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Deep inelastic collisions of $^{32}S + ^{27}Al$ reaction at 130 MeV bombarding energy

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Abstract. The $^{32}S + ^{27}Al$ reaction was studied to investigate the deep inelastic collisions at a bombarding energy of 130 MeV which is well above the Coulomb barrier. The energy distributions of the binary decay products of $6 \leqslant Z \leqslant 10$ were determined using a large area position sensitive ionization chamber. The average kinetic energies of the reaction products indicate that the exit shapes correspond to highly stretched scission configurations in the deep-inelastic processes.

Keywords. $^{32}S + ^{27}Al$ reaction; deep inelastic scattering; kinetic energy of reaction products.

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In recent years, there have been a number of experimental investigations to study the dynamical aspects of heavy ion collisions leading to fusion and deep inelastic processes. At energies around the Coulomb barrier, compound nucleus formation following fusion is the main reaction mechanism of heavy ion reactions. At higher energies, other processes such as incomplete fusion and deep inelastic reactions begin to become important. The compound nuclei, formed at large excitation energies ($E^* \approx 50$–100 MeV), deexcite predominantly by fission or by particle and gamma emission. The characteristics of various decay modes can be studied to derive information on the reaction mechanism and the structure of the compound nuclei produced in heavy ion collision processes [1–5]. There has been a lot of interest to study the binary fission like decay, particle and gamma decay of light compound nuclei. A number of measurements have been carried out for ^{59}Cu compound nucleus [6–8] produced in $^{32}S + ^{27}Al$ reactions. These studies have shown that at large angular momenta the compound nucleus may possess large spin induced deformation, connected with the dynamical effects in the shape relaxation during the formation of the compound nucleus. Since deep-inelastic collisions also correspond to events involving large damping of the kinetic energy and angular momentum, it would be of interest to study the features of this reaction for the above system. With this aim, we have measured, in the present work, the yields and the energy and angular distributions of various products emitted around the grazing angle in $^{32}S + ^{27}Al$ reaction at a bombarding energy of 130 MeV. The data were analysed to determine the average kinetic energies of the products. Assuming the products to arise from binary division of the composite system, it is found that the kinetic energies can be explained by invoking highly stretched configurations in the deep inelastic exit channels.

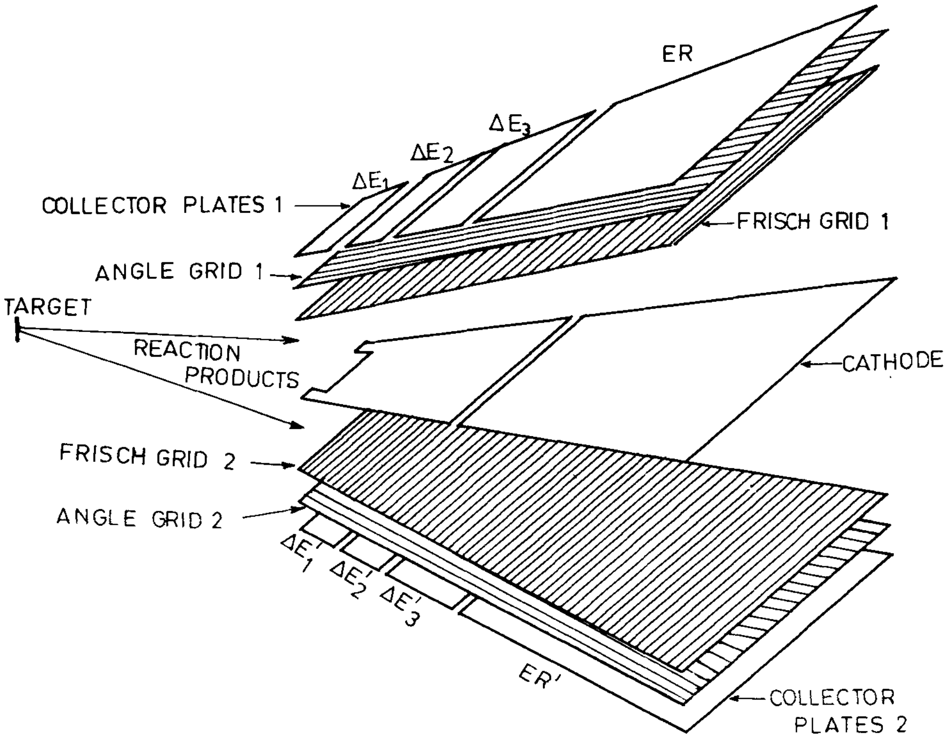

Figure 1. Schematic diagram of large area position sensitive ionization chamber (LIC).

