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Heavy Ion Reaction Mechanisms and Nuclear Structure

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The experiments and results that fall within the scope of this review have to a large extent been presented and discussed on other occasions in this symposium and I do not want to add to this but, in keeping with what I believe was the intention of the organizing committee, I would like to change somewhat the perspective and stress - in the selection of the material and in the discussion - the nuclear physics content and significance.

In the matter of technique the field is divided naturally into two classes: reactions in duced by polarized or aligned beams, and analysis and utilisation of the polarization of the product nuclei. I shall refer to both of these.

I have prepared transparencies that are composites of the title, authors and the main data and results and they are supposed to serve as guides or reminders.

I would like to discuss first the measurement of the quadrupole moment of the ground state of ^{7}Li obtained by studying the scattering of aligned ^{7}Li below the barrier (See Figs. 1 and 2)[1]. Also determined in the same measurement are the B(E2) of the lowest transition and the relevant E1 polarizabilities (See Table I). This measurement is remarkable in both its accuracy and vigour but the aspect I wish to stress now is the relation to Coulomb excitation. This method is essentially an extension and refinement of conventional Coulomb excitation. There is an important advantage and novelty in the introduction of redundancy: you measure functions instead of numbers, and so, for example, the onset of departure from pure Coulomb

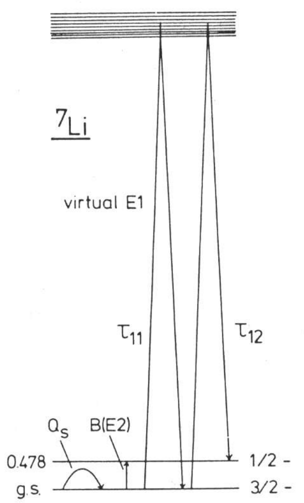


Fig. 1. Symbolic representation of the contributing effects.

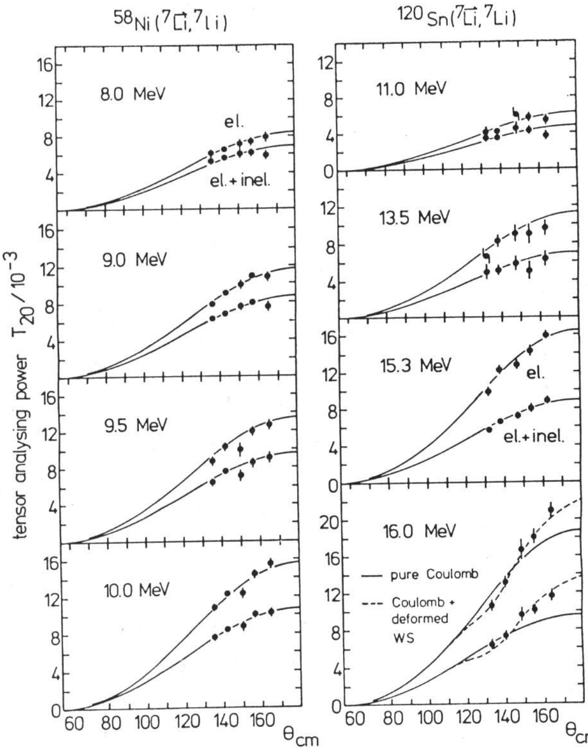


Fig. 2. Angular distributions of T_{20}^{el} and $T_{20}^{el+inel}$ for ^{7}Li scattering of ^{58}Ni and ^{120}Sn.

Table I

	Q_s	B(E2)	τ_{12}	τ_{11}	reference
present experiment	-3.70±0.08	8.3 ±0.5	0.23±0.06	0.23±0.06	
atomic and	-4.1 ±0.6				Orth et al. (1975)
molecular	-3.66±0.03				Green (1971)
spectroscopy	-4.06				Sundholm et al. (1984)
coulex with	-1.0 ±2.0	7.4 ±0.1			Bamberger et al. (1972)
unpolarized		8.3 ±0.6	0.21±0.03		Häusser et al. (1973)
beams	-4.0 ±1.1	7.42±0.14	0.15±0.01		Vermeer et al. (1984)
nuclear	-3.62	6.26			Bouten et al. (1981)
theory	-3.50	6.61			Kajino et al. (1984)
	-3.71	6.80			Hofmann et al. (1984)

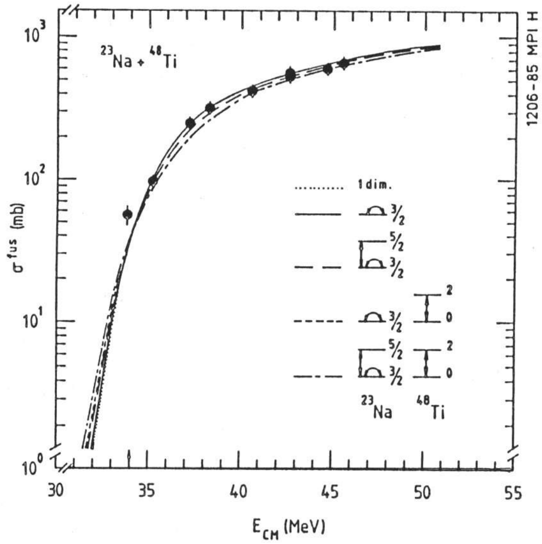


Fig. 3. Excitation function of the fusion cross section and theoretical predictions from various assumptions on the coupling schemes in projectile and target. The arrow indicates the S-wave barrier.

