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This study has been performed at the M.P. tandem in Orsay and the following physicists have participated to all or part of it : M. BERNAS, F. DIAF, B. FABBRO, F. NAULIN, A.D. PANAGIOTOU*, E. PLAGNOL, F. POUGHEON, G. ROTBARD, P. ROUSSEL, M. ROY-STEPHAN.

At first, a few informations will be given about the M.P. tandem in Orsay and its experimental equipments.

It has been noted by W.E.WEGNER in the conclusions of the second "International Conference on Electrostatic Accelerator Technology",held in Strasbourg in May 1977 (1), that "MP 9 in Orsay with its operating record of almost 40% of its running time between 12.5 and 13 MV is indeed impressive" ! A large variety of ions are produced from three types of sources : Duoplasmatron, Penning, Sputtering. Among the heavy ions one may note ^{14}C, ^{56}Fe and a 12 nA ^{40}Ca beam at 166 MeV obtained from CaH^-. A mechanical (laddertron) charge transport is now being installed in place of the belt, and in the same time, a second stripper is being set at an intermediate section of the high energy part of the tube. Another feature of the Orsay tandem is that, among the different experimental lines (2)(3), three are equipped with a system using a magnetic analysis : i) a triplet of quadrupole lenses set at 0° of the beam, for particle-particle or particle-gamma correlations. ii) a split-pole spectrograph, mainly used for high resolution light particle experiments. iii) an index (n=1/2) spectrograph, mainly used for heavy-ion experiments.

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Details concerning the machine, the experimental set up and the physics performed at the tandem from 1974 to 1978 can be found in ref.(3).

For the present experiment (its last developments rather) a device has been used for the reconstitution of H.I. trajectories in the focal space of a magnetic spectrometer. Since this is now published elsewhere (4), it will just be said here that it is based on the use of two gas counters and that it allows both the use of a large solid angle (~ 5 msr) and a good angular accuracy ($\delta\theta \sim 0.3°$ for ^{16}O ions at 68 MeV), hence a good energy resolution.

The experiment and its aims (5)(6)(7)

What has been studied is the polarization of the residual nucleus ^{20}Ne in the α transfer reaction $^{16}O(^{16}O,^{12}C)^{20}Ne^*$ at 68 and 90 MeV. This polarization has been deduced from correlation measurements between ^{12}C and one of the products (α or ^{16}O) of the subsequent decay of $^{20}Ne^*$:

$$^{16}O(^{16}O,^{12}C)^{20}Ne^* \longrightarrow \alpha + {}^{16}O$$

$$J^\pi = 0^+ \quad 0^+ \quad 0^+ \quad J^\pi \qquad 0^+ \quad 0^+$$

The spins of the involved particles have been indicated because, since they are all but one zero, the correlation function $W(\theta,\varphi)$, i.e. the coincidence rate between ^{12}C and the ^{16}O (or α) detected in a direction θ,φ, takes a simple form :

$$(1) \qquad W(\theta,\varphi) = \frac{2j+1}{4\pi} \left| \sum_m p_j^m (-)^m e^{im\varphi} d^j_{mo}(\theta) \right|^2$$

where p_j^m are the components of the polarization tensor which describes the state of $^{20}Ne^*$ (these components are related to the same frame of reference as the one used to determine θ and φ) and d^j_{mo} are the reduced elements of the rotation matrix.

Let us note that the p_j^m's are a function of θ_c, the detection angle of ^{12}C, since the state of polarization of ^{20}Ne, which they describe, usually depends on θ_c.

The p_j^m are normalized to the unity $\Sigma|p_j^m|^2 = 1$ and are related to the transition amplitude and to the cross section by the relations

$$T_j^m = p_j^m \sqrt{\frac{d\sigma}{d\Omega}} \quad (2) \qquad \text{and} \qquad \frac{d\sigma}{d\Omega} = \sum_m |T_j^m|^2 \quad (3)$$

It appears then that the measurement of $W(\theta,\varphi)$ after that of $\frac{d\sigma}{d\Omega}$ leads to a deeper knowledge of the reaction mechanism since the cross section depends on the sum of squarred modulus, whereas the correlation depends on the p_j^m's amplitudes and phases.

Experimental arrangement

A magnet is used on the ^{12}C side while a Position Sensitive Detector (P.S.D.) measure the position and energy of the coincident ^{16}O (or α) (fig.1). The P.S.D can be set either in or perpendicular to the reaction plane.