The experiment was carried out using the ^{32}S beam from the 14UD BARC–TIFR Pelletron Accelerator at Bombay. A $300\,\mu g/cm^2$ self-supporting target of ^{27}Al was used and the reaction products were measured using a large area position sensitive ionization chamber (LIC) mounted at a mean angle of 54°, and having an angular coverage of $\pm 11°$. Figure 1 shows a schematic diagram of the ionization chamber. A surface barrier detector was mounted at 25° to monitor the elastically scattered particles. The LIC detector has an active gas length of 1·2 m, with four anode sections to measure the differential energy loss for identification and energy measurement of the products emitted in the reaction. The angle is measured from the Θ-grid pulses using the delay line readout technique. The details of the ionization chamber and its performance have been described elsewhere [9]. Only the top half of the ionization chamber was used in the present experiment to detect the reaction products emitted in the reaction. The chamber was filled with P-10 gas at a pressure of 70 mbar so as to stop all products of $Z > 6$ inside the active gas length. The gas was flowed continuously to maintain long term stability in the chamber operation. The signals from the anodes and Θ-grid were recorded for each event. The energy calibration of the anode sections was done by measuring in a separate experiment the elastically scattered events in $^{32}S + {}^{197}Au$ reaction at different bombarding energies. The energy loss of the scattered ^{32}S ions in different anode sections was calculated from the energy loss tables and the pulse heights were normalized to these values for energy calibration. The accuracy in the measurement of energy was estimated to be about 1% by the present technique. The angle calibration was achieved from the dips in the position spectrum due to the shadows caused by the support structure in the window frame. Products of different charge could be identified from the correlation in the $\Delta E - E$ plots between the pulses of different anode sections of the ionization chamber. A typical plot between the pulse heights of 3rd and 4th anode sections is shown in figure 2, where it is seen that the lines for different product charges (circled numbers) are well separated. The energy distribution of different Z fragments is shown in figure 3. The energy spectra are seen to be broad and Gaussian like, suggestive of

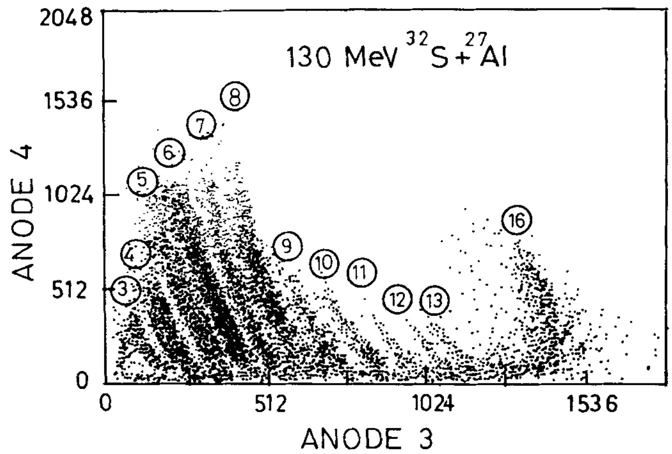

Figure 2. A typical particle identification spectrum with LIC.

