small pulses due to pulse height defects or incomplete charge collection. If, for example, half the events identified as reactions at 27 MeV (0.12% of the total) were of this type and an *equal* fraction was misidentified for this reason at 92 MeV, the true 92-MeV reaction probability would drop only from 1.70% to 1.58%. However, we expect such effects to become progressively less severe with increasing energy, as the ionization density decreases. In particular, the reaction probability for 9 MeV ^3He particles on Si, measured[3] by this method, is only .004%; moreover, these particles have twice the dE/dx of the slowest α particles studied here. We conclude that such a background is insignificant in the present experiment, particularly at the higher energies.

Two elastic scattering effects[3] can cause instrumental biases. The escape of an α particle after elastic backscattering in the stopping detector would simulate a reaction (unless it reentered the transmission detector, thereby rejecting the event). From elastic angular distribution calculations using Satchler's[4] optical model potentials, we estimate the probability of this occurrence to be below 10^{-5} at 27 MeV and still smaller at higher energies. In contrast, energy losses in small-angle elastic scattering shorten the projectile's range and thus "deprive" it of

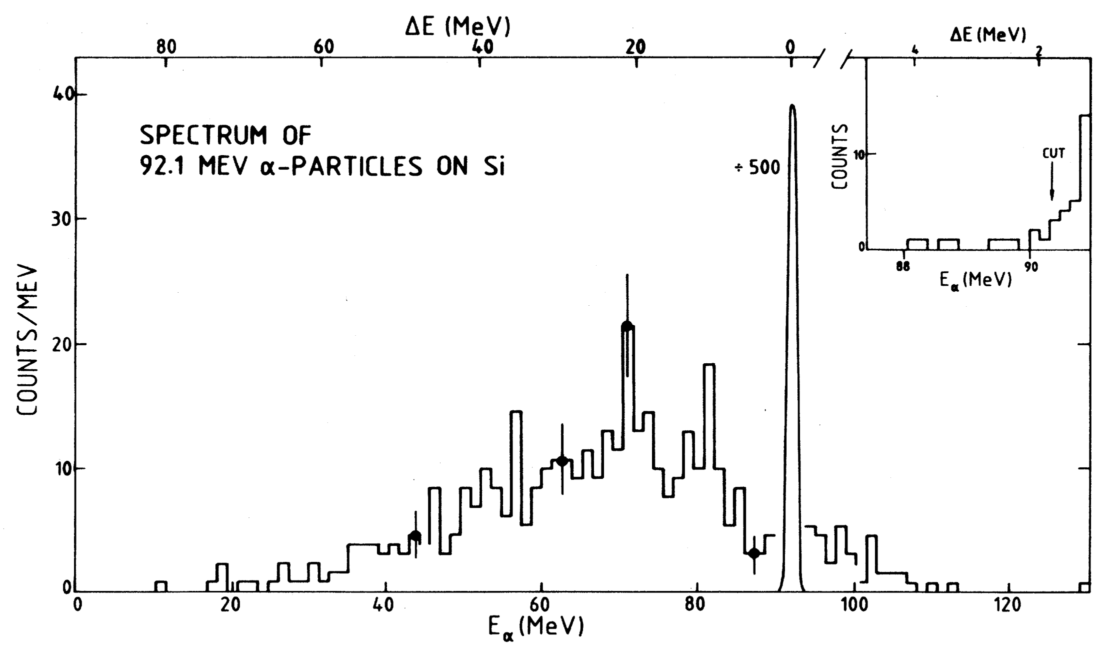

FIG. 1. Recorded energy spectrum of 92.1 MeV α particles incident upon 5 mm thick Si detector. Upper scale shows missing energy ΔE due to nuclear reactions of negative Q. Inset shows expanded spectrum near cutoff between reaction tail and stopped peak. Some typical error bars are shown.

