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Publication Date
1978-10-01

Submitted to Zeitschrift Physics

LBL-8303
Preprint c.2

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October 1978

Prepared for the U. S. Department of Energy
under Contract W-7405-ENG-48

A SCENARIO FOR THE 220-MeV $^{40}Ar + {}^{238}U$ REACTION*

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ABSTRACT

Singles and coincidence charge distributions are combined to illustrate the mechanism for the 220-MeV $^{40}Ar + {}^{238}U$ reaction. It is found that the apparent peak in the coincidence fragment distribution corresponding to $Z = 82$ $(A = 208)$ can be explained in terms of the fissionability of the target-like fragments produced in deep-inelastic collisions rather than as a manifestation of shell effects in compound-nucleus fission, as has been postulated for a similar system.

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*Research supported by the U.S. Department of Energy.

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Recently Kalpakchieva et al [1] have performed coincidence measurements for the reaction $^{40}Ar + ^{243}Am$. Relying on two-body kinematics they obtained mass distributions at several energies. At bombarding energies close to the Coulomb barrier they observed an asymmetry in the mass distributions which rapidly vanished at higher bombarding energies. They attributed this phenomenon to the effect of the shell closure in the ^{208}Pb region on the fission of the compound nucleus $^{283}[113]$. The formation of such a compound nucleus with appreciable cross section would indeed be of interest as evidence of superheavy element formation and also surprising in view of the by now well known fusion barriers which should inhibit compound nucleus formation for this system [2]. However, a mass distribution derived solely on the basis of a two-body coincidence measurement for such a heavy system does not provide a very complete picture of the reaction mechanism. This is because the coincidence measurement can be distorted by the absence of heavy fragments which have undergone sequential fission [3,4,5]. Heavy fragments produced in both quasi-elastic and deep-inelastic collisions [6] readily undergo fission due to the low fission barriers of these heavy nuclei.

In this paper we seek to better elucidate the reaction mechanism for a similar system, 220-MeV $^{40}Ar + ^{238}U$, by measuring both the singles and coincidence distributions with a technique that does not rely on two-body kinematics for the identification of fragments. We find, as in the recoil range study of Otto et al [7] and the radiochemical studies of de Saint-Simon et al [8], that the reaction mechanism is probably a quasi-elastic or deep-inelastic collision [6]. Further, we seek to demonstrate here that the specific structure observed by Kalpakchieva et al [1] near A = 208 in the coincidence mass distribution can be attributed to the reduced fission barriers for the sequential fission of product masses greater than 208.

The experiment employed thin UF_4 targets (~350 μg/cm^2) backed by ~200 μg/cm of aluminum. Products arising from the reactions of ^{40}Ar with F or the Al backing were not observed and therefore did not constitute a problem since these products are either of low atomic number or kinematically confined to forward angles. The ^{40}Ar beam was extracted from the Lawrence Berkeley Laboratory 88-Inch Cyclotron. A gas-ΔE solid-state-E telescope [9] was utilized to identify the atomic number of the light fragment (Z). This telescope provided the identification of individual Z's up to approximately Z = 40. The energy and angle of the coincident heavy fragments (Z_H) were measured with a one-dimensional ORTEC, solid-state, position-sensitive detector (PSD). This detector had an angular acceptance of 30° in plane and 5.5° out of plane, providing sufficient out-of-plane acceptance to detect a large fraction of the binary events. To compensate for undetected out-of-plane events the coincidence elastic events were normalized to the singles elastic peak. The overall coincidence efficiency was about 40%.

Figure 1 presents both coincidence and singles charge distributions at θ_{tel} = 50° lab (θ_{PSD} = 70° lab) for non-elastic (i.e. relaxed plus quasi-elastic [6]) events after normalization. For most Z's we observed the complete in-plane correlation. However, some events in the tail of the correlation function for Z > 34 and Z < 19 were outside the acceptance angle of the PSD. These data have therefore been corrected by assuming a symmetric distribution in θ as was observed for $20 \leqslant Z \leqslant 33$ where the PSD spanned the complete correlation function. In general we estimate that the error due to this correction is small (~a few percent).