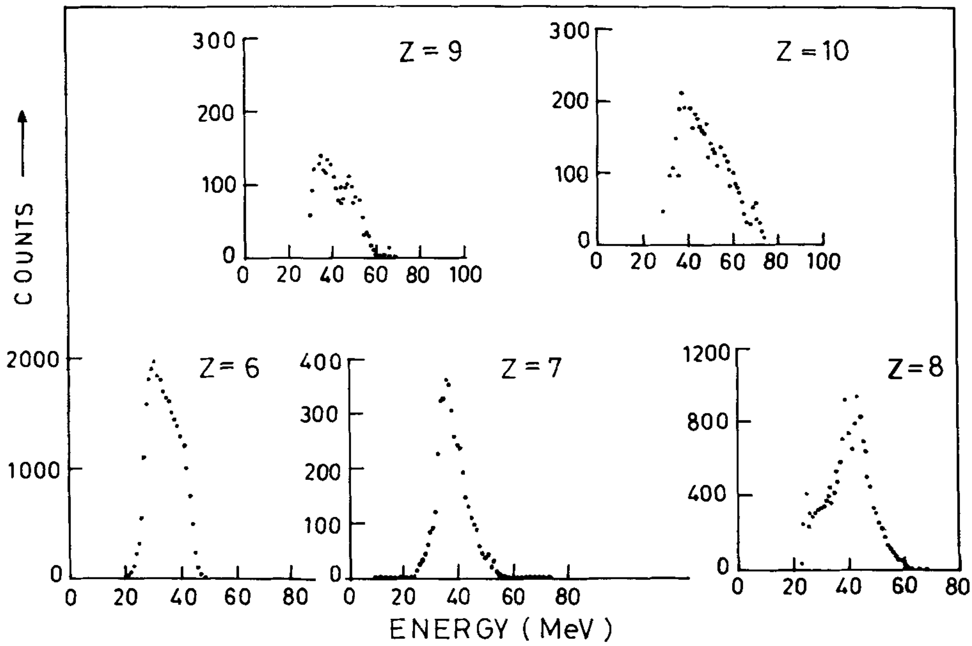

Figure 3. Energy distribution of fragments of $6 \leqslant Z \leqslant 10$.

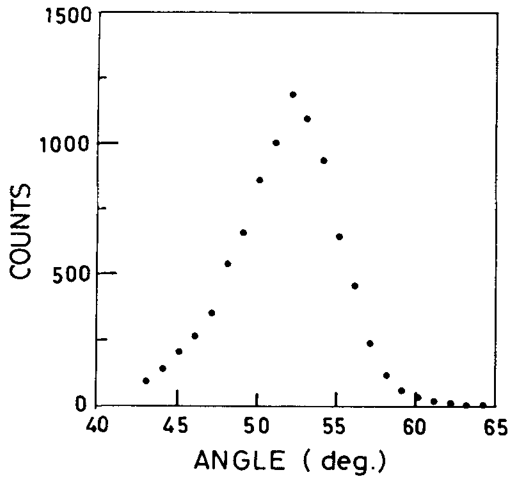

Figure 4. Typical angular distribution for $Z = 6$ products.

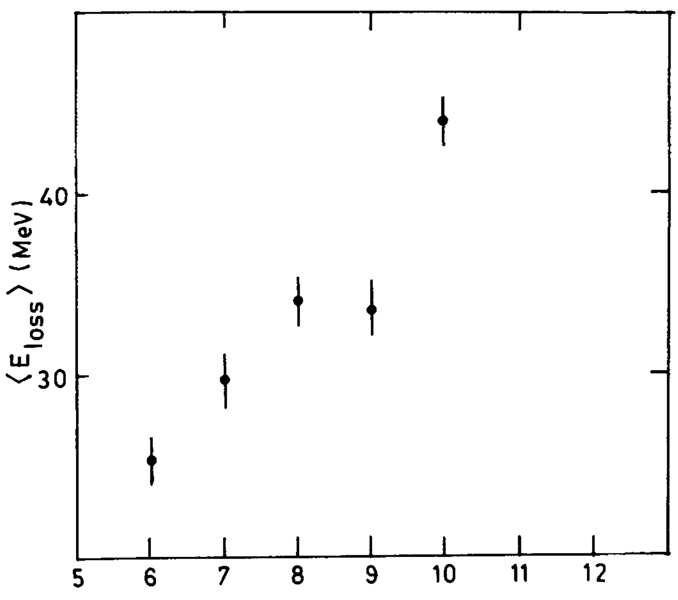

Figure 5. Variation of average energy loss with charge transfer from projectile nucleus.

a fully relaxed reaction mechanism such as deep inelastic or fission process giving rise to such events.

The angular distributions are seen to peak around 50 to 52°. The grazing angle for the reaction is given by

$$\Theta_g = 2\sin^{-1}(1/\varepsilon_g),$$

where $\varepsilon_g = r_g/a_0 - 1$, $a_0 = Z_P Z_T e^2/2E$, $r_g = r_B - \delta$.

