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IDENTIFICATION OF COMPLETE CHARGE TRANSFER REACTIONS FOR ^{20}Ne + ^{197}Au WITH A 4π DETECTOR

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Abstract:

A charged-particle detector with 4π solid angle has been constructed and used for the identification of transfer and breakup components in the reactions of ^{20}Ne+Au at 11 and 17 MeV per nucleon. Significant cross sections are observed for the transfer of large amounts of charge. The general characteristics of products from transfer and breakup reactions are shown to be similar.

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The inclusive products of heavy-ion reactions at bombarding energies above 10 MeV per nucleon in general result from several competing mechanisms.[1] Experimental methods that isolate and identify one or more of these mechanisms are able to make important contributions to the understanding of heavy-ion reactions. To illustrate how the new experimental method reported here may be applied, consider the inclusive reaction $^{20}Ne + ^{197}Au \rightarrow ^{12}C + X$. The ^{12}C ejectiles at forward angles might be produced by any of the following mechanisms: (i) transfer leading to a bound state of the ejectile: (^{20}Ne, ^{12}C); (ii) complete charge transfer followed by neutron decay: (^{20}Ne,$^{13}C^*$), $^{13}C^* \rightarrow ^{12}C + n$; (iii) transfer followed by charged-particle decay: (^{20}Ne,$^{16}O^*$), $^{16}O^* \rightarrow ^{12}C + \alpha$; (iv) inelastic scattering followed by sequential decay: (^{20}Ne,$^{20}Ne^*$), $^{20}Ne^* \rightarrow ^{12}C+2\alpha$; (v) direct fragmentation: $^{20}Ne \rightarrow ^{12}C + ^{8}Be$.

The last three mechanisms produce at least one additional light charged particle, normally energetic and kinematically correlated with the projectile-like fragment. The excited target-like nucleus is not detected; the momentum transfer is too low for it to escape the target with any appreciable kinetic energy. Furthermore, since the target is heavy, its statistical decay is dominated by fission and/or neutron and gamma-ray emission. A detector that observes the associated light charged particles in coincidence with a projectile-like fragment, but that is insensitive to fission fragments, neutrons and gamma rays, can thus discriminate mechanisms such as (iii) - (v) from (i) and (ii). We refer to the former loosely as breakup reactions and to the latter as complete

charge transfer reactions. This Letter describes the first application, for low and intermediate bombarding energies, of a 4π electronic charged-particle detector, the "Plastic Box", to distinguish transfer and breakup reactions.

The Plastic Box consists of a cubical array of 20 cm x 20 cm scintillators, each side having independent inner (A) and outer (B) scintillator elements. The beam traverses the cube, entering through a small hole in a rear wall; a slot in a forward wall allows both the beam to exit and the heavy-ion telescopes to view the target. Two additional walls located downstream serve to back up the telescopes and to reduce the inactive solid angle around 0° to less than 1 msr. The scintillators are thin (1 mm) to minimize the registration of neutrons and gamma rays. The use of two elements permits corrections for the detection of neutral particles by monitoring events of the type $\overline{A}\cdot B$. The thresholds for protons and alpha particles were typically 2 MeV and 8 MeV, respectively. Fission fragments were stopped in the thin aluminized mylar wrapping of the scintillators.

Related experimental methods for studying transfer and breakup are a) a small streamer chamber,[1] which records the associated charged-particle multiplicity on photographic film, b) the neutron ball,[2] which measures energy deposition in the target via the total neutron multiplicity, and c) coincidences with X-rays from the target-like nucleus.[3] These methods are, in fact, complementary in the quantities they determine. While the present detector system is most similar in principle to the streamer chamber, the use of electronic scintillation

detectors affords some particle identification and energy measurement for the light particles and a thousand-fold increase in data rate. The absence of a gas and exit windows results in much better energy resolution for the projectile-like fragment. Since it is known[1] that the associated multiplicity for peripheral reactions at bombarding energies less than 20 MeV per nucleon is typically one and seldom exceeds two, the relatively small number of elements (six) in this detector is not a serious limitation.