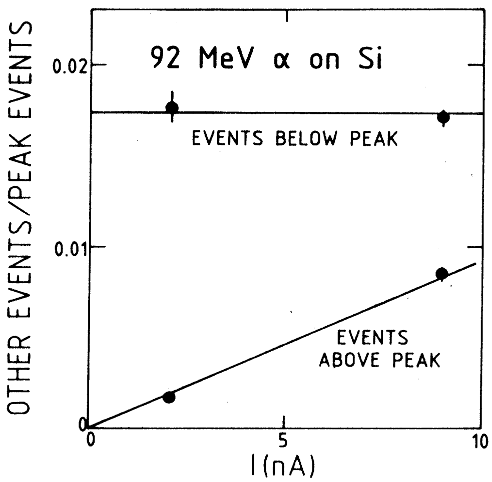

FIG. 2. Beam intensity dependence of ratios of reaction events to peak events, and of pileup events to peak events, for 92.1 MeV α-particles incident upon Si.

possible contact with some of the detector nuclei. We estimate, using multiple scattering theory, that our measured probabilities may be too low by no more than 0.1% of their stated values (e.g., 0.1% of 1.7% at 92 MeV). Both of these effects therefore appear to be very much smaller than our statistical uncertainties, and no corrections for them were made.

III. DATA ANALYSIS AND RESULTS

Events were accepted for analysis when the recoil telescope identified a deuteron of the correct energy and the measuring telescope's transmission counter recorded the energy loss expected for the associated α particle. Tight gates were set on all three of these energy parameters and the associated fast timing signals. Single-dimensional energy spectra were then obtained for the stopping counter in the measuring telescope, whose only gating requirement was that its pileup rejector did not fire. It was then assumed that a single α particle of the correct energy struck this counter.

Figure 1 shows the energy spectrum recorded by the stopping counter in the measuring telescope when 92.1 MeV α particles were injected into it. The large peak due to particles which stopped through normal electromagnetic ionization processes (called, hereafter, "the peak") is somewhat broad. Its width (about 1.5 MeV FWHM) is fully accounted for by the deuteron energy spread resulting from the recoil telescope solid angle. Also, some spectra suggested very small gain drifts which further broadened the peak. To reduce the likelihood of counting normally stopped particles as reaction events, we included in the peaks all events within ± 1.8 MeV (a large but arbitrary interval) of their centers. An inset to Fig. 1 shows the cutoff on the low-energy side of the peak.

It is highly improbable that the events above the peak in Fig. 1 are from reactions, since the only reactions of $^{28-30}$Si$+\alpha$ with positive Q values are radiative capture. Capture γ rays would be detected only with very low energy by the Si. Unless the γ-rays are detected, charged particles engaging in a capture reaction will show a "missing energy" $\Delta E \geq 0$ (upper scale, Fig. 1), with the lower limit applying only for capture at rest. Finally, capture cross sections are usually orders of magnitude smaller than those for charged particle reactions.[6] Therefore, the most probable explanation for these events is pileup of a lightly ionizing particle (proton or deuteron) with an α particle. Pileup probability per event is expected to be directly proportional to average beam intensity, and Fig. 2 shows this proportionality between normally selected events above the peak and those in it. For events in which the pileup circuits fired, there was also an enhanced yield above the peak. Figure 2 also shows that the yield below the peak is beam independent. Therefore, we classify events below and above the peak as "reaction" and "pileup" events, respectively.

Q values for reactions of $^{28-30}$Si$+\alpha$ which produce two charged particles, one with $A \leq 3$, range from -1.92 to -17.07 MeV for ^{28}Si$(\alpha,p)^{31}$P and ^{28}Si$(\alpha,t)^{29}$P, respectively. However, Fig. 1 shows that most reaction events have missing energies between 10 and 40 MeV. Spectra of inelastic α particles observed in studies[7] of the giant quadrupole resonance in ^{28}Si show large yields in this and still higher excitation regions. These result in part from the pickup reactions $(\alpha,{}^5\text{He})$ and $(\alpha,{}^5\text{Li})$. The missing energies may then exceed the nucleon separation energies (11.6 and 17.2 MeV, respectively, for p and n removed from ^{28}Si) since neutrons are not detected and the proton range can exceed the detector thickness. Breakup of the α particle may also be an important reaction channel, and the missing energy can then greatly exceed the 20-MeV nucleon separation energy for the same reasons.

The measured reaction probability is just the ratio of reaction events to (reaction+peak) events. Measured probabilities, extracted from spectra such as Fig. 1, are listed in Table I for α particles with incident energy $E_0=27-92$. The probabilities $\eta(E_0)$ may be calculated[2,3] from

$$\eta(E_0)=1-\exp\left[-\int_0^{R(E_0)}\rho\sigma_R\,dx\right]$$
$$=1-\exp\left[-\int_0^{E_0}\rho\sigma_R(dE/dx)^{-1}dE\right], \quad (1)$$

TABLE I. Experimental conditions and results. $E_{\alpha 0}$ is the energy of the α particle when it enters the stopping counter.

