electrode and Δ_{Al} that for aluminium. This behaviour was consistently followed for outer electrode materials ranging from tantalum with $2\Delta_t = 1$ meV to lead with $2\Delta_t = 2.6$ meV, and in each case the structure diminished and finally disappeared as the outer electrode was made thicker.

Granqvist and Claeson suggest that these phenomena arise from the stimulated emission of phonons (quanta of lattice vibrational energy) in the outer electrode. The tunnelling electrons must arrive there with an energy $eV-\Delta_{Al}-\Delta_t$ above the top of its energy gap, and it is known that most of these first relax to states just above the gap through emission of so-called relaxation phonons of energy $eV-\Delta_{Al}-\Delta_t$, subsequently falling into paired superconducting states below the gap with emission of recombination phonons with energy $2\Delta_t$. If V is such that the recombination and relaxation phonons have the same energy, then there is a probability that the relaxation process will be stimulated by the $2\Delta_t$ phonons to occur faster than it otherwise would, so that, because a larger number of empty states will therefore be available into which tunnelling can occur, the current will seem to be anomalously large for that particular value of V, leading to a peak in $\mathrm{d}i/\mathrm{d}V$. The required value of V is clearly $(\Delta_{Al}+3\Delta_t)/e$, so one would expect a peak in $\mathrm{d}i/\mathrm{d}V$, due to this effect, at $2\Delta_t/e$ above the gap voltage of $(\Delta_{Al}+\Delta_t)/e$, in agreement with experiment. Processes involving stimulated emission by two or more $2\Delta_t$ phonons should, by a similar argument, lead to further peaks at $4\Delta_t/e$, $6\Delta_t/e$ and so on, which is again consistent with experiment, although peaks beyond the one at $4\Delta_t/e$ are apparently too small to be observed.

The authors believe that these effects have not been observed previously because other workers were unable to prepare such thin outer electrodes: the thinner the electrode, the greater the density of recombination phonons, and so the larger becomes the probability of stimulated emission.

The density of these phonons must also be directly related to the recombination rate, so one would expect the magnitude of the new structure to depend markedly on the magnitude of the tunnelling current. A simple test of the theory would therefore be to repeat the experiment with junctions of different impedance, which can easily be arranged by varying the thickness of the oxide layer. The failure of a preliminary experiment of this nature to yield the anticipated result leads one to suspect that a complete explanation of Granqvist and Claeson's structure may turn out to be somewhat more complicated than they have suggested.

NUCLEAR PHYSICS

Resonance Transfer

from our Nuclear Structure Correspondent

WHEN an ion collides with an atom, the probability of electron transfer depends on the time they spend near each other (the collision time) and on the transfer time itself. If these times are similar, the transfer of one electron is most likely. If the collision time is twice the transfer time the electron can be transferred from the atom to the ion and back again, and so on. Since the collision time is inversely proportional to the relative velocity of the two atoms, the probability that an electron will be transferred from the atom to the ion attains peak values at a series of energies corresponding to one, three, five . . . transfers of the electron. A simple analysis shows that the cross section is of the form

$$\sigma(E)=A(E)+B(E)\cos^2(bE^{-\frac{1}{2}})$$

where $A(E)$ and $B(E)$ depend on the incident energy E and b is a constant. Measurements of electron transfer have been made by Ziemba and Everhart (*Phys. Rev. Lett.*, **2**, 299; 1959) that confirm this formula with surprising accuracy.

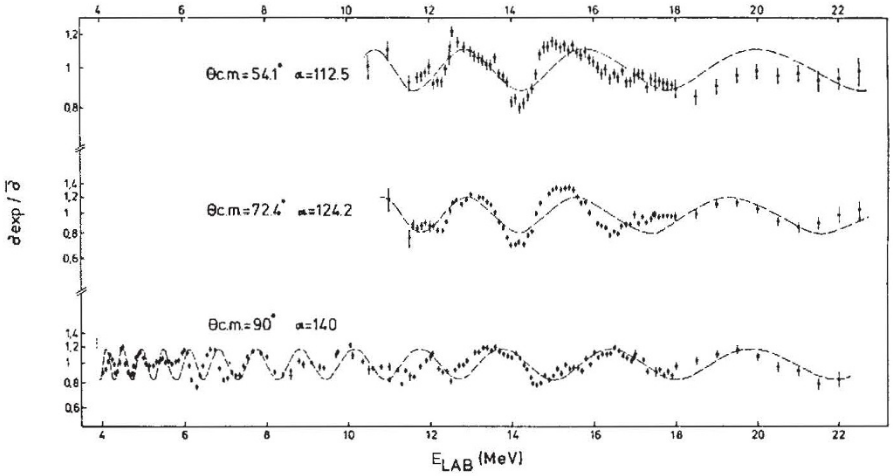
The simple theory works very well for the transfer of electrons between atoms because the electron is very light compared with the atoms themselves. If the transferred particle is comparable in mass to the colliding particles much of the simplicity is lost because of the increasing importance of recoil effects.

Resonant transfer processes, as they are called, have been looked for in nuclear reactions, and in particular it has been conjectured that they might be observable in neutron-proton collisions as multiple pion exchange or in heavy ion reactions as nucleon or cluster exchange. Some indications of the characteristic signature of resonant transfer, a cross section following the formulae outlined here, have been found from time to time, but have not been substantiated by further work.

Recently a more convincing example of resonant transfer has been found in a study by Kelleter, Hrehuss and Mayer-Böricke (*Nucl. Phys.*, **A210**, 502; 1973) of the scattering of alpha particles by ^{7}Li. The cross section of this reaction shows a rather irregular dependence on energy, as might be expected for such nuclei, but if it is plotted relative to the energy-averaged cross section an oscillatory behaviour is apparent, as shown in the figure. In particular, it shows an increase of 'wavelength' with energy very similar to that given by the resonant transfer, with small deviations readily attributable to the neglect of recoil and other effects in the simple theory. Since ^{7}Li can be considered as formed by a triton bound to an α particle, this oscillatory component of the reaction may be interpreted as due to transfer of a triton between the incident α-particle and the α particle in ^{7}Li.

This interpretation is strengthened by an estimate of the parameter b, which is approximately given by $E_{ex}t_{int}/\hbar$, where E_{ex} is the average exchange energy and t_{int} the interaction time. The values of b obtained in this way are in qualitative agreement with those found by fitting the resonant transfer formula to the measured cross sections.

Further work needs to be done to develop a detailed theory of the process, taking into account the recoil effects and the presence of other reaction channels, and it would be useful if additional examples could be found experimentally. It is likely that such studies of resonant transfer reactions will provide a useful opportunity to develop nuclear reaction theory.



Ratio of the cross section for the elastic scattering of alpha particles by ^{7}Li to the energy-averaged cross section as a function of energy showing oscillatory structure interpreted as due to a resonant transfer of a triton between the two α particles. The dashed curves show the variation expected from the simple theory of the resonant transfer process.