We have studied reactions of the system $^{20}Ne + ^{197}Au$ at 220 and 341 MeV with this detector; measurements were made at $\Theta_{lab} = 15^{o}$ and 20° at the lower energy, and at 8° and 16° at the higher energy. At each energy and angle, measurements were also made with a carbon target; comparison of results from the 5.3 mg/cm^2 Au target with those for the C target demonstrated that carbon contamination on the gold target posed no problem for the reaction products of interest here. A more detailed description of the detector, the procedures for establishing thresholds and the data collection will be reported elsewhere.[4]

Fig. 1 shows the relative and absolute magnitudes of complete charge transfer reactions at both 220 and at 341 MeV. The fraction of complete charge transfer events, which is defined as $N(Z,0)/\sum_{S\geqslant 0} N(Z,S)$, where S is the number of scintillator walls detecting a charged particle, diminishes with increasing bombarding energy and, in general, with increasing transferred charge ΔZ. Note that the absolute differential cross sections for transfer in Fig. 1b are comparable at the two energies. (From the range of angles measured it appears that this is true for angle-integrated cross sections as well.) We conclude that the larger inclusive cross

sections for producing lighter elements such as Be and B at higher bombarding energies[5] arise from projectile breakup processes, i.e., from events with $S \geqslant 1$. The most important feature of these data, however, is that substantial probability ($\gtrsim 17\%$) persists for transfer reactions with ΔZ at least as large as 7, i.e., for the transfer of ~14 amu, even at a bombarding energy of 17 MeV per nucleon. The 4π solid angle of the plastic box greatly facilitates the observation of this class of events.

Energy spectra for ^{16}O and ^{17}O ejectiles are shown, as an example, in Figs. 2a and 2b for inclusive, S=0, and S=1 reactions. The shapes of the energy spectra for the transfer and breakup reactions in the oxygen isotopes differ in detail. The transfer component lies at somewhat higher energies and, at this particular angle, appears to be narrower in width. These characteristics may be analyzed and compared with predictions of reaction models.[6,7] It is more useful in this Letter, however, to examine the characteristics of the different reaction products in a general way. This is done by determining the first three moments of each spectrum, the mean $\langle E \rangle$, the standard deviation $\sigma = (\langle E^2 \rangle - \langle E \rangle^2)^{1/2}$ and the skewness γ_1, defined here by $\gamma_1 = \langle (E - \langle E \rangle)^3 \rangle / \sigma^3$. The advantage of this procedure is that it involves neither arbitrary decisions on which portions of the spectrum to emphasize nor assumptions about the reaction mechanism.

The values of the moments are presented in Fig. 3. As in the case of the oxygen isotopes, the mean energy for the S=1 component is lower. This is observed at 8° as well and reflects the loss of kinetic energy associated with the liberation of an additional particle.

The energy widths (Fig. 3b) show a more complex behavior. The transfer (S=0) component is narrower than the breakup (S=1) component for masses close to the projectile (as predicted in Ref. 6), but for the lighter ejectiles the opposite is true. At 8°, however, the transfer component is broader than the breakup component for all ejectiles except fluorine. The largest widths at 8° occur for the oxygen isotopes, whereas at 16° the carbon and nitrogen isotopes are the broadest. It is clear that the second moment shows a strong angle dependence.

The skewness (Fig. 3c) indicates a trend toward spectra that are symmetric about the mean as more charge is lost from the projectile. (A spectrum that is symmetric about the mean has a skewness of zero; a low energy tail gives a negative skewness, as seen in Fig. 2). With few exceptions, the breakup spectra are more symmetric than the corresponding transfer spectra.

An interesting and striking feature of this global comparison in Fig. 3 is the overall similarity of the trends shown by the moments for transfer and breakup as a function of fragment mass. This feature is present at all angles and at both bombarding energies. An explanation for this similarity is suggested directly by a closer examination of the information from the scintillators. The thicknesses of the scintillators are such that alpha particles and protons with beam velocity normally will penetrate the first element of the wall and thus can be identified. Analysis of the scintillator signals shows that most of the associated charged particles are alpha particles or protons. This implies that when,

for example, ^{7}Be is detected with S=1 either four or five units of charge were still captured by the target. The most likely process responsible for this is transfer followed by charged-particle decay of the primary beam-like product (item iii above).[8] This subsequent emission of a light charged particle apparently does not alter drastically the gross characteristics of the secondary products.

In summary, we have constructed a charged-particle detector having nearly 4π solid angle. It is able to determine the absence or presence of additional charged particles associated with a given nucleus observed in a trigger detector. The use of this device has been illustrated with a study of the reaction ^{20}Ne + Au. The results of this study have shown that:

1) The quasi-elastic reaction products more than two charge units removed from the projectile are frequently accompanied by one or more additional charged particles.

2) Significant cross section still exists, however, for the complete transfer of large amounts of charge from the projectile to the target, leaving the projectile remnant in a particle-bound state.

3) The moments of the transfer and breakup spectra, while exhibiting some differences, behave in a remarkably similar manner.

