SYSTEMATICS OF THE K X-RAY MULTIPLICITY FOR (Li,xn) PRODUCTS WITH 180 $\lesssim$ A $\lesssim$ 210

S.E. Vigdor, H.J. Karwowski*, T.G. Throwe, W.W. Jacobs, S. Kailas, P.P. Singh, and F. Soga
Indiana University Cyclotron Facility, Bloomington, Indiana 47405

As part of our program of measurements of the decay characteristics of compound nuclei formed at high angular momentum and high excitation in Li-induced fusion reactions,[1] we have developed a new technique for determining absolute total cross sections, σ_{xn}, for (heavy-ion, xn) reactions. The technique involves measurements of the mean multiplicity $\langle M_K \rangle$ of K X-rays emitted during the de-excitation cascades in the xn residual nuclides.[2] The X- rays arise from internal conversion during the γ-cascades, so that $\langle M_K \rangle$ is sensitive to the multipolarity and to the energy of the nuclear transitions through which the γ-decay proceeds. This sensitivity is of little consequence for the determination of σ_{xn}, but provides the opportunity to learn something about the structure of the populated residues as a side benefit. Our results to date, for (Li,xn) reactions with a variety of target nuclei and bombarding energies, suggest an intriguing systematic behavior of $\langle M_K \rangle$, and hence of the nuclear structure, in a mass region just below the N=126 shell closure.

In all the cases we have studied so far, we have found $1.0 \lesssim \langle M_K \rangle \lesssim 3.0$. It is not a trivial matter to account in detail for the origin of as many as three X-rays per cascade. We have already argued in ref. 2, on the basis of various experimental constraints, that in the neutron-poor Tl and Pb isotopes studied, approximately two K X-rays arise from a narrow region of spin ($12 \lesssim J \lesssim 20$) dominated by low-energy M1 transitions. (The probability of K-shell conversion per unit spin change is an order of magnitude greater for M1 than for E2 transitions in the Z ≃ 80 region.) Such a structure peculiarity might, of course, arise in a few anomalous cases from some accidental near-coincidence among various quasiparticle excitations, but the effect in our case appears to be no accident. This is illustrated by the compilation of our multiplicity measurements in Figs. 1 and 2.

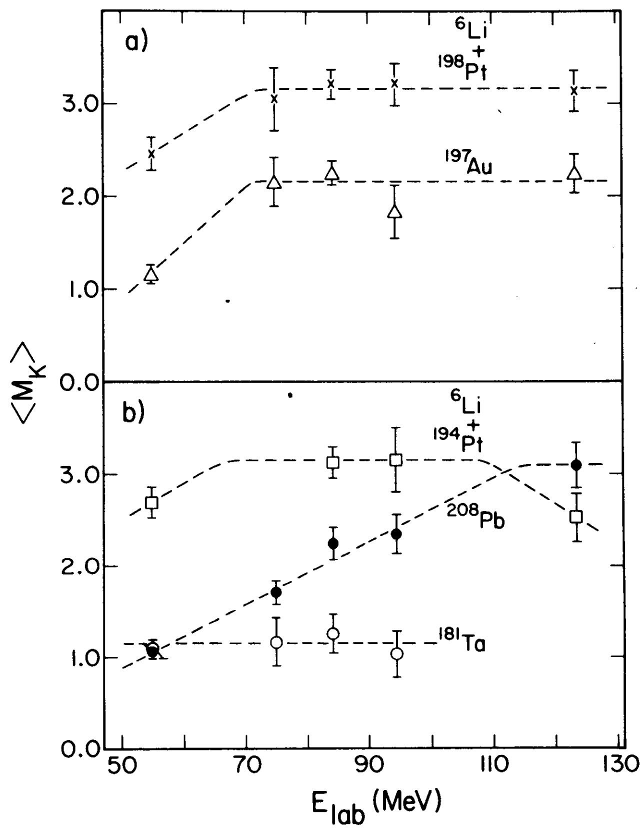

Figure 1. Measured K X-ray multiplicities for (^{6}Li,xn) reactions on five targets as a function of bombarding energy. The dashed curves are intended to guide the eye.

