Accurate spectroscopic factors

from Peter E. Hodgson
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DURING the past ten years the one-nucleon transfer reactions have been developed into one of the most powerful tools for studying the single-particle aspects of nuclear structure. Among these the (d,p) reaction has been most widely used, but extensive studies have also been made using (d,n), (p,d), (d,t), (d,h) and many similar reactions that either add a proton or neutron to or remove one from the target nucleus.

As a typical example, consider the (d,p) reaction on ^{24}Mg. The incident deuteron interacts with the ^{24}Mg target and deposits a neutron in one of the unoccupied neutron states, and the remaining proton goes on alone. At lower energies this process can take place by absorption of the deuteron to form a compound nucleus followed a long time after by proton emission, but at higher energies the direct process that takes place in a time comparable with the time taken by the deuteron to cross the target nucleus predominates to such an extent that the compound nucleus process is negligible.

The differential cross section for this direct (d,p) reaction can be written as the product of two factors, one depending only on the structure of the nuclei involved and the other only on the reaction mechanism:

$$[d\sigma/d\Omega] = S_{JL} F_{JL} (\theta,E)$$

All the dependence of the cross section on the angle of emission θ of the proton and on the incident deuteron energy E is contained in the reaction factor F_{JL} (θ,E), and this can be calculated by the distorted wave theory. These angular distributions are in general characteristic of the total quantum number J and orbital angular momentum quantum number L of the state entered by the captured neutron so that comparison between the observed angular distribution and those calculated for various J and L enable these quantum numbers to be determined, and these give the spins of the corresponding states of ^{25}Mg.

The spectroscopic factor S_{JL} is a measure of the single-particle strength of the neutron state and is given by the ratio of the measured cross-sections to the calculated value of the F_{JL} (θ,E).

The analysis is thus able to give the quantum numbers and the single-particle strengths of all the nuclear states of ^{25}Mg reached by the reaction. Numerous analyses of nuclear states in all stable nuclei have been made with this technique, and it is one of our main sources of information on nuclear structure. The main limitations to this method are, first, that it is not always possible to determine J and L and, second, that the uncertainties in the distorted wave theory make the spectroscopic factors uncertain to about 20%, even in the best circumstances.

A new method of analysing one-nucleon transfer reactions has now been proposed by C. F. Clement of Harwell (*Nucl. Phys.*, **A213,** 469 and 493; 1973) and used to obtain more reliable J,L and more accurate spectroscopic factors. This method depends on the j-dependent sum rules that relate the spectroscopic factors of the reactions that remove a neutron (or proton) from a nucleus to the spectroscopic factors for the corresponding reaction that adds a neutron to the same nucleus. The j is the total angular momentum of the transferred nucleon. These sum rules provide a rigid set of equations that must be satisfied by the spins of the final states and by the spectroscopic factors of the corresponding transitions.

These sum rules must be distinguished from the more familiar J-dependent total sum rules that relate the spectroscopic factors to the total single-particle strengths of the states. The j-dependent sum rules provide additional constraints on the spectroscopic factors only if the spin of the ground state of the target nucleus is different from zero; if it is zero they are the same as the total sum rules. The method is thus applicable only to nuclei with ground state spins different from zero. All these sum rules were derived long ago by J. P. French, but it is only recently that they have been applied to nuclear structure analyses.

Clement and Perez (*Nucl. Phys.*, **A213,** 510; 1973) have now applied this analysis to the reactions (d,t) and (d,p) that remove neutrons from or add them to the states of ^{45}Sc with spin 7/2. The sum rules give a set of eight equations connecting sixteen sums of spectroscopic factors for stripping and pick-up to states of different spin. The measured spectroscopic factors satisfied these equations to an accuracy of 4% in relative magnitude and 10% in absolute magnitude. Several additional spin assignments to states of the residual nuclei ^{46}Sc and ^{44}Sc were made by this analysis.

An important problem in all analyses of single-particle states is the fraction of the strength that is far removed from the main concentration. Clement and Perez find that it would be difficult to maintain their fits to the sum rules if more than 10% of the total is in the continuum. Thus nearly all the f7/2 strength is concentrated in a limited energy region; this is an important conclusion for the basic single-particle model of nuclear structure and supports the validity of the distorted wave theory.

Subsequently Clement and Perez have applied the sum rule analysis to other nuclei and have still further reduced the uncertainties in the absolute spectroscopic factors. This is clearly a technique of great power that can provide valuable information on nuclear structure and stringent tests of the present techniques for obtaining it.

Fitting the flower to the bee

from a Correspondent

WITH the increasing use of F_1 hybrids in insect-pollinated agricultural crops and vegetables, special methods have to be devised to get enough effective pollinating insect visitors to achieve the complete cross fertilisation that is necessary. At the Third International Symposium on Pollination organised in Prague from May 15-18 by the International Commission for Bee Botany of IUBS, the Bee Research Association and the Academy of Agricultural Sciences and other bodies in Czechoslovakia, examples discussed included red clover, lucerne, field bean, melon and cucumber. A detailed knowledge of floral biology, pollen and nectar production, and their composition is needed; for instance, Ing. H. Haslbachová (College of Agriculture, Brno) reported success in increasing pollination (and hence seed yield) in tetraploid red clover by applying growth regulators which alter the morphology of the subsequent flowers in ways which make them easier for the bees to work.

Visitation by bees is necessary for good crops of strawberries from some cultivars, and L. J. Connor (Ohio State University) has found that the number of visits a flower receives depends on its structure. Flowers with stamens short in relation to the receptacle are difficult to work and not much visited. Unfortunately the first flower on a stem (giving the earliest, most profitable, fruit crop) has short stamens, even in cultivars whose later flowers have long stamens. Here the most likely solution is breeding plants for floral morphology that suits the pollinating bees.

G. D. Waller (US Department of Agriculture Laboratory, Tucson), in seeking to find out why it is difficult to achieve adequate pollination in onion seed plots (*Allium cepa*), found that honeybees—the major pollinator—are unwilling to forage on the onion flowers. The only difference between these flowers and others available nearby is that the potassium concentration of the onion nectar is about ten times as high as that of other nectars. An interspecific hybrid *Allium cepa* × *A. fistulosum* produces nectar with a normal potassium