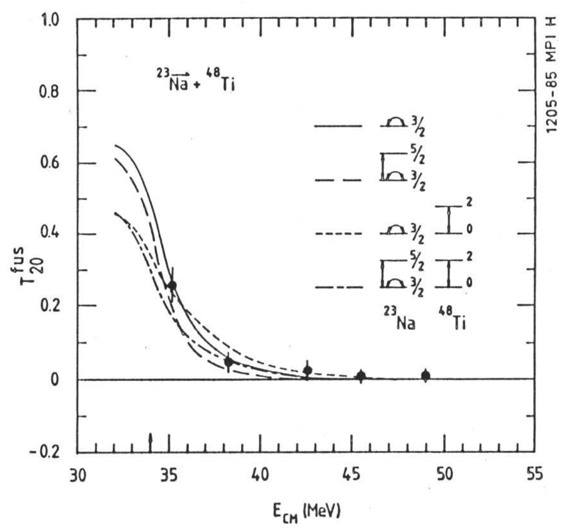


Fig. 4. Tensor analyzing power T_{20}^{fus} as function of CM-energy. The symbols are the same as in Fig. 3. A 1-dim. model would yield $T_{20}^{fus}=0$!

interaction can be found by inspection. Similarly, as we have seen, the strength of the virtual E1 transitions can be determined directly. Both these matters have consistently been thorns in the flesh of Coulomb excitation in its more sophisticated aspects and I would look forward to a combined attack by this method and conventional Coulomb excitation that could greatly enhance both the accuracy and reliability of measurements of static and dynamic electromagnetic moments.

We next have the fusion of aligned ^{23}Na with ^{48}Ti below the barrier (See Figs. 3 and 4)[2]. The object here is to study the effect of various degrees of freedom on barrier penetration. One such parameter - the nuclear deformation was studied before, in particular for Sm by comparing the fusion cross sections for a series of isotopes ranging from spherical to highly deformed, but now the comparison is within one system - without these extra degrees of freedom the signal would be zero. This is obviously a great advantage. In this particular case the quadrupole moment is so small that other parameters become equally important and it would clearly be of interest to extend this type of measurement to aligned beams or targets of highly deformed nuclei.

We now come to the polarization of product nuclei and consider a study of the polarization of the ^{12}B in two proton transfer reactions, a measurement carried out in the best Osaka tradition (See Figs. 5 and 6)[3]. The data were analyzed in terms of a friction force, a force that appears in a natural way in such studies and we heard some comments on this matter yesterday by Dr. Dünnweber[4]. An important aspect of the results is the near constancy of the force parameter over a wide range of systems and data which helps to convince us of this force's reality (See Fig. 7).

I would also like to mention another similar systematic study for one proton transfer which is potentially of equally rich content but has as yet not been fully analyzed and exploited (See Fig. 8)[5]. I am very happy to present this as a testimony of our fruitful Osaka-Rehovot collaboration.

I turn next to some results presented in our poster from Rehovot[6]: isomeric nuclear levels are polarized after their production and used to measure signs of quadrupole moments of high spin isomers and this is an up-to-date collection of the results (See Table II). Probably the most significant is the one for $^{147}Gd[49/2^+]$. We have here an example of a nucleus that is nearly spherical in its ground state and acquires a large deformation at high spin. This remarkable phenomenon is nowadays

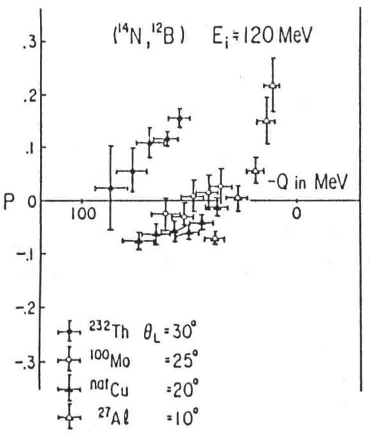


Fig. 5. Superposed illustration of the experimental polarization for various target around the second zero crossing (SZC).

