degree of adiabaticity of the excitation process.

For the atomic case and Coulomb scattering combined with nuclear phase shifts, the arrangement of the calculation in terms of S_g and S_n has been related to the expression for the Coulomb modification of the plane wave ψ^C so as to make estimates of quantum corrections to classical effects possible. The asymptotic form of ψ^C for $kr \gg 1$, including correction terms to the plane-wave and outgoing-wave parts $\mathcal{O}(1/kr)$ and corresponding approximations to the three-dimensional Green's function, give for any multipole exact compensation without the $\mathcal{O}(1/kr)$ corrections. With their inclusion there appear effects involving an extra power of $1/(ka_H)$, $a_H = 0.529 \times 10^{-8}$ cm, which at 1 Mev are of the general order of 10^{-6} of the Coulomb scattering and are negligible. A more detailed report is in preparation, but the appearance of an extra factor $1/(ka_H)$ removes doubts[1] regarding low-energy nucleon-nucleon scattering as a method for dealing with nuclear forces.

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EMISSION OF ALPHA PARTICLES FROM A COMPOUND SYSTEM OF HIGH ANGULAR MOMENTUM*

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The energy spectra of alpha particles emitted following bombardment of Ni with high-energy oxygen ions have been measured. Emitted particles pass through a proportional counter and into a CsI crystal. The energy of a particle is measured in the CsI crystal while its dE/dx is measured in the proportional counter. The relation between E and dE/dx identifies the particle. Spectra are recorded on a 20-channel analyzer gated by coincidences between E and dE/dx pulses of selected amplitudes or are observed and photographed on an oscilloscope as a display of dE/dx *vs* E for individual particles.

The spectra of alpha particles emitted at various laboratory angles from the bombardment of a Ni target with 162-Mev O ions are shown in Fig. 1. Observations were made at laboratory angles of 17°, 31°, 46°, 60°, 90°, 110°, 134°, and 158°. For clarity, only three of the spectra are shown in Fig. 1. The peaks of all of the spectra are shifted toward progressively lower energies as the angle of observation is increased. The total number of particles in any spectrum decreases rapidly with increasing angle up to about 90 degrees and then remains approximately constant at backward laboratory angles. The shapes of the spectra indicate that the total numbers of alpha particles would actually increase at backward angles were it not for the effect of the low-energy cutoff of the detecting system.

In Fig. 2 are shown the spectra transformed into the center-of-mass system of a 162-Mev O ion incident on a Ni target nucleus. Again for clarity only a few of the spectra observed are shown. Laboratory angles of observation are

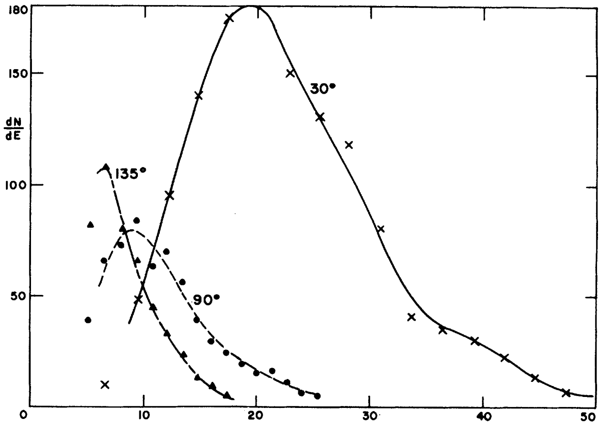

FIG. 1. Energy spectra in the laboratory system of alpha particles emitted in the bombardment of Ni by 162-Mev oxygen ions. Laboratory angles of observation are indicated.