$E_{\alpha 0}$ (MeV)	θ_α (lab)	θ_d (lab)	Reaction probability η (%)
26.9	29.5°	24.0°	0.234±0.071
36.8	30.2°	30.0°	0.310±0.061
49.6	29.2°	37.0°	0.557±0.045
58.8	28.0°	41.0°	0.888±0.060
64.9	26.5°	45.0°	1.002±0.042
78.2	23.0°	52.0°	1.345±0.045
92.1	19.0°	60.0°	1.700±0.041

where ρ is the number of nuclei per unit volume, σ_R is the reaction cross section, (dE/dx) is the stopping power, and $R(E_0)$ is the range of the particle incident upon the stopping detector. Ranges and stopping powers are taken from Williamson et al.;[8] their values differ by about 1% from those of Ziegler.[9] In Fig. 3 measured probability is plotted versus range. Such a plot, if the probability is small and σ_R is energy independent, is a straight line; otherwise, it determines the average σ_R throughout the investigated energy range. The curve is drawn for a constant σ_R of 1147 mb. It fits the data with a χ^2 per degree of freedom of 1.15; our data are therefore consistent with constant σ_R throughout this energy region. We assign ±52 mb uncertainty by finding those values of the average σ_R for which χ^2/d doubles.

The upper-energy cutoff chosen for reactions ($\Delta E = 1.8$ MeV) may have excluded some events from reactions with small negative Q values. The most important such group would be inelastic scattering to the first 2^+ state of ^{28}Si ($E_x = 1.78$ MeV), for which the cutoff would coincide with the center of the group. We estimated in three different ways the number of events which could have been lost. First, it was assumed that the peak and the inelastic group had equal widths (about 0.8 MeV HWHM) and that all events within one peak HWHM below the cutoff were from the 2^+ group. The number of additional events in the upper half of the inelastic group was calculated for each E_0, and an analysis similar to that which produced Fig. 3 then indicated an additional cross section of 37 ± 15 mb. Next, since the yield of events just below the peak in Fig. 1 was rather flat, the number of events in the upper halt of the 2^+ group was estimated from the average yield in the interval 1.8 MeV $\leq \Delta E \leq 5.9$ MeV. This produced an estimate of 11 ± 5 mb for the missing cross section. Finally, published[10,11] angular distributions for inelastic scattering at 22 and 104 MeV are consistent with integrated cross sections of about 40 mb, suggesting that we may have excluded half this amount. Therefore we estimate that we may have excluded a cross section of 23 ± 18 mb from this group, and increase our reported average σ_R to 1170 ± 55 mb.

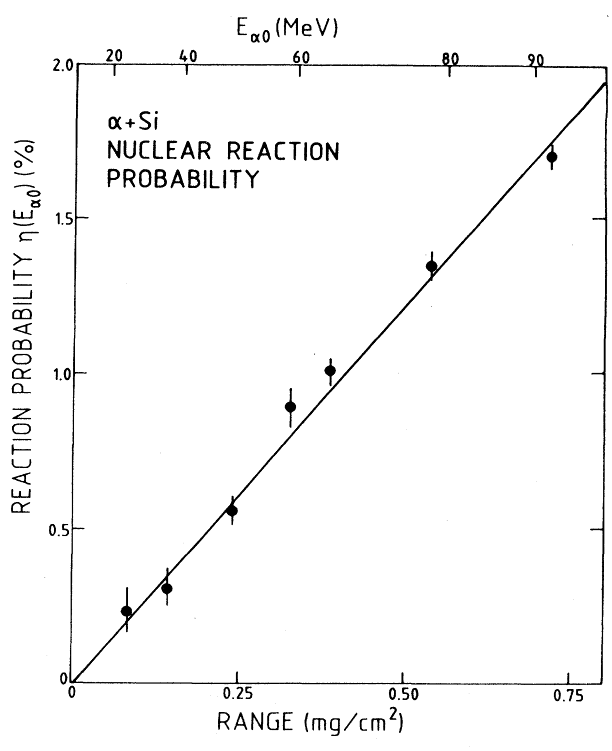

FIG. 3. Total nuclear reaction probability for 27 to 92 MeV α-particles incident upon a thick Si detector, plotted versus their range and initial energy. The curve is calculated by assuming a constant reaction cross section of 1147 mb.

