Mass and Excitation Energy Dependence of Gamma Ray Multiplicities in Heavy Ion Induced Fission

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It is well documented that considerable angular momentum is imparted to the fragments resulting from fission. This angular momentum results from the excitation of various collective modes plus any additional Coulomb torque exerted by the nascent fragments [1,2]. While a number of studies have been performed to investigate fission fragment spins through measurements of their gamma ray multiplicities [3-5], these investigations have only revealed the gross features of the multiplicities. We have recently performed experiments with considerably higher mass resolution than previously achieved.

The vast majority of the work was conducted at Texas A&M. The systems ^{12}C + ^{238}U, ^{18}O + ^{208}Pb and ^{18}O + ^{232}Th were each studied at a variety of beam energies ranging from the Coulomb barrier to 12.MeV/u. Near barrier measurements of the ^{18}O + ^{208}Pb system were previously performed using the Catania tandem facility [6]. In the measurements, the gamma rays were detected with an array of six NaI detectors. Fission fragments were detected using the DEMAS-3 spectrometer [7], which consists of four large 2D position sensitive detectors and two thin start detectors. Fission fragment masses and total kinetic energies were obtained from kinematic reconstruction. The mass resolution was approximately 3 amu.

Figure 1 shows the multiplicities four the reaction ^{18}O + ^{208}Pb at five different beam energies. As previously hinted at [8], there is a definite correlation between the multiplicity and the shell structure of the fragment masses. What is surprising about these data is that the complex structure continues up to bombarding energies of 200 Mev. At first thought, one might expect any structure to be washed out due to pre- and post-neutron evaporation.

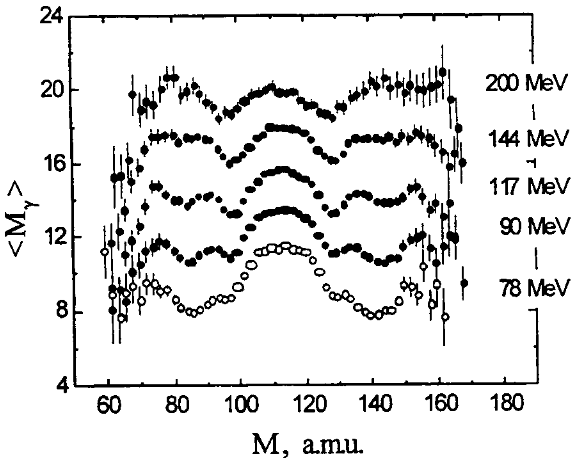

Figure 1. Gamma ray multiplicities for several reactions.

It is interesting to compare the data in Fig. 1 with the mean measured gamma ray energies for the same reaction. As observed in comparing Figs. 1&2, the maximum multiplicities are anticorrelated with the maximum gamma ray energies. As a point of interest, the product of the multiplicity and the mean energy is relatively flat as a function of mass asymmetry. This is expected since the total gamma energy should reflect the neutron binding energy plus any additional rotational energy.

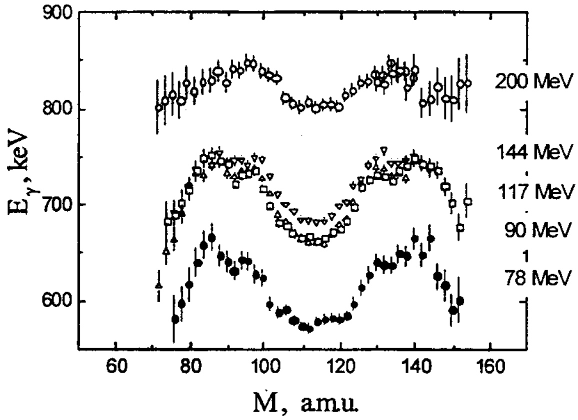

Figure 2. Mean gamma ray energies for several reactions.