In Fig. 1(a) we observe a similar dependence on bombarding energy for ^{198}Pt(^{6}Li,xn) and ^{197}Au(^{6}Li,xn), with $\langle M_K \rangle$ remaining remarkably constant over the range from 75 to 124 MeV, despite significant changes over this range in the mass and spin distributions of the populated residues. The observed reduction in $\langle M_K \rangle$ for both targets at E_{lab} = 55 MeV is consistent with our expectation of a lower spin cutoff ($J \simeq 12$) on the region of highly converting transitions. In particular, we have evidence that the low-energy falloff is not associated with the change in neutron excess of the dominant residues between 55 and 75 MeV: a measurement for ^{7}Li + ^{197}Au at E_{lab} = 68 MeV (not included in Fig. 1), populating the same residues (^{197,198}Pb) as 55-MeV ^{6}Li + ^{197}Au, but at appreciably higher spin, yielded $\langle M_K \rangle$ = 2.04 ± 0.16, in excellent agreement with the higher-energy Au results.

The results for other targets in Fig. 1(b) seem to complicate the issue, exhibiting quite different energy dependences of $\langle M_K \rangle$ for different target nuclei. However, an apparent simplicity in the variation of $\langle M_K \rangle$ is restored in Fig. 2, where we have plotted the measurements (including a few for projectile-target combinations not presented in Fig. 1) not against energy, but rather as a function of the neutron number N_{peak} corresponding to the peak in the mass distribution of residual nuclides appropriate to each target and energy. (We have omitted 55-MeV results from Fig. 2, with the exception of the dashed triangle for ^{208}Pb, since they are low for reasons independent of N_{peak}.) While the fall-offs in $\langle M_K \rangle$ for $N \lesssim 110$ and $N \gtrsim 120$, indicated by the dashed lines in the figure, are not very well established by measurements to date, the existence of two separate plateaus (for even-Z and for odd-Z compound nuclei) of high and remarkably constant multiplicity in the intermediate-N region seems clear. We intend to carry out new measurements shortly to fill in gaps in Fig. 2, in order to establish whether the variation of $\langle M_K \rangle$ with N in this mass region really follows the simple "universal

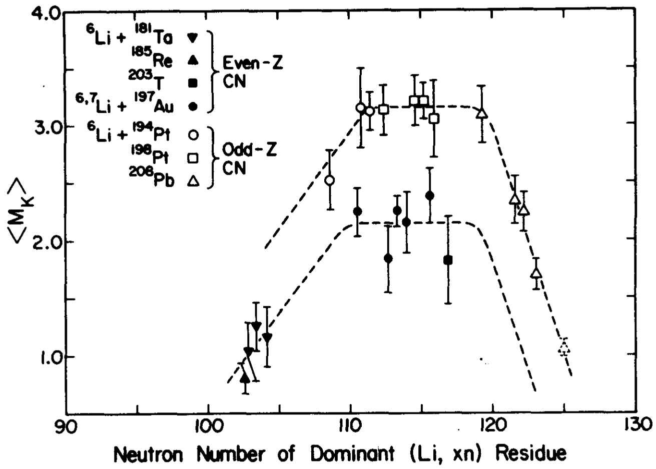

Figure 2. Compilation of measured K X-ray multiplicities for (Li,xn) reactions induced on the targets shown at bombarding energies from 75 to 124 MeV, plotted vs. the neutron number N_{peak} corresponding to the peak in the residual-nuclide production distribution appropriate to each target and energy. The values of N_{peak} are deduced from systematics established by γ-singles measurements in the present experiment and in the work of ref. 3. The dashed triangle represents a 55-MeV measurement for ^{6}Li+^{208}Pb. The dashed curves are intended to guide the reader's eye to the author's conclusion (see text).

curves" suggested in the figure.