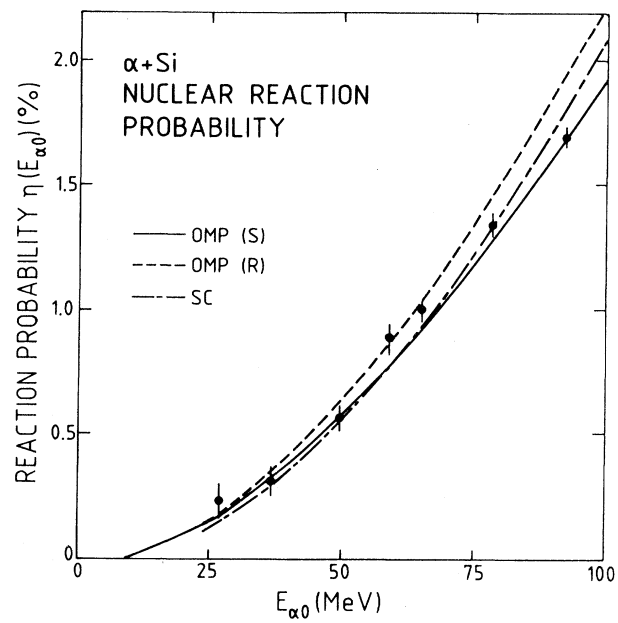

FIG. 4. Total nuclear reaction probability for 27 to 92 MeV α-particles incident upon a thick Si detector, compared with predictions from two optical model parameter sets and the semiclassical theory described in the text.

IV. COMPARISON OF RESULTS WITH PREDICTIONS

The c.m. energies of the α particles observed in this study vary from about 6 to 20 MeV per nucleon. Reaction cross sections[12] for other light targets (indirectly determined from optical model analysis) are only weakly energy dependent in this energy range, and in fact appear to be near a maximum. Thus it is reasonable that our data are satisfactorily fitted by a constant σ_R. Its magnitude, 1170 mb, also is reasonable since it falls about halfway between the σ_R's for α particles of these energies on ^{12}C and ^{40}Ca (about 900 and 1400 mb, respectively[12]).

Our reaction probability data are plotted versus initial α particle lab energy in Fig. 4, where they are compared with both optical-model and semiclassical predictions. No corrections for possible loss of some of the first inelastic group were made to the individual data; thus they are consistent with an average σ_R of 1147 rather than 1170 mb.

Optical model predictions of σ_R were calculated with the code SNOOPY8Q (Ref. 13) for two optical model parameter sets[4,14] (OMP's) obtained from $\alpha+{}^{28}Si$ elastic scattering analyses. These σ_R's, combined with stopping powers from the Williamson tables,[8] were used in Eq. (1) to predict reaction probabilities. The fit obtained using Satchler's OMP, derived[4] from 28 MeV elastic scattering data, is shown by a solid curve in Fig. 4. These parameters predict that σ_R varies from about 1210 to 1040 mb in our energy region. The quality of fit obtained ($\chi^2/d=1.17$) is as satisfactory as we obtained with a constant σ_R of 1147 mb. The fit using Rebel's OMP (Ref. 14) from 104 MeV elastic scattering, shown by a dashed curve, is much worse ($\chi^2/d=7.7$).

Nadasen[15] has surveyed optical model parameters used to describe elastic scattering of complex projectiles. He finds, for α particles, that the volume integrals of the real potential divided by A of the target nucleus (i.e., J_R/A) extrapolate to zero at an α particle bombarding energy of 3500 MeV. However, there is some spread in the J_R/A's at any given bombarding energy. We investigated the effect of giving the Satchler and Rebel real potentials this energy dependence; their geometric parameters were held fixed, and their real potential depths V_0 were varied appropriately. In both cases, the effect was to make χ^2/d about 1.5 times larger than that obtained for energy-independent potentials. For the Satchler potentials, anchored to $V_0=52.5$ MeV at $E_\alpha=28$ MeV, the reaction cross section fell to 995 mb at 92 MeV, lowering the average cross section somewhat further from the measured value. In contrast, the Rebel potential, with depth fixed at $E_\alpha=104$ MeV and increased at lower energies, gave low energy cross sections as high as 1380 mb. Thus it overpredicted the average cross section by a still larger amount.