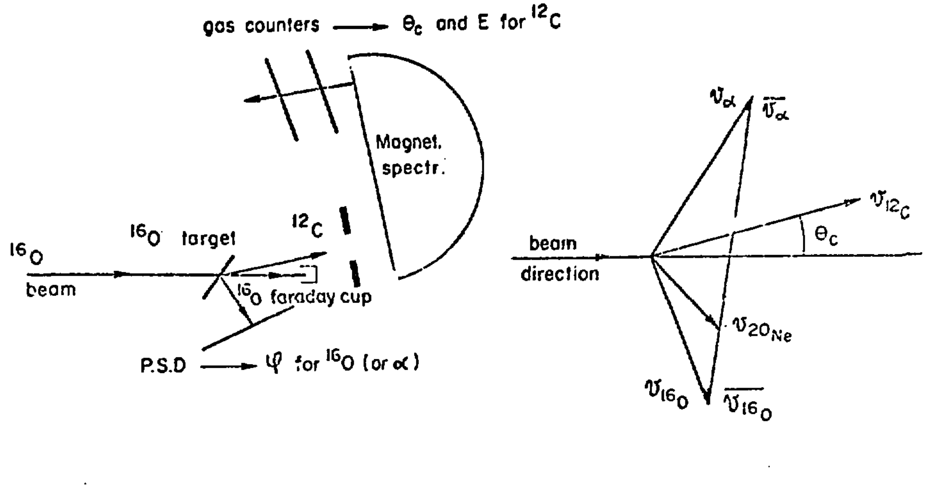

Fig.1. Scheme of the experimental set-up and scheme of the kinematics. The $\bar{v}$'s are in the ^{20}Ne center of mass; the v's are in the lab.

Results concerning the primary reaction : $^{16}O(^{16}O,^{12}C)^{20}Ne$

On the ^{12}C spectrum, shown on fig.2, it is seen that the most populated levels in ^{20}Ne are those known to have a large overlap with $\alpha + {}^{16}O$. For the high excitation energy part of the spectrum, the high spin states are enhanced. This is even more true at 90 MeV (not shown). The angular distributions shown on fig.3 are well reproduced by DWBA calculations using standard potentials (5). The full and dotted lines correspond to two different (0.4 and 1.5 MeV) α binding energies. Good α relative spectroscopic factors are found for the prominent peaks (from 0^+ to 6^+). It is concluded that the reaction proceeds mainly through a direct α transfer.

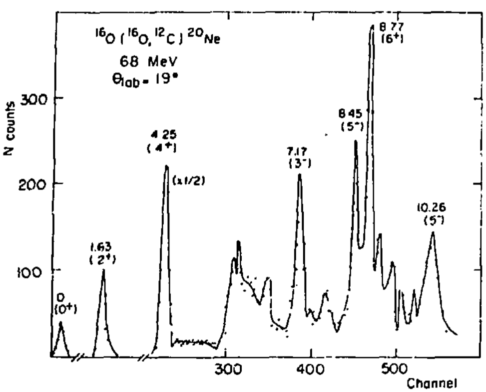

Fig.2. ^{12}C energy spectrum

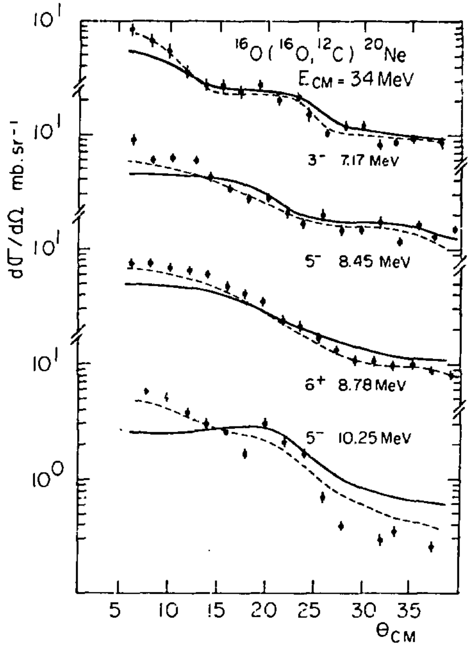

Fig.3. Angular distributions and DWBA fits.

Results for the correlation measurements

The correlations have been studied for the levels at 7.17 MeV (3^-), 8.45 MeV (5^-) and 8.78 MeV (6^+). At a given angle, i.e. for a given window set on the angle spectrum (see ref.(4)), the raw data consist in the bidimensional spectrum P ⊗ E (position,energy) of the coincident ^{16}O (or α) detected in the P.S.D. Fig.4 examplifies the display of such a spectrum. From this spectrum can be determined the correlation $W(\theta,\varphi)$, with $\theta = \pi/2$, φ variable if the P.S.D is set in the reaction plane; with θ variable, $\varphi = \varphi_{recoil}$ if the P.S.D is set in the perpendicular plane. This is shown on fig.5 where the dotted lines correspond to the fit with formula (1) obtained from a χ^2 procedure which provides the population amplitudes p_j^m.