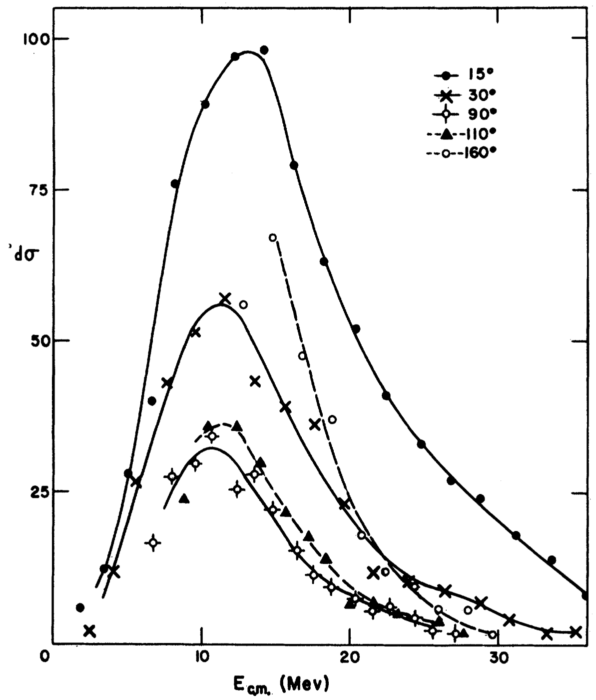

FIG. 2. Energy spectra in the center-of-mass system of emitted alpha particles. The ordinate is proportional to differential cross section per Mev per steradian. Laboratory angles of observation are indicated although each laboratory angle corresponds to various center-of-mass angles (see text).

indicated. It should be noted, however, that these are continuous spectra and that particles of different energies observed at a given angle in the laboratory come from different angles in the center-of-mass system. For example, particles in the laboratory spectrum at 90° correspond to center-of-mass angles of 119° at 8 Mev (center-of-mass energy), and 105° at 25 Mev. The spectra in the center-of-mass system all peak at approximately the Coulomb barrier energy (12 Mev) to be expected for the emission of alpha particles from the system O plus Ni. The relative differential cross sections are now at a minimum at 90° center-of-mass angle and strongly peaked in the forward and backward directions. The spectra appear to be predominantly of the nuclear evaporation type[1] except for a pronounced forward peaking of the alphas at about twice the peak energy in the center-of-mass system. Proton spectra from this reaction show similar features.

Figure 3 shows the angular distributions in the center-of-mass system of alpha particles of various energies. The values for the relative cross sections have been taken from spectra plotted as in Fig. 2. Here it is seen more clearly that most of the alpha particles fall into distributions approximately symmetric about 90° with maxima in the forward and backward directions. There is some indication of forward peaking at small angles at all energies and the spectra are predominantly peaked in the forward direction at the highest energies.

The angular momentum involved in the formation of a compound system by a 162-Mev O nucleus incident upon a Ni nucleus has a mean effective value of about 50 in units of $\hbar$. Particles from such a system should be preferentially emitted in directions such that their orbital angular momenta are aligned with the initial angular momentum of the system.[2,3] In the limit of high angular momentum and decreasing density of levels with increasing angular momentum, an angular distribution of particles proportional to $(\sin\theta)^{-1}$ is expected.[3] The distributions in Fig. 3 are consistent with $(\sin\theta)^{-1}$ in the backward direction for the angles observed and rise more rapidly than $(\sin\theta)^{-1}$ in the forward direction.

We interpret the spectra as indicating that this reaction proceeds primarily by the formation of a compound system of high excitation from which alpha particles, among other particles, are emitted. The angular distributions of the alpha particles show the effects of the extremely high angular momenta with which these systems are formed. The asymmetric portions of the spectra presumably indicate the presence of some direct-interaction process or processes. It is perhaps