4) The associated charged particles in the case of breakup are predominantly alpha particles or protons, and not large fragments. These results provide further evidence in favor of the importance of two-body transfer reactions in the <u>primary</u> stage of the reaction, even for energies up to 20 MeV per nucleon.[1,5,8]

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References

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1. M. J. Murphy et. al., Phys. Lett. 120B, 319 (1983).
2. U. Jahnke et. al., Phys. Rev. Lett. 50, 1246 (1983).
3. H. W. Wilschut et. al., Phys. Lett. 123B, 173 (1983).
4. K. Van Bibber et. al., to be published.
5. Ch. Egelhaaf et. al., Nucl. Phys. A405, 397 (1983).
6. K. W. McVoy and M. C. Nemes, Z. Physik, A295, 177 (1980).

7. P. J. Siemens et. al., Phys. Lett. 36B, 24 (1971). D. M. Brink, Phys. Lett. 40B, 37 (1972). T. Udagawa et. al., Phys. Lett. 118B, 45 (1982). B. G. Harvey and M. J. Murphy, Phys. Lett. in press.

8. H. Homeyer et. al., Phys. Rev. C 26, 1335 (1982). R. K. Bhowmik et. al., Nucl. Phys. A390, 117 (1982).

Figure Captions

1a. The probability for complete charge transfer, i.e., that no wall detects a charged particle when an ejectile of atomic number Z is observed in the solid state telescope.

1b. Absolute differential cross sections for complete charge transfer (S=0). The uncertainty is ± 15%.

2. Energy spectra of oxygen ions produced at 341 MeV and $\Theta = 16^{o}$ for inclusive reactions (heavy line), complete charge transfer (fine line) and for S=1 (broken line) a) for ^{16}O; b) for ^{17}O.

3. Moments of the energy spectra for ejectiles observed in the telescope. Solid points are for spectra with S=1, open points for S=0. a) The mean energy; b) the standard deviation; and c) the skewness.

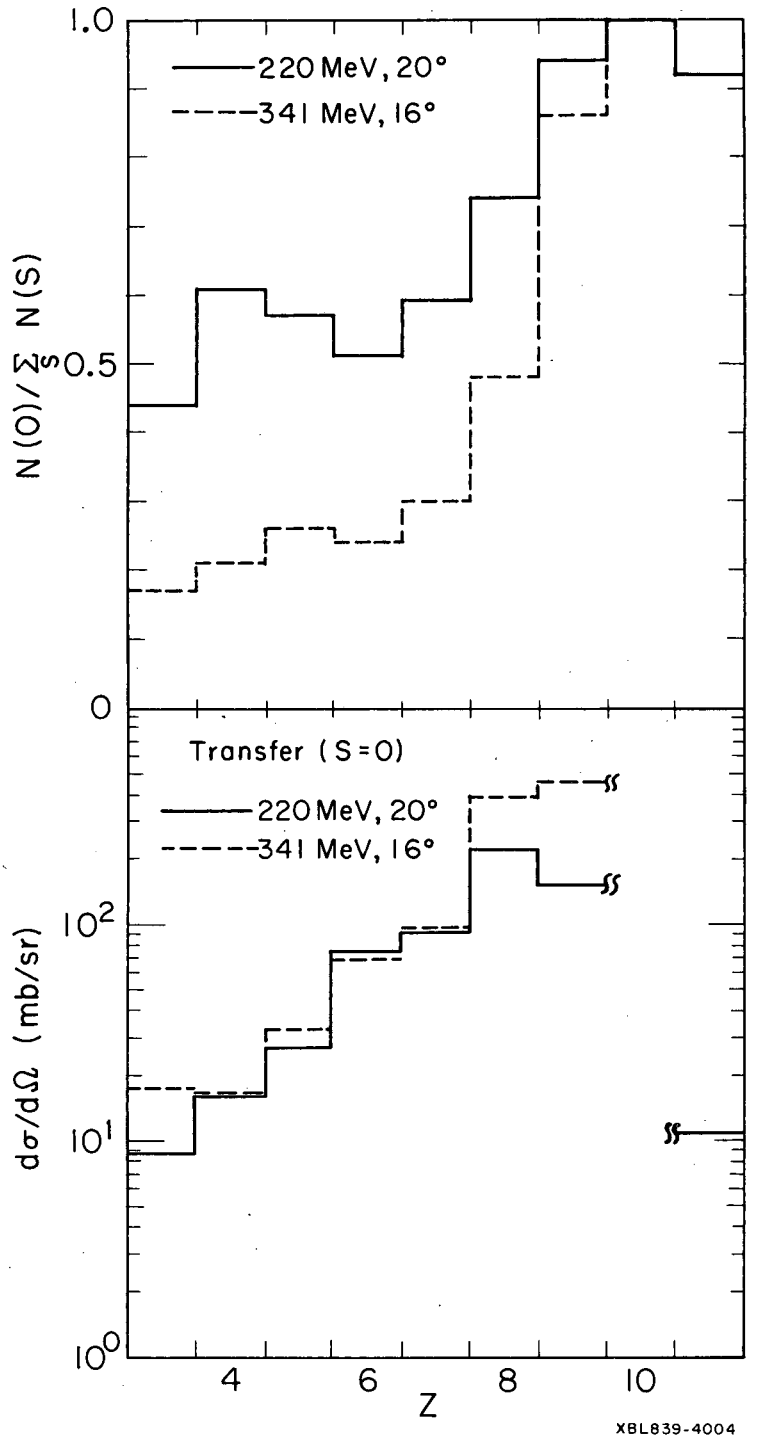
1.0
0.5
0
N(O)/Σ N(S)
220 MeV, 20°
341 MeV, 16°
Transfer (S=0)
220 MeV, 20°
341 MeV, 16°
10^2
10^1
10^0
dσ/dΩ (mb/sr)
4
6
8
10
Z
XBL839-4004

