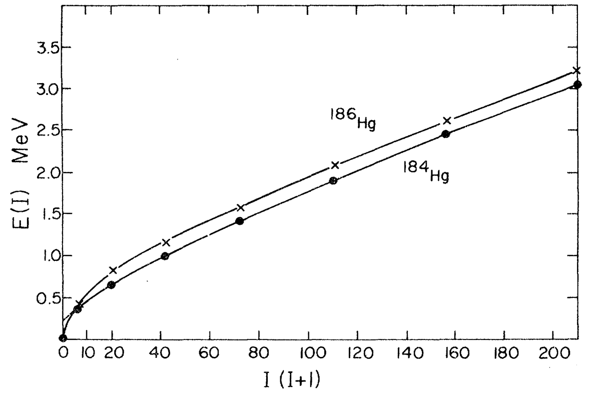

FIG. 2. Level systematics for ^{184}Hg and ^{186}Hg. The 12^+ and 14^+ points in ^{184}Hg are tentative ($12^+ \rightarrow 10^+ = 551$ keV, $14^+ \rightarrow 12^+ = 604$ keV). A well-developed rotational band seems to develop at 4^+ in ^{184}Hg and at $\sim 6^+$ in ^{186}Hg.

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Strongly Oscillating Angular Distributions in the Reaction ^{32}S(^{16}O, ^{12}C)^{36}Ar at $E_{\text{c.m.}} = 30$ MeV

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The elastic scattering of ^{16}O on ^{32}S and the reaction ^{32}S(^{16}O, ^{12}C)^{36}Ar have been measured at $E_{\text{c.m.}} = 30$ MeV. The elastic-scattering angular distribution exhibits a smooth Fresnel-type diffraction pattern, whereas for the (^{16}O, ^{12}C) reaction we observe strong oscillations in the ground-state transition.

Heavy-ion–induced transfer reactions usually exhibit characteristically bell-shaped angular distributions at energies not too far above the Coulomb barrier and for medium-mass target nuclei[1,2] ($A \geq 20$). These angular distributions can be qualitatively understood by the following simple semiclassical argument. The maximum transfer probability will occur for grazing collisions corresponding to the scattering angle θ_{gr}. For collisions with smaller inpact parameters, i.e., for scattering angles $\theta > \theta_{\text{gr}}$, the transfer cross section decreases because of the strong absorption of the colliding nuclei; for larger impact parameters, i.e., $\theta < \theta_{\text{gr}}$, the decrease of the cross section is due to the exponential falloff of the overlap of the bound-state wave functions in the initial and final channels. The corresponding elastic scattering angular distributions exhibit smooth Fresnel-type diffraction patterns.[3]

Qualitatively different angular distributions have been observed for energies far above the Coulomb barrier and for light target nuclei ($A \leq 20$). For these cases strongly oscillating angular distributions have been measured both for the transfer and for elastic scattering.[4,5]

Only very recently a few exceptions from these cases have been reported for target nuclei $A \geq 20$.[6-9] These "anomalous" angular distributions exhibit a rise of the transfer cross section towards smaller angles and show more or less pronounced oscillations. It is the aim of this paper to give further evidence for the occurrence of strongly oscillating transfer angular distributions at energies a few MeV above the Coulomb barrier. This has been observed for the reaction ^{32}S(^{16}O, ^{12}C)^{36}Ar at 45-MeV incident energy.

The experiment was carried out with the ^{16}O beam of the Heidelberg MP tandem Van de Graaff accelerator. Cadmium-sulfide targets of approximately 150 μg/cm^2 thickness evaporated on thin carbon backings have been used. Particle identification has been done in two different ways: For scattering angles larger than $\theta_{\mathrm{lab}} = 29°$ the data were taken with a semiconductor telescope measuring ΔE, E, and the time of flight. For smaller scattering angles we used a time-of-flight telescope,[10] which is able to deal with higher counting rates but does not yield such background-free spectra as are obtained with the three-dimensional system. The angular resolution of both telescopes was 0.5° in the lab system; the energy resolution was 300 keV.

The relative cross sections for the elastic scattering of ^{16}O on ^{32}S were normalized both on integrated beam current and on the Rutherford scattering of ^{16}O on Cd. Both methods yielded identical results. The transfer cross sections were normalized independently on the integrated beam current, on the Rutherford scattering of ^{16}O on Cd, and on elastic scattering on ^{32}S. All methods yielded results identical to within 5%, indicating that the targets could stand beam currents of up to 300 nA of ^{16}O^{5+} for days without significantly changing in composition.

Absolute cross sections for the elastic scattering of ^{16}O on ^{32}S and for the transfer reaction have been obtained from the Rutherford scattering of ^{16}O on ^{32}S at forward angles.

Although the targets contained a 4.2% contamination of ^{34}S, we did not observe any counts originating from the reaction ^{34}S(^{16}O,^{12}C)^{38}Ar. Since both transitions to the ground state and first excited state in ^{36}Ar are different in energy from each transition to ^{38}Ar by at least 550 keV in the whole angular region covered, our energy resolution would have been sufficient to separate important contributions from transitions to ^{38}Ar. In this respect it is helpful that most of the contaminant peaks would have to be found on the clean high-energy side of the observed peaks.