The data also were compared with predictions from a semiclassical formula:

$$\sigma_R=\pi(R_i+\lambdabar)^2\left[1-\frac{zZe^2}{(R_i+\lambdabar)E_{\text{c.m.}}}\right](1-T)\ . \qquad (2)$$

This formula, introduced by Renberg *et al.*,[5] was later used by DeVries and Peng[12] as the starting point for a description of total reaction cross sections using a Glauber approach. The formula is based on the assumption that a projectile following the classical Coulomb trajectory has a probability $(1-T)$ of interacting if the distance of closest approach does not exceed the sum of the effective hard-sphere interaction radius R_i and the reduced wavelength $\lambdabar$ of the projectile. The hard-sphere radius is taken to be

$$R_i=\sqrt{5/3}(r_\alpha+r_t)\ . \qquad (3)$$

We took the Si rms radius[16] to be 3.1 fm and let that of the α particle, r_α, be a variable parameter.

DeVries and Peng[12] show that the transparency T in Eq. (2) is small when the projectile's mean free path in nuclear matter is small or, equivalently, when the nucleon-nucleon total cross section σ^{NN} is large. Thus at very low bombarding energies T approaches zero. We therefore began our analysis with $T=0$ and varied r_α to fit the data. Our best fit ($\chi^2/d=2.8$) was obtained with $r_\alpha=1.83$ fm; the accepted value[16] is 1.70 fm. The predicted reaction probability versus E_α for this r_α is shown in Fig. 4, and the quality of fit versus r_α is shown in Fig. 5. Thus, with $T=0$, the semiclassical formula fits the data considerably better than the Rebel OMP, but does less well than the constant σ_R and Satchler OMP predictions.

Our data may be used to roughly estimate T, which should be largest at our largest E_α (92 MeV). Moreover, that particular datum can be better fitted with $T>0$ since the $T=0$ prediction exceeds the measured probability. We let T be directly proportional to E_α. Setting $T=6\%$ at $E_\alpha=92$ MeV gave a predicted η of 1.74, in agreement with the measurement for that E_α, but did not improve the overall quality of fit. The overall χ^2 was doubled when T at 92 MeV was increased to 12%. Thus we roughly estimate T to be $(6\pm6)\%$ when E_α is 92 MeV. For α particles on ${}^{40}Ca$, DeVries and Peng[12] found a maximum transparency of 40% near 300 MeV/nucleon, where the σ^{NN} have reached their minimum. At our highest energy (23 MeV/nucleon) the *p-p* and *n-p* total cross sections are about 6 and 10 times, respectively, their minimum values; a transparency of 6% therefore seems reasonable by comparison with their results.

The DeVries-Peng survey compared calculated σ_R's for deuterons, ${}^3He$, and α particles incident upon the same nucleus. They found that Eqs. (2) and (3) always required larger radii for ${}^3He$ than for d and α, even though the known radius of ${}^3He$ is between those of the other two projectiles. This anomaly is now confirmed by the direct measurements for these three projectiles on Si. The earlier low-energy measurements[3] were best fitted by

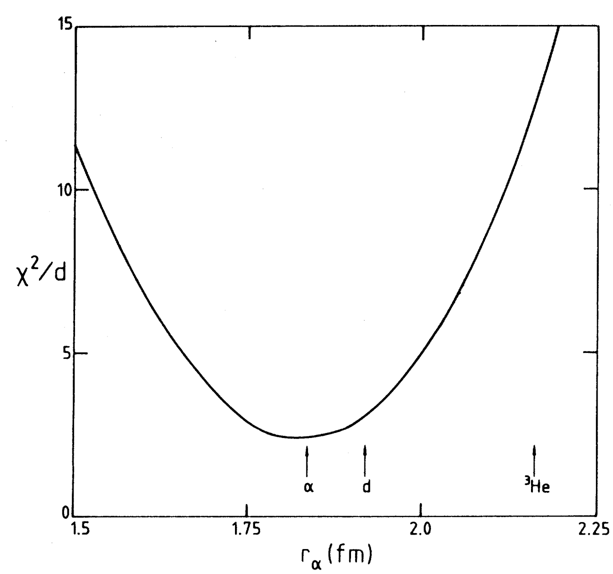

FIG. 5. Quality of fit to reaction probability data vs rms α-particle radius assumed in semiclassical theory calculations. Optimum radii for d and ${}^3He$ from an earlier study,[3] and α from this study, are indicated.

d and ^{3}He radii of 1.92 and 2.16 fm, respectively; these values, and that obtained for r_α in the present study, are shown on Fig. 5. Further measurements for d and ^{3}He in the 25–100 MeV region would now be of interest.