If only binary processes contributed to this reaction (i.e. deep-inelastic scattering and compound-nucleus fission), there would be no differences between the singles and coincidence distributions. However, we see in Fig. 1 that the coincidence yield (which is very similar to the yield observed by Kalpakchieva et al [1]) is significantly lower than the singles yield for products with $Z < 28$ or $Z > 34$. These discrepancies between the singles and coincidence spectra can be explained in a straightforward manner. For reactions leading to $Z \leqslant 28$ (i.e. $Z_H > 82$), decreased fission barriers should enhance sequential fission [5] of the heavy fragment and therefore diminish the observed yield of coincidence events. This is exactly what is observed, i.e., below $Z = 28$ in Fig. 1 the yield of coincident binary events decreases relative to the singles yield, giving the appearance of a shoulder in the coincidence distribution near $Z = 28$ (or $Z_H = 82$, or $A \cong 70$, $A_H = 208$). Similarly, the secondary fission fragments should produce an enhancement [3] of the singles yield over the binary events which peaks near $Z \cong 46$ (i.e. $Z_H/2$). Although we do not identify fragments as heavy as $Z = 46$, certainly some evidence for this enhancement is also observed in the region above $Z = 34$ in Fig. 1. As a final note regarding Fig. 1, it is worthwhile to point out the rapidly decreasing singles yield for $Z < 18$. This trend perhaps dramatizes the unlikelihood for this system to reach a compound nucleus configuration during the collision.

We have also made some preliminary angular distribution measurements of the light fragments. For the projectile Z they are side-peaked at about 110° but give way to a $1/\sin\theta$ distribution within several Z's of the projectile, a feature which is rather typical of deep-inelastic collisions at low bombarding energies [10]. These angular distributions, together with the above comments on Fig. 1, therefore support the scenario suggested in Refs. [6] and [8], namely, that of a dominately quasi-elastic or deep-inelastic (rather than fusion-fission) process. In this work we reconcile this scenario with the data of Ref. [1] by demonstrating the important influence of sequential fission on the coincidence mass distribution.

In conclusion it seems clear that for reactions like 220-MeV $^{40}_{18}Ar + ^{238}_{92}U$ there is no need to suggest asymmetric fission of the $^{278}110$ compound nucleus to explain the appearance at low energies of an asymmetry in the binary fragment yield. Nevertheless, the interpretation of this peak as due to the effect of the $Z = 82$ closed shell, which was suggested in Ref. [1], is in some sense correct, although as we have seen, the effect of the shell is probably to decrease the sequential fission of the target-like fragment rather than to enhance the compound-nucleus fission yield. The fact that the mass or charge distributions rapidly become symmetric at higher bombarding energies is a natural consequence of the increasing yield [8] from sequential and compound-nucleus fission and the decreasing importance of shell effects as the excitation energy available to the system increases.

The $^{40}Ar + ^{238}U$ system is also of interest in the framework of the diffusion model, and in particular, the possibility of diffusion as a mechanism for compound nucleus formation. Therefore in future experiments we plan to acquire more detailed charge and angular distributions so that quantitative comparisons with theoretical predictions can be made.

References

[1] Kalpakchieva,R., Oganessian,Yu.Ts., Penionzhkevich,Yu.E., and Sodan,H.: Z. Physik A283, 253 (1977).

[2] Bass,R., Nucl. Phys. A231, 45 (1974).

[3] Russo,P., Schmitt,R.P., Wozniak,G.J., Cauvin,B., Glässel,P., Jared,R.C., and Moretto,L.G.: Phys. Lett. 67B, 155 (1977).

[4] Dyer,P., Puigh,R.J., Vandenbosch,R., Thomas,T.D., and Zisman,M.S.: Phys. Rev. Lett. 39, 392 (1977).

[5] Wozniak,G.J., Schmitt,R.P., Glässel,P., Jared,R.C., Bizard,G., and Moretto,L.G.: Phys. Rev. Lett. 40, 1436 (1978).

[6] Moretto,L.G. and Schmitt,R.: J. de Physique 37, C5, 109 (1976), and references therein.

[7] Otto,R.J., Morrissey,D.J., Seaborg,G.T., Loveland,W.D.: Z. Physik A287, 97 (1978).

[8] de Saint-Simon,M., Otto,R.J., and Seaborg,G.T.: Phys. Rev. C18, 1651 (1978).

[9] Fowler,M.M. and Jared,R.C.: Nucl. Instr. 124, 341 (1975).

[10] Mathews,G.J., Wozniak,G.J., Schmitt,R.P., and Moretto,L.G.: Z. Physik A283, 247 (1977).