If we indeed find continued evidence for a simple systematic behavior of $\langle M_K \rangle$, what will this tell us about nuclear structure in the region? This is still a matter of speculation, but the following scenario seems most plausible to us. Suppose that at moderately high spins ($J \gtrsim 12$) in the transitional-shape nuclei with $110 \lesssim N \lesssim 120$, the γ-cascades proceed at least partly through strongly coupled (deformation-aligned) rotational bands built upon mildly deformed (probably, though not necessarily, oblate), high-K, few-neutron quasiparticle intrinsic states. Adjacent levels within such a band differ by one unit of spin, and can be connected by either M1 or E2 transitions of energy

$$E_\gamma(I+1 \rightarrow I) = \frac{\hbar^2}{\mathcal{J}}(I+1), \qquad (1)$$

where $\mathcal{J}$ is the moment of inertia for rotations about an axis orthogonal to the symmetry axis. Assuming axial and R-symmetry for the nucleus, the ratio of leading-order collective M1-to-E2 transition probabilities is given by[4)]

$$\frac{B(M1;\ KI_1 \rightarrow KI_2)}{B(E2;\ KI_1 \rightarrow KI_2)} = \frac{(\frac{3}{4\pi})\ (\frac{e\hbar}{2Mc})^2\ (g_K - g_R)^2\ K^2\ \langle I_1 K 1 0 | I_2 K\rangle^2}{(\frac{5}{16\pi})\ e^2\ Q_0^2\ \langle I_1 K 2 0 | I_2 K\rangle^2} \quad . \qquad (2)$$

The B(M1)/B(E2) ratios for transitions within such bands would thus be enhanced by the postulated large values of K (easily accessible because of the availability of high-j particle orbitals) and small quadrupole moments Q_0 (characteristic of the transitional nuclei). In addition, the microscopic configuration would have to be appropriate to yield a significant difference between the intrinsic (g_K) and collective rotation (g_R) g-factors.

Despite the mild deformation, the moments of inertia for such heavy nuclei are relatively large, and the rotational transition energies correspondingly small enough to give large K-shell conversion probabilities. The unit difference observed in $\langle M_K \rangle$ for even-Z vs. odd-Z compound nuclei might be attributed to similar bands at lower spin built, for example, upon an $h_{9/2}$-particle state for the unpaired proton (as are known to exist in the relevant odd Tl isotopes, see refs.5,6). A significant decrease in $\langle M_K \rangle$ would be expected for $N \lesssim 110$, as we enter the strongly deformed region, where yrast cascades are dominated by collective E2 transitions, and as we approach spherical symmetry at the N=126 shell closure, where collective rotational bands should disappear.

Detailed verification of this speculation throughout this transitional region would require a very extensive program of γ-ray spectroscopy, which we are not proposing. We have already performed a γ-γ coincidence experiment aimed primarily at investigating the presently unknown level scheme in ^{198}Pb at J > 12, where the observed X-rays originate. The results of that experiment are still being analyzed. It is our hope that by combining such detailed data for a selected case with more extensive (and easily acquired) systematics of $\langle M_K \rangle$ vs. N_{peak}, we can provide sufficient evidence to support or reject the above nuclear structure scenario.

*Permanent address: Institute for Nuclear Research, Swierk, Poland

1) S.E. Vigdor, lectures at the XIII-th Masurian Summer School on Nuclear Physics, Mikolajki, Poland, Sept. 1-11, 1980, to be published in Nukleonika.

2) H.J. Karwowski et al., Phys. Rev. Lett. 42, 1732 (1979).

3) J. Kropp et al., Z. Physik A280, 61 (1977).

4) A. Bohr and B.R. Mottelson, Nuclear Structure, Vol. II (W.A. Benjamin, Reading, Massachusetts, 1975).

5) F.S. Stephens, in "Elementary Modes of Excitation in Nuclei," ed. A. Bohr and R.A. Broglia (North-Holland, Amsterdam, 1977), p. 172.

6) A.J. Kreiner et al., Nucl. Phys. A308, 147 (1978).