Taking account of the symmetry properties of p_j^m, 2j real parameters are deduced from a correlation for a level of spin j. However, for a quantization axis (Oz) perpendicular to the reaction plane, it appears that the populations are concen-

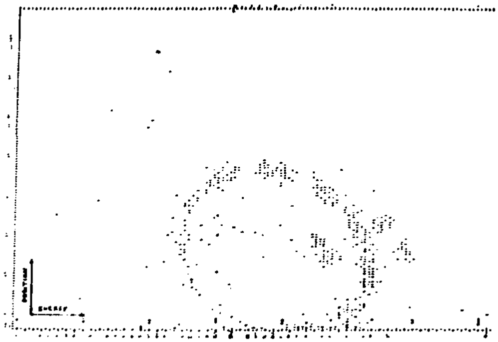

Fig.4. An example of the position-energy bidimensional display of the coincident ^{16}O detected in the PSD.

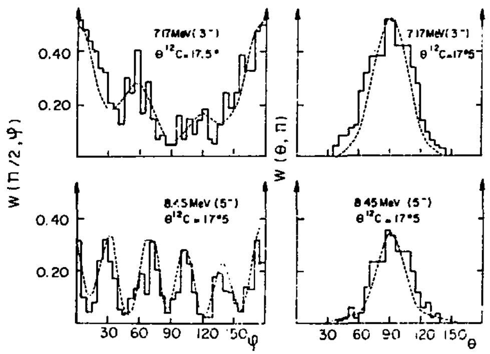

Fig.5. Correlation functions in the reaction plane (left) and in a perpendicular plane (right).

trated only on the two extreme values $m = j$ and $m = -j$, and in fact mainly on one of them.

This is shown on figs.6 and 7 where the polarization, $P = |p_j^j|^2$, and the alignment, $A = |p_j^j|^2 + |p_j^{-j}|^2$, are plotted versus the ^{12}C angle for the three studied levels. All levels are found strongly aligned and polarized along this axis perpendicular to the reaction plane. It is only at very small ^{12}C angles that P and A decrease towards the limit value L.F. (Litherland and Ferguson), independent of the mechanism, at 0°.

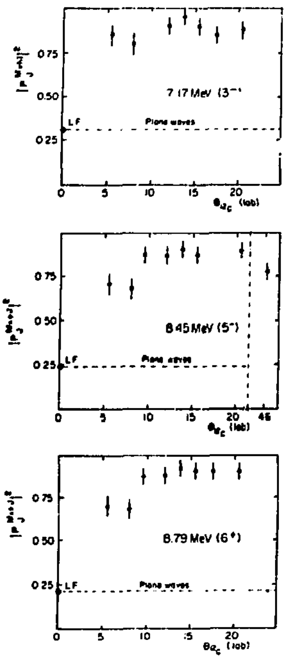

Fig.6. Angular distribution of the polarization.

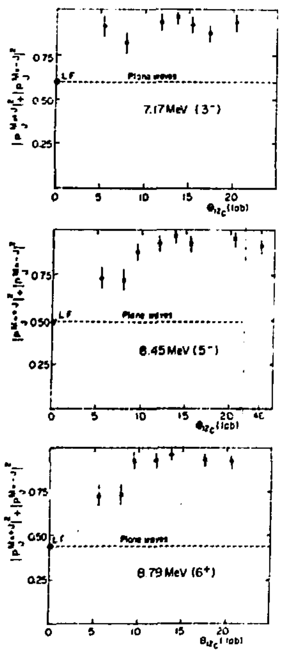

Fig.7. Angular distribution of the alignment.

Analysis

The present experimental results have been compared both to the predictions of different models and to the experimental results obtained when the same ^{20}Ne levels were populated by the (^{7}Li,t) reaction (8).

In the semi-classical model, one considers that all the fragments (incident, transferred and exit) move in the common plane of their centers of mass. This leads to a transferred angular momentum perpendicular to the reaction plane and along one direction or the opposit one, depending on whether the trajectories have a positive or negative deflection angle. Therefore, the resulting alignment is 1.00, and the polarization is found between 0.50 and 1.00 depending on the admixture of trajectories with positive and negative deflection angles. Although crude, this model appears to be able to reproduce both the observed alignment and polarization.

In the single partial wave model (S.P.M.) it is assumed that only one partial wave contributes in the incident channel (ℓ_i), and in the exit channel (ℓ_f). This model introduces in a simplified and drastic way the ℓ-localisation found in the interaction of strongly absorptive particles. ℓ_i is taken equal to the incident grazing partial wave. ℓ_f is taken equal to the exit grazing partial wave, if this value lies in the allowed range from $(\ell_i - j)$ to $(\ell_i + j)$, or to the closest allowed one if not. With $\ell_f = \ell_i \pm j$ (the actual value of ℓ_f is close to $\ell_f - j$) the S.P.M. model reproduces well the cross section and the alignment (fig.8) but it cannot reproduce the polarization since it always predicts $|p_j^m| = |p_j^{-m}|$.

