COMPLEX FRAGMENT EMISSION IN THE p + Ag REACTION AT 160 MeV

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Studies of complex fragments emitted in the reaction of 200-500 MeV protons with silver nuclei have indicated a predominantly non-equilibrium formation mechanism[1]. In order to examine the extent to which this behavior persists at lower energies, intermediate-mass fragment yields (IMF: $3 \leq Z \lesssim 14$) have been measured for the p + ^{nat}Ag reaction at 160 MeV. Natural silver targets of thickness 1.3 mg/cm^2 were bombarded with 160 MeV protons. Fragments were detected with an axial gas-ionization chamber/310 μm-thick silicon surface-barrier detector telescope. At forward angles the fragment energy spectra are Maxwellian in shape, with momenta extending up to 2.5 times the beam momentum; these evolve toward more Gaussian shapes at larger angles and for heavier fragments. Coulomb peaks in the spectra were in general agreement with those predicted by fission-fragment kinetic-energy-release systematics.

For all atomic numbers the angular distributions fall off exponentially with increasing angle. As the fragment Z increases, the angular dependence of the yields becomes increasingly isotropic, with forward-to-backward ratios decreasing from $\sim$ 7 for Li and Be to $\sim$ 2 for F and Ne ejectiles. In Fig. 1 a rapidity plot of the invariant cross section contours in the longitudinal versus transverse momentum plane ($p_{||}$ vs. $p_{\perp}$) is shown for carbon fragments. This figure is typical of all IMF products. Constant cross-section loci (semi-circles) are drawn about momentum values corresponding to emission from an isotropic source moving with an average velocity β=0.0056 (β_{cn}=0.0054). It is observed that the backward-angle data fall on these loci relatively well, whereas at forward angles the data are skewed toward much larger momenta. Thus, we infer a two-component source for these fragments, one of statistical nature that is largely responsible for fragments at back angles and one associated with a fast, precompound mechanism that accounts for most of the forward-angle yield. The relative ratio of equilibrated-to-non-equilibrated components increases with fragment charge. The interpretation is consistent with ^{3}He and heavy-ion data at intermediate energies[2], but does not agree with the observation of Ref. 1 for higher-energy protons.

Based on the results of Fig. 1, a two-component moving source fit has been applied to these data, employing a statistical emission model for the equilibrated events[3] (EQ) and a Maxwellian distribution for the non-equilibrated component (NEQ). An excellent fit to the energy spectra for all Z values and angles is found with values of $\beta_{EQ} = 0.0054$, T_{EQ} = 3.4 MeV=T_{cn}, $\beta_{NEQ} = 0.04$ and T_{NEQ} = 9.1 MeV.

Fig. 2(a) shows the cross sections for the equilibrated component of the IMF yield as a function of fragment Z-value. These results are compared with the statistical decay model of Gomez del Campo[4], shown by the histogram. A value of $J_{max} = 5\hbar$ for the maximum angular momentum provides a good description of the data. The strong dependence of