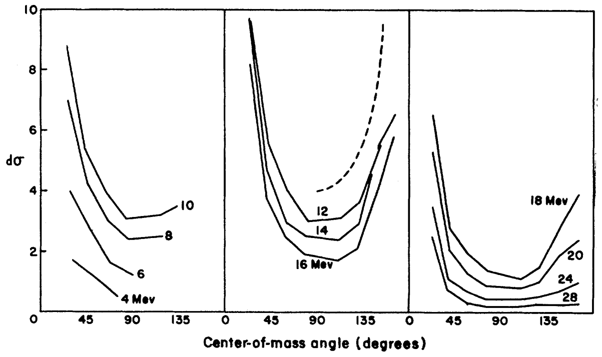

FIG. 3. Angular distributions of emitted alpha particles in the center-of-mass system. The ordinate is proportional to differential cross section per Mev per steradian. The dashed curve in the center figure is proportional to $(\sin\theta)^{-1}$, the predicted distribution in the limit of high angular momentum.[3]

significant that the most prominent feature of the forward-peaked alpha particles is their relatively large number at about 40 Mev in the laboratory system. Alpha particles of 40 Mev have the same velocity as that of the incident oxygen ions.

The symmetric parts of the energy spectra in the center-of-mass system will be compared to nuclear evaporation calculations.[1] Similar measurements on other reactions of this type are in progress. A detailed description of the apparatus used will be published elsewhere.

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[*] This work has been supported by the U. S. Atomic Energy Commission.

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X-RAY YIELDS IN μ-MESONIC ATOMIC TRANSITIONS

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In a series of very careful experiments Stearns and Stearns[1] have shown that the total K x-ray yield per stopped muon for muons stopping in various light materials is smaller by a considerable amount than would be predicted on the grounds of any simple theory of the effect. In the actual experimental arrangement used by Stearns and Stearns the incident μ-meson flux is known and the outgoing x-ray energy is measured. The data are interpreted as follows: On the basis of a plausible picture of the capture process the μ mesons, in the main, pass through the $2P$ μ-mesonic atomic state. In this state the fate of the μ meson is decided in a competition between the radiative $2P-1S$ transition and a $2P-1S$ transition in which the energy released is taken up by an Auger electron ejected into the continuum. Other nonradiative processes such as direct muon capture by the nucleus contribute negligible branching ratios. Since the Auger probability is roughly independent of Z and since the radiative transition goes like Z^4, we might expect, on this picture, that the x-ray yield Y would go like

$$Y = \text{const}\, Z^4/(C_1 + Z^4\text{const}),$$

where C_1 gives the Auger probability. Indeed Stearns and Stearns find that empirically the yield as a function of Z has this form, but that the constant C_1 determined from experiment would require an Auger probability some 300 times larger than that computed by standard perturbation-theory methods.[2] In an attempt to account for this large discrepancy, Day and Morrison[3] have invoked collision mechanisms involving the μ-mesonic atom and its neighbors in the dense material. Since this explanation in terms of collisional de-excitation has gained considerable acceptance,[4] we felt that it would be worthwhile to indicate why, in our belief, it cannot be correct.

According to their argument the μ-mesonic atom may undergo a collision with a neighboring atom whose electrons take up the $2P-1S$ de-excitation energy. Day and Morrison estimate that the cross section for this, $\sigma(2P\to 1S) \simeq \pi a_0^2$, where a_0 is the electron Bohr radius. The fact that the collision cross section emerging from their calculation depends on a_0 and not on a_μ, the muon Bohr radius, is what gives them the factor of 300 needed to explain the experimental results of Stearns and Stearns. In this discussion the usual perturbation theory calculation of the Auger effect is not questioned. Now the collision de-excitation process of Day and Morrison may be looked at as an "external" Auger effect, i.e., one taking place during the time of collision t. It can readily be seen that the cross section πa_0^2 implies a transition probability of the order 10^{14}/sec for this "external" Auger effect; whereas the usual perturbation theory gives the value $\sim 10^{11}$/sec for the same Auger transition, $2P\to 1S$, in a free atom. It appears to us that it is a priori unlikely that the Auger process which is inefficient for taking up the $2P-1S$ nonradiative transition energy in an isolated atom could be made so much more efficient by collision with another atom. More exactly speaking, we asked why should an electron in a neighboring atom be ejected by an Auger process ~ 300 times more efficiently than an electron in the given atom itself? In fact, if we estimate the cross