V. SUMMARY AND CONCLUSIONS

The average nuclear reaction cross section for α particles on ^{nat}Si has been directly measured to be 1170±55 mb. This includes a 23 mb contribution for inelastic scattering to the first excited state, which may have been partially hidden by our energy resolution.

These data also show that σ_R has very weak energy dependence below 100 MeV laboratory α energy. A detector efficiency correction proportional to range will therefore adequately account for reaction losses in most experiments. This correction extrapolates to 2.07% at 100 MeV.

The data are adequately fitted both by an energy-independent σ_R and by σ_R's calculated from Satchler's[4] OMP; the Rebel[14] OMP gives σ_R's too large to fit the data. The semiclassical formula of Renberg *et al.*[5] gives somewhat lower-quality fits than the Satchler OMP. However, its use permits a rough estimate of the nuclear transparency (rising from 0 to about 6% as E_α increases from 0 to 92 MeV) which is reasonable compared with the larger transparencies found by DeVries and Peng[12] at intermediate energies. Moreover, these calculations, together with similar ones[3] used to fit low-energy reaction probability data for d and ^{3}He on Si, require an ^{3}He radius larger than that of either d or α. This is unexpected since electron scattering measurements give a ^{3}He radius intermediate to d and α, but it agrees with a finding of DeVries and Peng.

Measurements of the reaction probabilities in Si for d and ^{3}He in this energy range would now be of interest, as would more accurate α-particle measurements which could better define the energy at which the expected maximum of σ_R occurs.

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[1]J. N. Palmieri and J. Wolfe, Nucl. Instrum. Methods **76**, 55 (1969).

[2]D. Friesel, P. Schwandt, A. Nadasen, G. Caskey, A. Galonsky, and R. E. Warner, Nucl. Instrum. Methods Phys. Res. B **16**, 96 (1986).

[3]R. E. Warner, C. P. Browne, S. E. Darden, J. J. Kolata, A. Rollefson, P. A. Kimoto, and A. Galonsky, Phys. Rev. C **37**, 1884 (1988).

[4]G. R. Satchler, Nucl. Phys. **70**, 177 (1965).

[5]P. U. Renberg, D. F. Measday, M. Pepin, P. Schwaller, B. Favier, and C. Richard-Serre, Nucl. Phys. **A183**, 81 (1972).

[6]H. E. Gove and A. E. Litherland, in *Nuclear Spectroscopy, Part A,* edited by F. Ajzenberg-Selove (Academic, New York, 1960), p. 260.

[7]D. H. Youngblood, C. M. Rozsa, J. M. Moss, D. R. Brown, and J. D. Bronson, Phys. Rev. C **15**, 1644 (1977).

[8]C. F. Williamson, J.-P. Boujot, and J. Picard, Commissariat d'Energie Atomique Report No. R3042, Saclay, 1966.

[9]J. F. Ziegler, *The Stopping and Ranges of Particles in Matter* (Pergamon, New York, 1977), Vol. 4.

[10]D. E. Batchley and R. D. Bent, Nucl. Phys. **A61**, 641 (1965).

[11]H. Rebel, G. W. Schweimer, J. Specht, G. Schatz, R. Löhken, D. Habs, G. Hauser, and H. Klewe-Nebenius, Phys. Rev. Lett. **26**, 1191 (1971).

[12]R. M. DeVries and J. C. Peng, Phys. Rev. C **22**, 1055 (1980).

[13]P. Schwandt, private communication.

[14]H. Rebel, G. W. Schweimer, G. Schatz, J. Specht, R. Löhken, G. Hauser, D. Habs, and H. Klewe-Nebenius, Nucl. Phys. **A182**, 145 (1972).

[15]A. Nadasen and P. G. Roos, Bull. Am. Phys. Soc. **29**, 1040 (1984).

[16]C. W. de Jager, H. de Vries, and C. de Vries, At. Data Nucl. Data Tables **14**, 479 (1974).