In the above, Z_p, Z_T are the projectile, and target charges and E is the c.m. bombarding energy, r_B is the Coulomb barrier radius and $\delta \approx 0{\cdot}75$ fm. Θ_g was calculated to be about 49° for the $^{32}S + ^{27}Al$ reaction at 130 MeV. The angular distributions of the outgoing products are seen to be peaked at angles around the grazing angle, which establishes the peripheral nature of reaction contributing to the observed products. A typical angular distribution for $Z = 6$ products is shown in figure 4. Assuming two-body kinematics, the average kinetic energy loss $\langle E_{loss} \rangle$ could be derived from the measured energy spectra for different reaction channels. Figure 5 shows the variation of $\langle E_{loss} \rangle$ with the amount of the charge transfer (ΔZ) from the projectile nucleus. It is seen that with increasing charge or mass transfer during the collision, there is higher kinetic energy loss from the system.

Another way to examine the energetics of the reaction is to study the average kinetic energy with the product charge as shown in figure 6. This can be compared with the Coulomb energy of the dinuclear complex at the point of separation. The dashed line in figure 6 corresponds to the Coulomb energy of the product pair assuming them to be two touching spheres. It is seen that the observed kinetic energies are much lower than those calculated for the touching sphere configuration. The centre-to-centre distance, R_D for different charge pairs, are calculated by the liquid drop expression given by Myers and Swiatecki [10] lies in the range of 6·6 to 6·8 fm. The average kinetic energies are well reproduced using the values of R_D to be 9·4 fm, which would correspond to a deformed shape of the interacting nuclei at the time of separation. It is interesting to note that the grazing radial distance of the reaction is also at $r_B \approx 9{\cdot}4$ fm, which matches with the separation distance required to explain

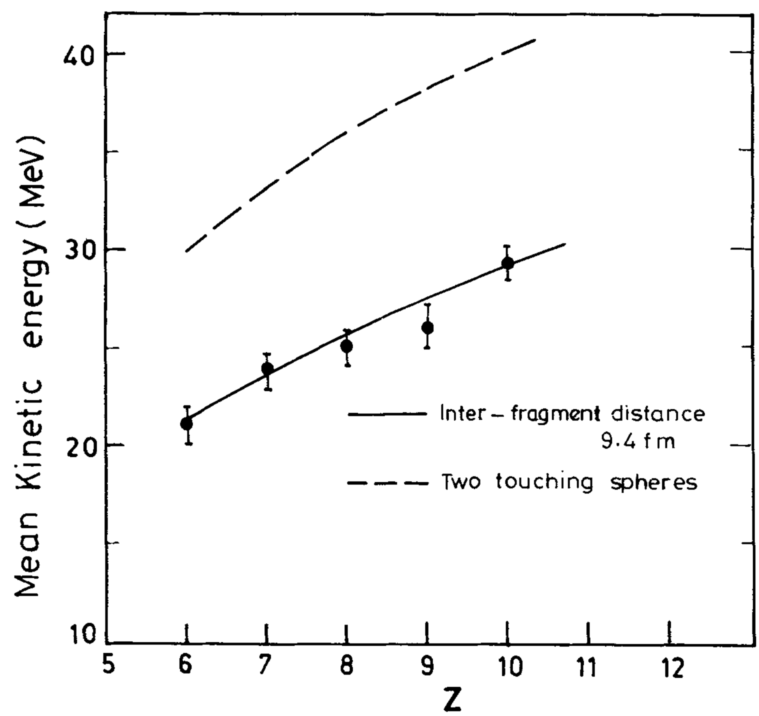

Figure 6. Variation of average kinetic energy with the charge of ejectile fragments.

the observed kinetic energies. One may therefore, conclude that in the $^{32}S + ^{27}Al$ reaction, at the grazing radial distance the kinetic energy is completely damped, and large mass/charge transfers take place leading to fully relaxed deep-inelastic processes. The grazing angular momentum for this system is calculated to be of the order of $40\hbar$. The exit shapes for the deep inelastic reactions correspond to highly stretched scission configurations of the dinuclear complex. The present results are complementary to the earlier observations of large spin induced deformations [6, 8] of the compound system formed in the $^{32}S + ^{27}Al$ reaction at similar bombarding energies.

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