The results illustrated above are not unique to the ^{18}O + ^{208}Pb system. The same tendencies are also observed in the other reactions. However, the minima in multiplicity shift in accord with the shells in the fragments. The mean energies remain in anticorrelation.

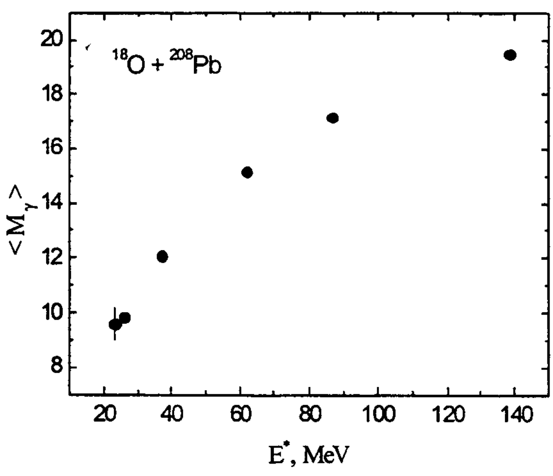

Figure 3. Multiplicities as a function of excitation energy.

The bombarding energy dependence of the multiplicity represents somewhat of a puzzlement. In Fig. 3, the results for the ^{18}O + ^{208}Pb system are shown. The multiplicities show a clear increase even up to 200 Mev incident energy. The same trend is observed for two more systems in Fig. 4. Collective mode model calculations would indeed predict a rise in the multiplicities with increasing temperature [2]. However, if these modes were excited in the vicinity of scission, one would expect pre-scission neutron emission to limit the degree of excitation, producing a saturation in the multiplicity. Why this saturation is not observed

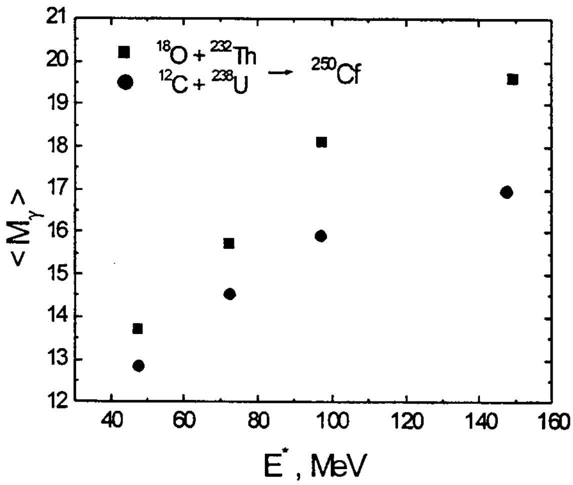

Figure 4. Multiplicities as a function of excitation energy for two systems.

needs further experimental observation. To be very speculative, it is possible that a significant fraction of the so-called pre-scission neutrons are actually emitted near scission without producing a noticable cooling effect. New experiments are underway to address this issue together with the investigation of fission phenomena in the heavy element domain.

References

[1] R. Nix and W. J. Swiatecki, Nucl. Phys. **A71**, 1 (1965).

[2] L. G. Moretto and R. P. Schmitt, Phys. Rev. C **21**, 204 (1980).

[3] R.P. Schmitt, G. Mouchaty and D.R. Haenni, Nucl. Phys. **A427**, 614 (1984).

[4] R. Bock, *et al.*, Nucl. Phys. **A388**, 332 (1982).

[5] B. B. Back, *et al.*, Phys. Rev. C **41**, 1495 (1990).

[6] A. Kelic, *et al.*, *Progress in Research*, 1998-1999, Cyclotron Institute, Texas A&M University, p.II-18.

[7] G. G. Chubarian, *et al.*, In Proc. of the Tours Symposium on Nuclear Physics III 1997, AIP, **425**, 189 (1987).

[8] R. P. Schmitt, G. Mouchaty, D. R. Haenni, and M. Tirion, Z. Phys. **A321**, 411 (1985).