Fig. 1

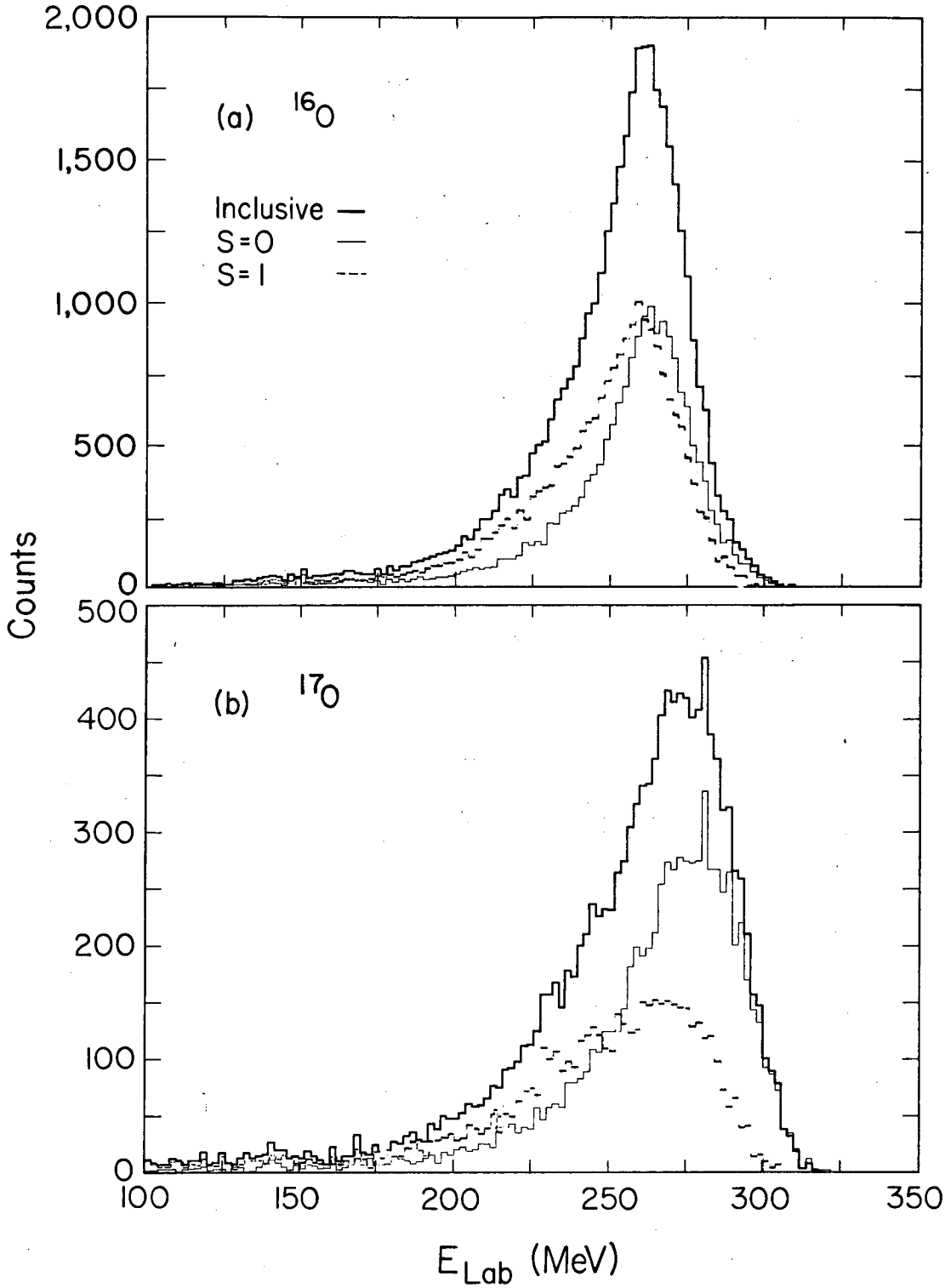

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Fig. 2

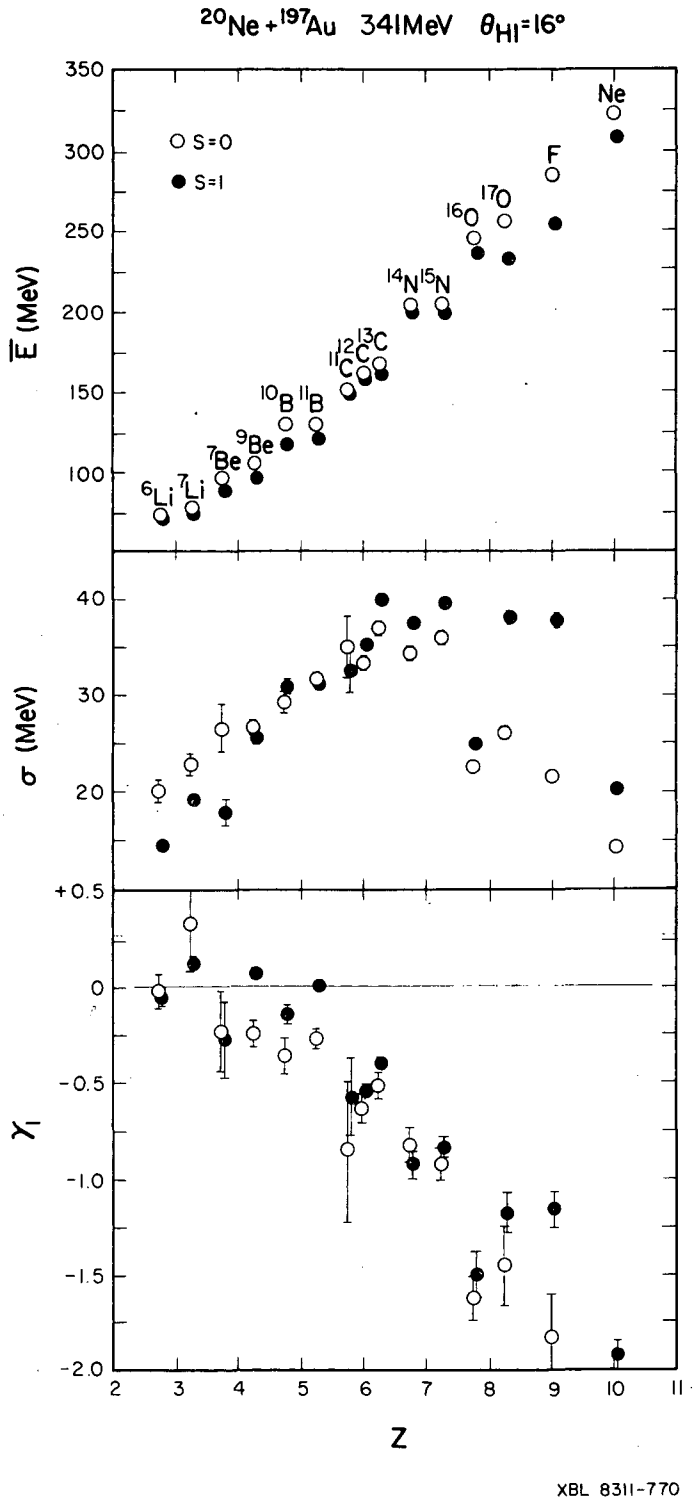
^{20}Ne + ^{197}Au 341MeV θ_{HI}=16°
S=0
S=1
$\bar{E}$ (MeV)
σ (MeV)
χ_1
Z
^{6}Li
^{7}Li
^{7}Be
^{9}Be
^{10}B
^{11}B
^{11}C
^{12}C
^{13}C
^{14}N
^{15}N
^{16}O
^{17}O
F
Ne
XBL 8311-770

Fig. 3

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