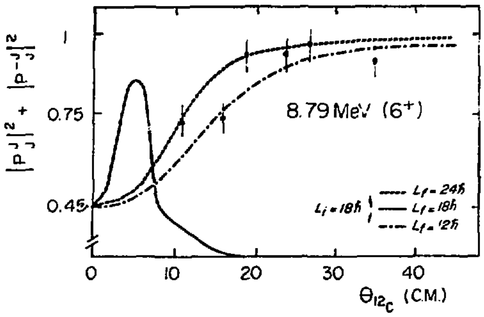

Fig.8. Comparaison of the experimental alignment with the predictions of the single partial wave model.

In the Distorted wave Born Approximation (D.W.), a finite range code has been used with two sets of optical model parameters : a standard one (5) and a highly absorptive one (9) which was shown (9) to be able to increase both the predicted alignement and

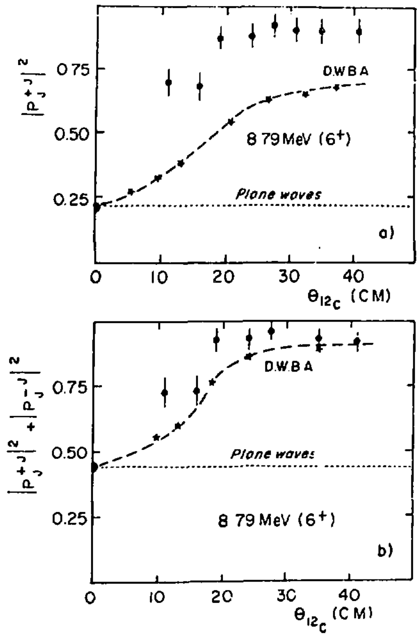

Fig.9. DWBA predictions for the alignment and the polarization, using a strongly absorptive potential (9), as compared to the experimental values.

polarization. Only the second one accounts well for the alignment but its predicted polarization is still too low (fig.9). It is not likely that another potential, compatible with the elastic scattering, can fit the polarization but it has to be further explored.

In both the spectator ejectile model and in the plane wave (P.W.) model, the same result is predicted : a population of the m = 0 state only, but with a quantization axis along the recoil direction (this do not depend on the reaction). The rotation of the reference frame is necessary before comparison to the other models and the result is given in table I.

What was found (8) in the (^{7}Li,t) reaction was a dominant population of the m = 0 state on an axis of quantization close to the recoil direction. A standard DWBA calculation could reproduce this result which corresponds, on an axis of quantization perpendicular to the reaction plane, to the same polarization and alignment as the P.W. predictions.

The test of the different models and the comparison of the two experiments are presented in table I where the alignments and polarizations are given for the 6^+ level at 8.78 MeV and for an angle close to the grazing one. Apart from the crude semi classical model, no model is able to reproduce both the polarization and the alignment experimentally observed.

Table I

Summary of the results shown on the example of the 6^+ state at 8.78 MeV, at the grazing angle.

Reaction		Polarization $\|p_6^6\|^2$	Alignment $\|p_6^6\|^2+\|p_6^{-6}\|^2$
$^{16}O(^{16}O,^{12}C)^{20}Ne$	Experiment	0.85	0.90
	Semi-classical model	0.50 to 1.00	1.00
	Single partial wave model $\ell_f = \ell_i - j$	0.45	0.90
	Distorted waves: normal	0.53	0.56
	Distorted waves: highly absorptive	0.70	0.90
$^{16}O(^{16}O,^{12}C)^{20}Ne$ and $^{16}O(^7Li,t)^{20}Ne$	Spectator ejectile or Plane Waves	∿ 0.22	∿ 0.45
$^{16}O(^7Li,t)^{20}Ne$	Distorted waves	∿ 0.22	∿ 0.45
	Experiment	∿ 0.22	∿ 0.45

Conclusion

This study has shown that polarization measurements do bring information on the reaction mechanism. It seems that some part of the mechanism is different for an α transfer occuring from a light and a heavy projectile. Different hypothesis can be seen as being at the origin of this difference : i) orbit polarization phenomenon as studied by G.Delic and N.K.Glendenning (10) ; ii) Coulomb excitation or reorientation in the exit channel as suggested by W.E.Frahn (11) ; iii) necessity to treat the full three body aspect ($^{16}O+^{12}C+\alpha$) of the problem (12). Further experimental studies are needed (different incoming and exit systems, different incident energies) to decide which of those hypothesis (they are not in fact completely independent one from each other) is the correct one.

Acknowledgments

We are indebted to P. Benoist-Gueutal for suggesting the use of the single partial wave model and to P.D.Bond for communicating the results of his calculation prior to publication.

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