FURTHER CONFIRMATION OF THE "EXTRA PUSH" CONCEPT§

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In light- to medium-mass heavy-ion reaction systems, it seems clear[1] that the only significant entrance-channel limitation to fusion is that a pocket exist in the one-dimensional internuclear potential, and that the reaction partners have enough energy to overcome the repulsive coulombic and centrifugal forces at surface contact. For heavier systems, however, evidence has recently appeared[2] which can be interpreted[2,3] as a need for an extra inward radial velocity at contact for fusion to occur, a so-called "extra push". The amount of extra push is related to a parameter called the "effective fissility", $(Z^2/A)_{eff}$, and systems with similar $(Z^2/A)_{eff}$ are expected[2,3] to be *dynamically equivalent*. Thus, the systems $^{132}Xe + ^{nat}Fe$ ($(Z^2/A)_{eff}$ = 32.3) and $^{208}Pb + ^{48}Ca$ ($(Z^2/A)_{eff}$ = 31.9) should exhibit equivalent amounts of extra push in their fusion excitation functions. Fusion model calculations based on this extra push concept have been modified *via* scaling parameters fitted to experimental data[2], enabling one (in principle) to calculate fusion excitation functions for other heavy-ion reaction systems. The question remains open as to whether or not the scaling parameters derived from the data fits are universally valid, as implied by the model.

A series[4-7] of experiments on the heavy-ion systems $^{132}Xe + ^{nat}Fe$ and $^{56}Fe + ^{238}U$ has been performed, in which the systematics of fusion and deep-inelastic transfer were studied, using off-line radiochemical methods. Mass- and charge-yield curves have been constructed for both thick targets, in which the yields are integrated physically over the entire energy range from initial bombarding energy to reaction barrier, and thin targets. The yield curves are clearly separable with respect to various reaction mechanisms. Cross sections for evaporation residues, symmetric fragmentation, deep-inelastic transfer, and quasielastic transfer have been determined. Summing the cross sections for evaporation residues and symmetric fragmentation, we obtain the complete fusion yields which are listed in Table 1.

In order to test the extra push concept, and also to clarify discongruities with counter data for the system $^{132}Xe + ^{nat}Fe$[8], we have calcu-

Table 1: Comparison of observed fusion yields with theoretical predictions.

System	E_{lab}/u (MeV)	σ_{fus}^{exp} (mb)	σ_{fus}^{CT} (mb)	σ_{fus}^{CM} (mb)
^{132}Xe + ^{nat}Fe	≤ 4.56	205 ± 40	264	202
"	≤ 5.90	430 ± 45	661	416
"	≤ 7.12	490 ± 40	728	508
"	5.90	654 ± 157*	919	610
^{56}Fe + ^{238}U	≤ 9.60	173 ± 48	375	216
"	6.70	112 ± 31*	467	86

*Preliminary value

lated complete fusion excitation functions for the above systems using the classical trajectory[1)] (CT) and coalescence models[2,3)] (CM). We have adopted the algorithm used in Ref. 2, which takes into account the existence of a limiting angular momentum cutoff in the entrance channel. Parameters entering the extra push calculation (thud wall slope coefficient "a" and threshold effective fissility $(Z^2/A)_{eff}^{thr}$) were those obtained from fits to experimental data for reactions[2)] of ^{208}Pb with targets ranging from ^{26}Mg to ^{64}Ni. For the latter systems, $(Z^2/A)_{eff}$ extends from 25.2 to 39.0 . For the system ^{132}Xe + ^{nat}Fe, CT and CM calculations were performed using the friction parameter value of 0.781[1)] (*i.e.*, 89/114 = $\ell_{pocket}^{SB}/\ell_f^M(SB)$) whereas for ^{56}Fe + ^{238}U, the "standard" value of 5/7 (rolling) was taken. In both reaction systems, the effective fissilities are such $((Z^2/A)_{eff}$

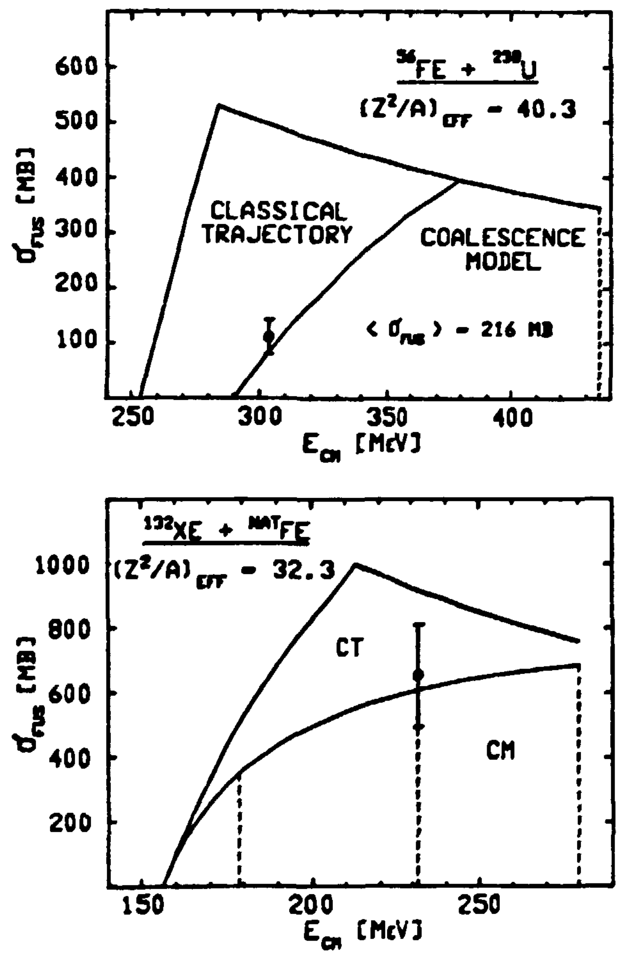

Fig. 1: Calculated fusion excitation functions for ^{56}Fe + ^{238}U and ^{132}Xe + ^{nat}Fe. Points represent thin-target experimental data. Dotted lines indicate bombarding energies for thick-target experiments.

for ^{132}Xe + ^{nat}Fe = 32.3, and for ^{56}Fe + ^{238}U = 40.3) that considerable differences between CT and CM calculations are to be expected. Figure 1 shows the calculated excitation functions for the two reaction systems, together with our experimental data (see Table 1 for thick-target data).

It is at once clear that our experimental fusion yields are strikingly lower than expected from CT calculations, but are in good agreement with CM predictions. It should also be noted that in the ^{56}Fe + ^{238}U system, the very large fusion barrier shift (*ca.* 35 MeV) is confirmed. We conclude that the agreement of our results and those of others[2] with CM calculations indicates that the extra push parameters (a = 10 ± 1 and $(Z^2/A)^{thr}_{eff}$ = 32.5 ± 1) seem to be generally valid, and that systems of similar effective fissilities are indeed dynamically equivalent.

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