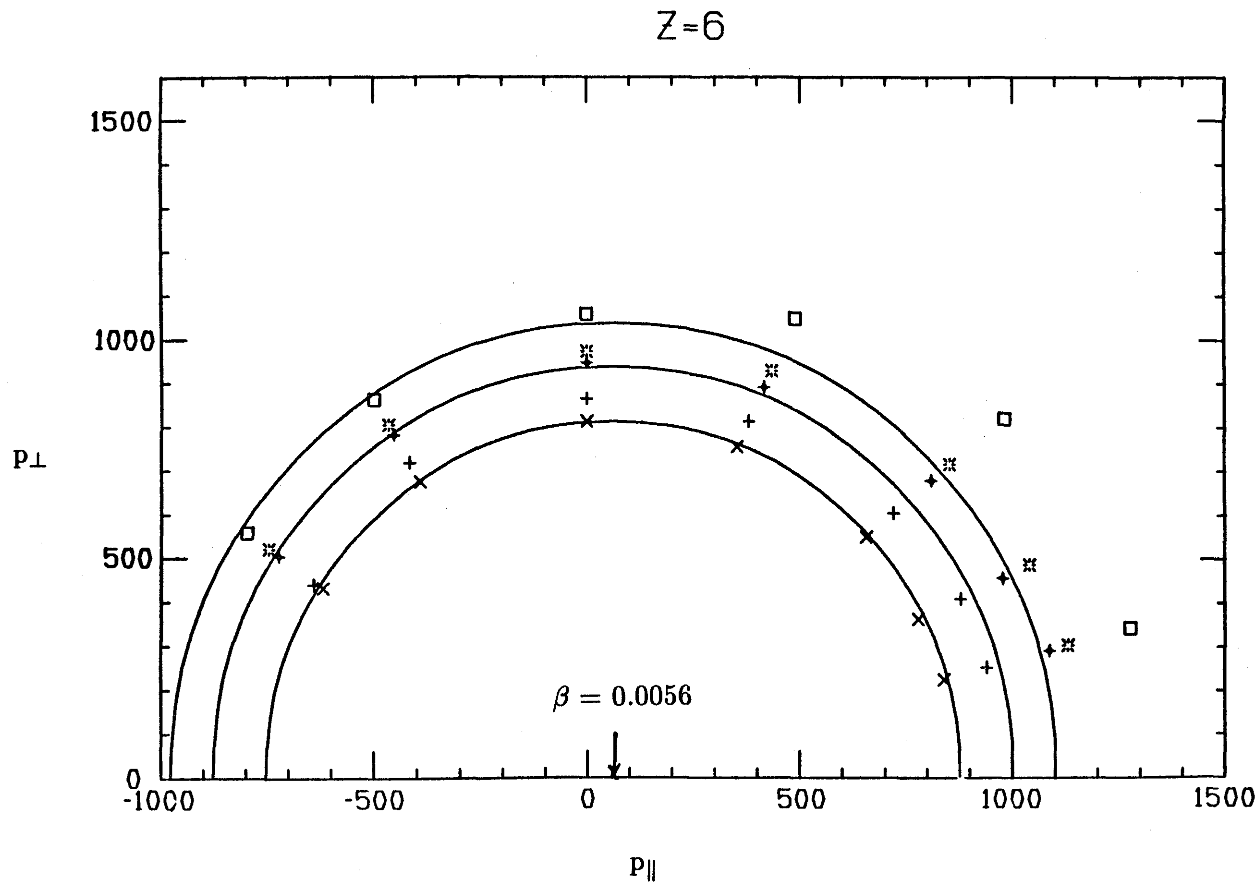

Figure 1. Invariant cross section in longitudinal versus transverse momentum plane for carbon fragments emitted from the 160-MeV p + ^{nat}Ag reaction. Symbols represent constant cross-section contours (x represents the Coulomb peak at each angle). Loci are constant cross-section contours for an isotropic source moving with velocity B = 0.0056 as determined from fits with two-component source, as described in the text.

IMF yield on angular momentum is demonstrated by the much poorer fits obtained with J_{max} = 4 and 6$\hbar$.

Fig. 2(b) presents the cross sections for IMF formation as a function of fragment Z. The yields follow a power-law decrease, $\sigma(Z) \propto Z^{-\tau}$, where $\tau = 4.9$ provides the best fit to the data. This value is much larger than that observed at higher proton energies[1,5]. These data are compared with the accreting source model of Friedman and Lynch[6], shown by the solid line in Fig. 2(b) and normalized to the Z = 7 yield. This model, which permits fragment emission at various stages in the time evolution of the equilibration process, provides a satisfactory fit to the data.

1. R.E.L. Green, et al., Phys. Rev. C **29**, 1806 (1984); Phys. Rev. C **22**, 1594 (1980).
2. K. Kwiatkowski et al., Phys. Lett. B **171**, 41 (1986).

3. L.G. Moretto, Nucl. Phys. A **247**, 211 (1975).
4. J. Gomez del Campo, Zeit. für Physik **A326**, 335 (1987).
5. J.E. Finn, et al., Phys. Rev. Lett. **49**, 1321 (1982).
6. W.A. Friedman and W.G. Lynch, Phys. Rev. C **28**, 950 (1983); C **28**, 16 (1983).

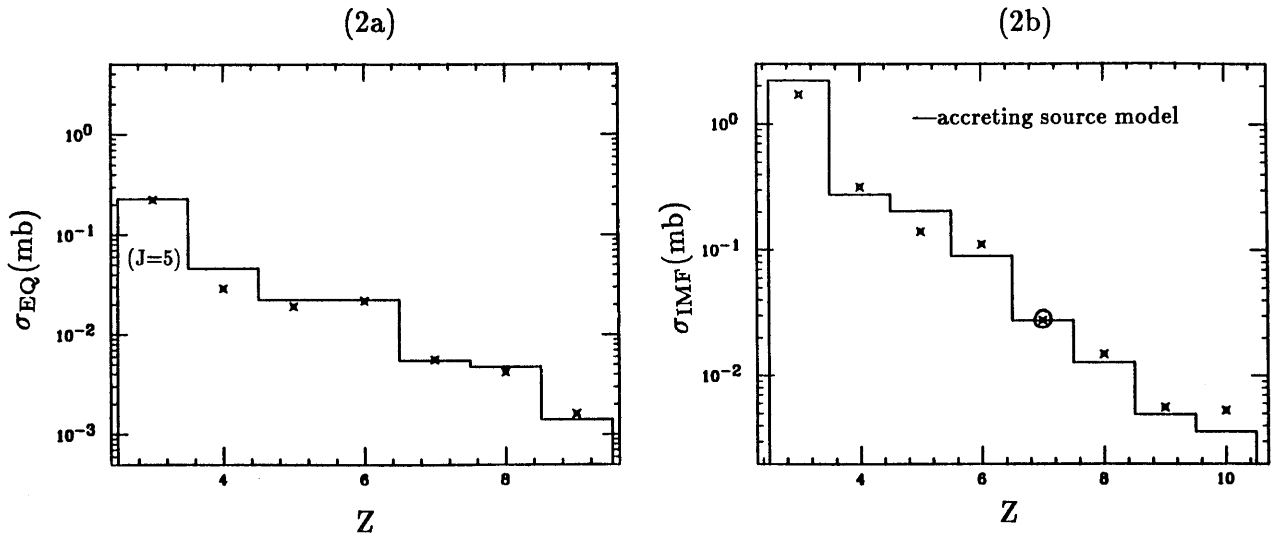

Figure 2. (a): Cross sections for equilibrated IMFs as a function of fragment Z. Solid line is for statistical decay model of Ref. 4 with $J_{max} = 5$. (b): Total cross sections for IMFs as a function of fragment Z. Solid line is prediction of accreting source model (Ref. 6.), normalized to $Z = 7$.