haemoglobin components in definite proportions in all erythrocytes may be required to maintain a functional situation dependent on a balance of properties of the various components.

J-dependence in nuclear reactions

from P. E. Hodgson

THE general character of the differential cross sections of direct one-nucleon transfer reactions is dominated by the orbital angular momentum L of the transferred particle. Except at low energies when the angular distributions are backward-peaked and similar for all L values, the angular distributions are peaked at an angle in the forward hemisphere that increases with the value of L. In most cases a comparison between the experimental data and distorted wave calculations enables the value of L to be determined.

Since the transferred nucleon also has a spin of $\frac{1}{2}$, the total transferred angular momentum J is the vector sum of L and $\frac{1}{2}$, and since these can be added or subtracted, $J=L\pm\frac{1}{2}$. If the target nucleus has zero spin, this J is just the spin of the final state of the residual nucleus.

The angular distributions of reactions of the same L but different J are usually very similar, but in some cases small but systematic differences have been found. These are called the *J*-dependent effects, and have proved quite useful in assigning spins to nuclear states simply by the shape of the angular distribution, without any detailed calculations.

These *J*-dependent effects depend on the transferred orbital angular momentum L and on the incident energy, and are more marked in some cases than in others, so it is clearly important to understand how they arise, both for their intrinsic interest and in order to enhance their utility in nuclear spectroscopy.

The most marked *J*-dependent effects are found for $L=1$ transitions, and Robson has shown that these can be accounted for very well by distorted wave calculations with a spin-orbit interaction in the incoming and outgoing channels, provided the optical potentials are chosen to fit both the differential cross section and the polarisation of the corresponding elastic scattering.

For $L=2$ and 3 the *J*-dependent effects cannot be accounted for in this way and several attempts have been made to develop the distorted wave theory, in particular by including the deuteron D-state. This is a complicated calculation, and some of the results show *J*-dependent effects that are similar to those observed. The difficulty of the calculations has however deterred an extensive study, so most of the *J*-dependent effects remain unexplained.

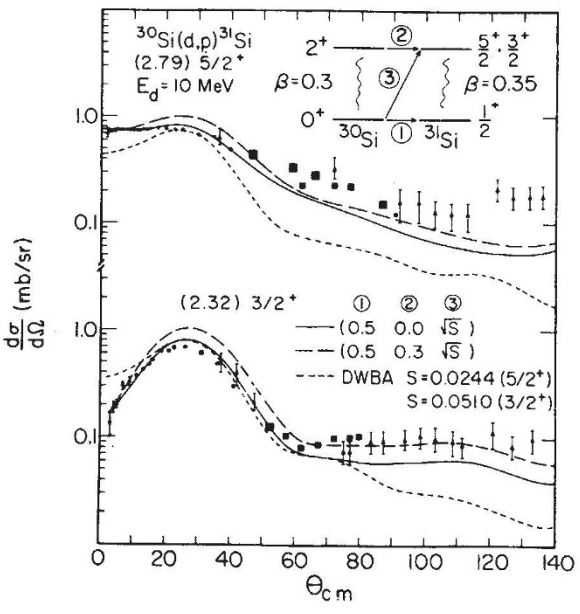
Quite recently a new explanation of *J*-dependent effects has been proposed: they are attributed to the contributions of two-step processes to the reaction amplitude. The importance of two-step processes is now widely known, especially when the nuclei are deformed and when the direct one-step transition is forbidden or inhibited by some selection rule. A substantial proportion of the reaction can proceed by the incident particle first exciting the target nucleus to a low-lying collective state by inelastic scattering, followed by the particle transfer to the final state. Similarly, the particle transfer can take place first to the ground or to an excited state of the residual nucleus, which can then be excited to the final state by an inelastic process as the outgoing particle leaves. All possible processes of this type combine to give the observed cross section.

In recent years the formalism for calculating such processes has been extensively developed, and many studies have shown the importance of including two-step processes. It has now been applied by Hoffmann, Udagawa, Coker, McIntyre and Mahlab (*Phys. Lett.*, **50B**, 249; 1974) to study the *J*-dependent effects in the reaction ^{30}Si(d,p)^{31}Si at 10 MeV to the 2.32 MeV ($3/2^+$) and 2.79 MeV ($5/2^+$) states of the residual nucleus. As the figure shows, the cross sections of these two reactions differ markedly in the forward direction, although they are both $L=1$ and very similar in energy. The short-dashed curves are standard DWBA calculation, which gives very similar angular distributions for the two reactions, and does not account at all for the difference between them. The calculation including the two-step process via the $1/2^+$ state of ^{31}Si at 0.75 MeV gives the full curves, which are in excellent accord with the data in the forward direction. The small differences in the backward hemisphere are probably attributable to compound nucleus contributions. A final calculation including those two-step processes through the lowest 2^+ state of ^{30}Si gave the long-dashed curves which do not agree with the data, which is expected since the excited states of the two states of ^{31}Si have a small parentage in terms of the 2^+ state in ^{30}Si, so that this process does not contribute significantly to the reaction.

Inclusion of the two-step contribution to this reaction is thus able to give a very good account of all the *J*-dependence of the cross sections to the $3/2^+$ and $5/2^+$ states of ^{31}Si. Other effects, such as those caused by the deuteron D-state, may contribute, but in this case at least they are small.

Further calculations by Coker, Udagawa and Hoffmann have shown that the two-step process is also able to account for the $L=2$ *J*-dependent effects in the ^{28}Si(d,p)^{29}Si reaction at 10, 13 and 18 MeV to several final states.

This work shows that two-step processes via low-lying collective excitations account for some of the *J*-dependent effects in one-nucleon transfer reactions in deformed nuclei. The *J*-dependent effects, however, are also found for nuclei to which this explanation cannot apply. It is therefore necessary to carry out a series of analyses for a range of nuclei and incident energies for different L-values with consistent parameters for the distorting potentials. This will make it possible to establish in a systematic way the contribution of two-step processes to *J*-dependent effects in nuclear reactions.



Differential cross sections for the one-nucleon transfer reaction ^{30}Si(d,p)^{31}Si at 10 MeV to the 2.32 MeV $3/2^+$ and 2.79 $5/2^+$ states of ^{31}Si compared with distorted wave calculations. The short-dashed curves are the simple one-step calculation and the full curves show the effect of including the two-step process (1). The long-dash curves show the effect of including the coupling (2) between the excited states, which does not contribute significantly. The figures in the brackets are the spectroscopic factors for the various transitions.