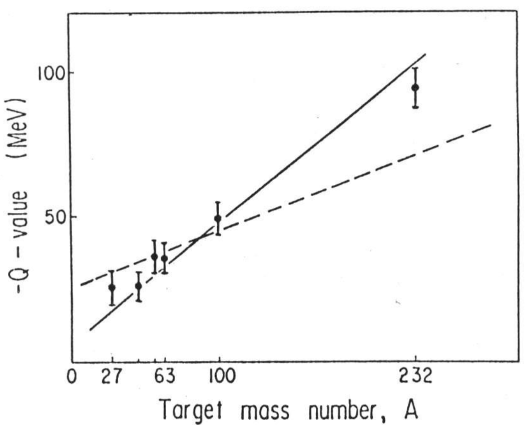
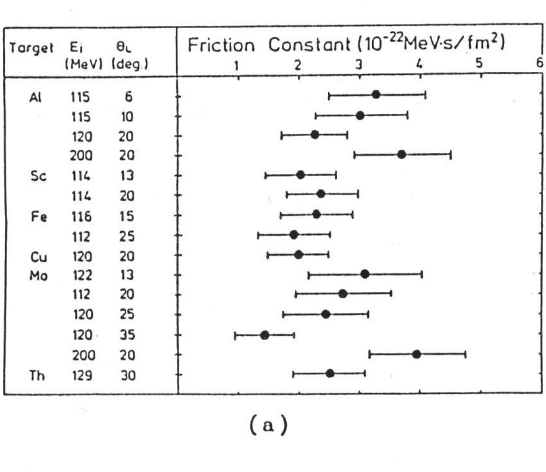
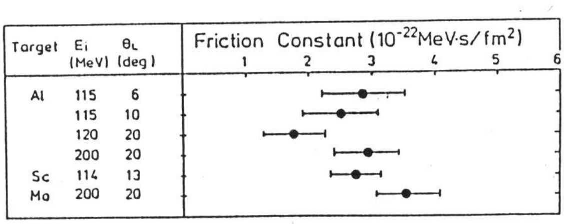


Fig. 6. Experimental Q-values of SZC plotted against target mass number A.



(a)



(b)

Fig. 7. Experimental results of the friction constant. The values used for E_{loss} are $-[Q(V_{cf}) + Q(SZC)]/2$ (left) and -Q for the largest negative polarization (up).

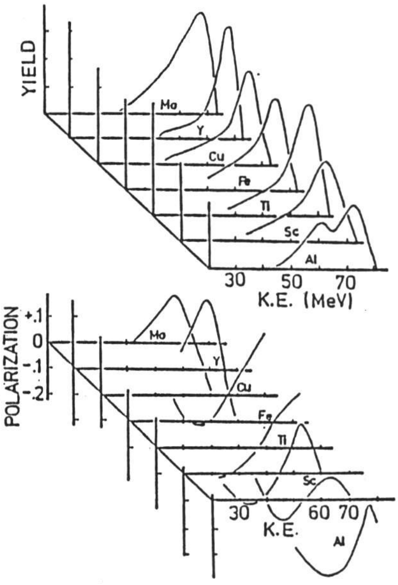


Fig. 8. Energy spectra (upper) and polarization (lower) of ^{12}B from the reactions (^{13}C,^{12}B) on various target nuclei at θ_L=20° using 91 MeV ^{13}C beams.

Table II

State	g	$Q/e.fm^2$
$^{54}Fe(10^+)$	+0.728	+29.7(4)
$^{88}Zr(8^+)$*	-0.18	+51(3)
$^{90}Zr(8^+)$*	+1.36	-51(3)
$^{134}Ce(10^+)$*	-0.187	+132(12)
$^{142}Sm(7^-)$*	-0.06	+112(27)
$^{144}Gd(10^+)$	+1.276	-146(6)
$^{147}Gd(13/2^+)$	-0.037	-73(7)
$^{147}Gd(27/2^-)$	-0.840	-126(8)
$^{147}Gd(49/2^+)$	+0.446	-324(18)

* results not previously published

explained in terms of what is called rotation alignment which has a direct consequence that the deformed shape must be oblate, the quadrupole moment negative. This is the first direct observation and confirmation of the oblate shape.

There are quite a few studies in the contributions which are obviously close to revealing significant nuclear information and we may evidently expect some novel results in this field by the time of the next symposium.

References

1) P. Egelhof et al.: High Precision Spectroscopy on the Electromagnetic Moments of ^7Li by Coulomb Scattering of Aligned Li Ions. Contribution to this conference, 2.11.
2) R. Butsch et al.: Fusion near the Barrier with Polarized Heavy Ions. Contribution to this conference, 2.12.
3) K.H. Tanaka et al.: Study of ^{12}B Polarization in ^{14}N-induced Reactions. Contribution to this conference, 2.15.
4) W. Dünnweber: Characteristics of Heavy Ion Reactions from the Study of Spin Orientation. This conference.
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6) G. Goldring et al.: Multi-Tilted Foil Polarization and the Signs of Nuclear Quadrupole Moments. Contribution to this conference, 8.49.