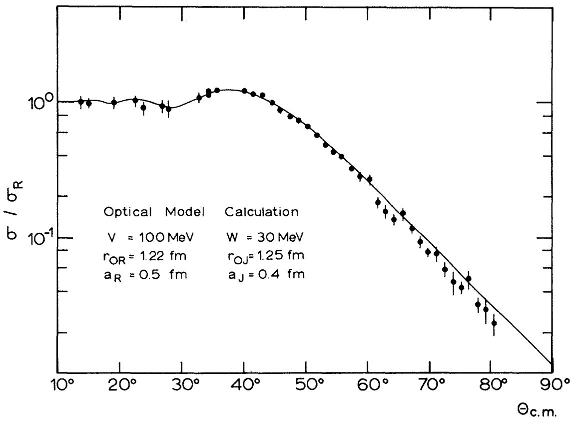

FIG. 1. Comparison of the elastic scattering of ^{16}O on ^{32}S with an optical-model calculation using a deep and strongly absorbing potential.

The experimental results are shown in Figs. 1 and 2. As expected, the elastic-scattering angular distribution shows the characteristic Fresnel-type diffraction pattern.[3] It is readily reproduced by optical-model calculations using a deep and strongly absorbing potential similar to those which have been used by many authors[4,11,12] ($V = 100$ MeV, $r_{0R} = 1.22$ fm, $a_R = 0.5$ fm, $W = 30$ MeV, $r_{0J} = 1.25$ fm, $a_J = 0.4$ fm).

In contrast to the elastic scattering, the four-particle transfer leading to the ground and first excited states in ^{36}Ar shows very pronounced structures in the angular distributions (see Fig. 2). For the ground-state transition, regular oscillations are observed. The transition to the first excited state, on the other hand, exhibits a strong rise of the cross section at forward angles and beginning oscillations at $\theta_{\mathrm{c.m.}} = 40°$. A similar difference between the angular distributions for the transitions to the ground and excited states has been observed by Maher *et al.*[6] for the (^{16}O,^{12}C) reactions on ^{24}Mg and ^{28}Si.

We performed schematic distorted wave Born-approximation calculations using the optical potential determined from the elastic scattering and a simple α-cluster form factor calculated

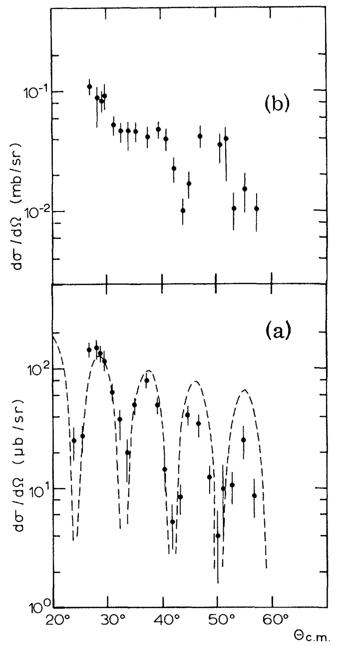

FIG. 2. Angular distributions of the (^{16}O,^{12}C) reaction on ^{32}S leading to (a) the ground state and (b) first excited state in ^{36}Ar. The dashed line in (a) shows the square of the Bessel function $|J_0(20.5\theta)|^2$.

with the Buttle and Goldfarb approximation,[13] which is reasonable at our energy for strongly absorbing potentials. This has been verified by setting lower R cutoffs in the radial integrals. These calculations do not reproduce the experimentally observed oscillations. Our calculations did not show an influence of the steepness of the form factor on the shape of the angular distributions as has been suggested by Christensen *et al.*[9] This may be because our potential is strongly absorbing at the nuclear surface, whereas the potential used in Ref. 9 seems to contain some surface transparency (the radius of the imaginary potential of Ref. 9 is about 0.5 fm smaller than the radius of the real potential).

One possible explanation for the occurrence of anomalous angular distributions has been proposed in Refs. 7 and 8, where it was suggested that heavy ions might not be as strongly absorbed as has been assumed until now. At the present time it is very difficult to perform meaningful calculations to investigate the interesting questions of reduced absorption and surface transparency since one has to know the form factor in the nuclear interior, and cannot use the Buttle and Goldfarb approximation. A quantitative analysis should also take account of recoil effects.

It should be noted that the oscillation pattern for the ground-state angular distribution is essentially given by the square of a single Bessel function $|J_0(20.5\theta)|^2$ (see Fig. 2). Since the oscillations of the Legendre polynomials $P_l(\cos\theta)$ may be very well approximated by the Bessel function $J_0((l+\frac{1}{2})\theta)$ [see Eq. (37) of Frahn and Sharaf[14]], the angular distribution might be as well described by $|P_{20}(\cos\theta)|^2$. The grazing angular momentum $\hbar L_0$ calculated with the classical formula $L_0+\frac{1}{2}=\eta\cot(\theta_0/2)$ is $L_0=20$ [η is the Coulomb parameter and θ_0 is defined by $\sigma/\sigma_R(\theta_0)=0.25$].

An angular distribution characterized by a single Legendre polynomial is expected if one partial-wave transition amplitude is enhanced by some reaction mechanism. One such possible mechanism might, for example, be the occurrence of intermediate resonances describing quasimolecular rotations, as has been suggested by Rinat.[15] On the other hand, a $|J_0((L_0+\frac{1}{2})\theta)|^2$ angular distribution is obtained for an $l=0$ transition in the sharp-cutoff limit of the strong-absorption model.[14,16]

It is the aim of this note to draw more attention to the phenomenon of anomalous angular distributions. As our data show, strong oscillations may occur in the angular distributions even at energies only a few MeV above the Coulomb barrier. Consequently, reliable spectroscopic information may only be obtained from carefully measured angular distributions since the relative intensities of different final states can vary drastically with scattering angle. It is well possible that the angular distributions of many heavy-ion-transfer reactions contain more fine structure and more detailed information than has been assumed until very recently.

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