design criteria for fatigue in composites. The question hinges, as M. J. Owen (University of Nottingham) pointed out, on one's inability to define exactly the nature of defects in reinforced plastics and their likely effect on static and cyclic properties. N. J. Parratt (Explosives Research and Development Establishment, Waltham Abbey) observed that although in whisker reinforced aluminium alloys the minute whiskers do not *per se* act as flaws or crack starters, unfortunately it happens that the effects of small defects in such materials are larger than could be expected from fracture mechanics investigations on larger, more easily studied defects.

The second topic concerns the appositeness or otherwise of the experimental work that is currently being carried out. Owen took up the point made by a member of the audience, that uniaxial fatigue tests on simple aligned or biaxially-oriented composites were hardly likely to provide information that would be useful for realistic design problems. He showed how a fracture mechanics approach could be used to develop safe-life design criteria for notched plates of glass reinforced plastics. A. W. Cardrick (RAE, Farnborough) gave added weight to these arguments when, during his paper on the properties of CFRP/aluminium composite joints, he listed as being most urgently required information on the effects of secondary stresses and stress concentrations, accidental damage, joint design and cumulative damage characteristics. He also emphasised that constant amplitude and frequency loading conditions were not as useful as narrow band random loading.

The third important question—fatigue damage—was also discussed by W. S. Carswell (National Engineering Laboratory, East Kilbride), who described an approach to defining residual strength of fatigued composites in terms of a damage function which, however, is extremely difficult to define, is even more difficult to measure and is likely to be different in different types of composite. Of particular importance in this respect were the contributions of W. N. Reynolds (Atomic Energy Research Establishment, Harwell), who discussed non-destructive testing methods as a means of assessing fatigue damage, and those of C. Kim (Chelsea College, London) and of M. Fuwa (University of Sussex), who showed how acoustic emission detection techniques can be used to give information about the damage sustained during loading and cycling of test pieces or components. It could well be that these non-destructive testing methods will have to be used in conjunction with design criteria in order to overcome or allow for the deleterious effects of variability and manufacturing defects.

NUCLEAR THEORY

Heavy Ion Transfer

from our Nuclear Theory Correspondent

MANY studies of nucleon transfer reactions between heavy ions have shown typically bell-shaped angular distributions centred at angles around 30°. These distributions can easily be understood using a classical model of the interaction. The lighter of the two ions approaches the heavier along a Coulomb hyperbolic orbit and the reaction in which a nucleon is transferred from one ion to the other is most likely when this orbit just grazes the surface of the heavier ion. For larger impact parameters the lighter ion passes beyond the nuclear field of the heavier ion and no nuclear reaction can take place. For smaller impact parameters the ions interact strongly and many complicated reactions take place, so that the probability of the simple transfer reaction is again reduced. Thus there is a maximum in the cross section at the angle corresponding to the deflection characteristic of a grazing collision, and it falls for smaller and for larger angles giving the observed bell-shaped curve.

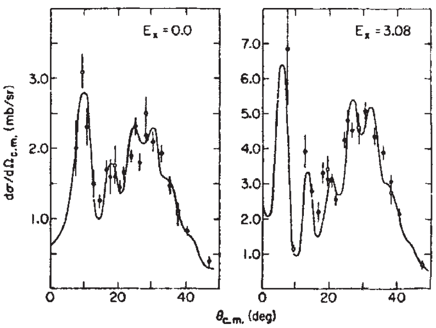
Quantum mechanical analyses of such reactions can be made using the distorted wave theory and taking into account finite range and recoil effects. These are generally in agreement with the data but in some cases they have shown rapid oscillations superposed on the overall bell-shaped curve. It thus becomes interesting to see if these rapid oscillations can be detected experimentally and also if they can be understood theoretically. This has recently been done by a group at Brookhaven National Laboratory (Chasman, Kahana and Schneider, *Phys. rev. Lett.*, **31**, 1074; 1973).

They measured the differential cross section for the proton-transfer reaction $^{48}Ca(^{14}N,^{13}C)^{49}Sc$ to the ground and 3.08 MeV states of ^{49}Sc at an incident energy of the nitrogen ions of 50 MeV. Preliminary data (open circles in the figure) showed the expected bell-shaped curve at 30° but with an additional peak at about 10°. The first distorted wave calculations gave a smooth bell-shaped curve without the forward peak but it was found that if the absorbing part of the optical potential describing the motion of the incident particle is slightly reduced, the forward peak appears and in addition oscillations of higher angular frequency (about 6°) appear on the bell-shaped curve.

Further measurements were therefore made to see if these oscillations are real, and the solid points on the figure show that this is indeed the case. The distorted wave calculations reproduce these complicated oscillations remarkably accurately, confirming the reliability of the calculations.

The physical origin of these small-angle oscillations is still not understood. Diffraction theory suggests that they must be associated with a distance of the order of the diameter of the target nucleus, so the obvious explanation is that they are due to interference between the projectile paths on opposite sides of the target nucleus. This is confirmed by calculations starting with the quantum mechanical expression for the cross section and using approximate analytical forms for the partial wave amplitudes and phases. It is then possible to obtain an expression very similar to those of classical diffraction models consisting of two terms, corresponding to interactions on opposite sides of the nucleus. The form of the cross section is then determined by the relative magnitudes of these terms, which varies with the incident energy and the interaction potential.

At low energies the classical scattering angle corresponding to grazing collisions is large, the two terms do not interfere and the classical bell-shaped cross section results. At higher energies the scattering angle is less, and the small-angle oscillations appear superimposed on the classical cross section. The onset of these oscillations depends on the absorbing potential. The lower this potential the lower the energy for which the incident particle feels the real nuclear potential and so the lower the energy at which the oscillations appear.



Differential cross sections for the proton transfer reaction $^{48}Ca(^{14}N,^{13}C)^{49}Sc$ to the ground and 3.08 MeV states of ^{49}Sc at an incident nitrogen energy of 50 MeV, compared with distorted wave calculations which include recoil.

The distorted wave calculations also allow the absolute magnitude of the transfer cross section to be related to the spectroscopic factor for the single-particle transition. The values extracted from the experimental results are found to be in excellent agreement with the nuclear structure calculations of Cohen and Kurath.

This work shows nuclear transfer between heavy ions is very well understood theoretically, so that it is now a powerful method of obtaining information on nuclear structure.