Figure Caption

Fig. 1. Singles and binary-coincidence charge distributions for the 220-MeV $^{40}Ar + ^{238}U$ reaction at 50 degrees in the lab. The differences in the two distributions below $Z = 28$ and above $Z = 34$ are attributed to secondary fission of the target-like fragment. The errors on the coincidence distribution include both a statistical error and an uncertainty in the correction for events outside the angular acceptance of the PSD.

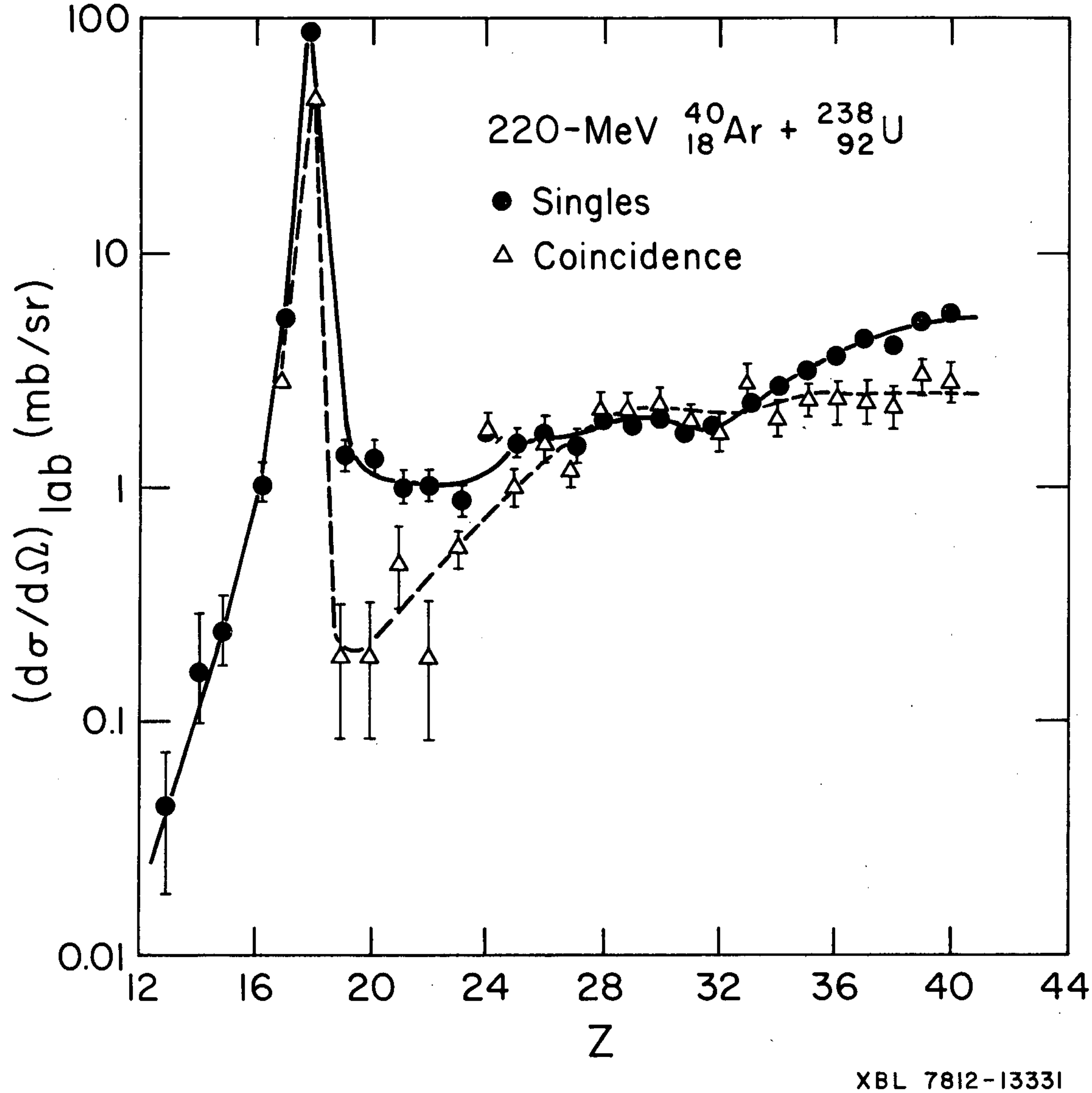
220-MeV $^{40}_{18}Ar + ^{238}_{92}U$
Singles
Coincidence
$(d\sigma/d\Omega)_{lab}$ (mb/sr)
100
10
1
0.1
0.01
12
16
20
24
28
32
36
40
44
Z
XBL 7812-13331

Fig. 1

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

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