the interpretation of the colours of very distant galaxies, where the ultraviolet light is redshifted into visible wavelengths.

An alternative approach to seeking remote luminous galaxies is to perform deep counts of all galaxy images on a photographic plate. Ellis showed that counts obtained by several groups, including those at Durham with the AAT, were now probing cosmological distances. At 22nd magnitude in the blue, one expects to find many galaxies at a redshift of 0.5 or greater. Comparison of the available data suggests that evolution in blue luminosity may be required. The amount of evolution is rather modest, and in fact is very similar to that used by Bruzual in interpreting the colours of the high-redshift radio galaxies. This would again imply that many galaxies were bluer and more luminous in the past.

Where does all this leave us? The evidence for evolution in distant galaxies is growing. Unfortunately, it is impossible to arrive at a unique interpretation of the observations. There may be many possible evolutionary tracks that yield the mature galaxies we now see, and extrapolation into the past becomes exceedingly dangerous while we are still uncertain of what is happening in nearby galaxies and, indeed, in our own Galaxy. We require an improved understanding of the evolution of the youngest stars and of the oldest stars. We must discover how these processes depend on metallicity. We need to understand how star formation is initiated and to measure the initial distribution of stellar masses. And we cannot neglect the effects of galactic environment. Some recent UKIRT observations (N. Robertson, Imperial College, London) show that tidal interactions between galaxies may stimulate star formation. Other environmental effects that may plague distant galaxy observations include those of galactic cannibalism, whereby a luminous galaxy swallows its lesser neighbours, and galaxy mergers.

The goal of using distant galaxies to determine whether the Universe is open or closed seems as remote as ever, but our understanding of galactic evolution is likely to be improved considerably. The challenge posed by theories of galaxy formation is clear. Accumulating evidence from the large-scale distribution of galaxies (G. Efstathiou, Institute of Astronomy, Cambridge) points to the existence of large-scale coherence. Numerical simulations of galaxy clustering only match the observed correlation function if collapse on a large scale occurs at a relatively late epoch, corresponding to a redshift of less than three. Could galaxy formation coincide with this collapse phase, and have occurred at such a recent epoch? To prove or disprove this hypothesis is the immediate challenge facing the observers of remote galaxies. □

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Quantum mechanics

Phonokinetic analogue of the photoelectric effect?

from J.F. Allen

In this issue of *Nature* (p.325), Baird *et al.* describe how they have demonstrated the thermal energy equivalent to the photoelectric effect first described by Einstein to explain the observation that the kinetic energy of electrons ejected from metal surfaces by irradiation with light depends not on the intensity of the irradiant light but on its frequency. Einstein suggested that the phenomenon could be understood if the beam of light were treated as a stream of bombarding photons, with the light acting as quasi-particles of energy $h\nu$, where h was Planck's then newly proposed constant quantum of action and ν was the frequency. This was the first great achievement of quantum physics.

A little later, Millikan made confirmatory measurements of the photoelectric effect but at the same time suggested that Einstein's idea about discrete photons was pretty well discredited. Even Einstein later expressed doubts about quantum mechanics, and certainly 70 or 80 years ago it was intellectually difficult to treat an electromagnetic wave, such as light, as having at the same time both wave and particle properties.

Then 40 years ago Landau described the thermal excitation spectrum of superfluid helium in terms of phonons and rotons. He said that if light, as black-body radiation in a uniform temperature enclosure, could be treated as a kind of gas of photons with a defined energy density but with an unconserved number, so one could treat the random thermal motions of atoms in a liquid or solid as a gas of quasi-particle sound waves or phonons; again with total energy determined but with numbers of phonons unconserved. (The rotons need not concern us here.)

The treatment of thermal energy as a phonon gas has been very fruitful. Arising from it has been the suggestion, made from time to time, that there should be some kind of phonokinetic analogue of the photoelectric effect. Just as an electron coming out of a metal must have sufficient energy to overcome the work function, so a gas atom must overcome the binding energy, that is the latent heat per atom, in order to escape from the liquid surface.

Although saturated vapour pressures are usually quite high, the microscopic picture of evaporation is not very clear. What has been lacking has been the ability to produce an identifiable high-energy phonon to knock out an identifiable atom from the liquid.

This problem has now been solved by Baird, Hope and Wyatt in Exeter. In a bath of superfluid helium at 0.1K, where the

vapour pressure is effectively zero, they put a short powerful heat pulse into an immersed heater which produces a burst of phonons with a normal energy distribution. These are directed towards the bath surface and the ejected atoms impinge on a sensitive bolometer in the 'vacuum' vapour space above the liquid.

The phonon excitation spectrum of the superfluid is unusual. The low-energy phonons travel faster and reach the surface first, but they have a short mean free path and decay readily, giving a small bit of noise on the bolometer signal. They form a 'thermodynamic' background.

At higher energies, however, where the equivalent phonon temperature is of order 10K, the graph between ordinate energy and abscissa momentum is convex upwards, which means that normal decay, involving conservation of both energy and momentum, is no longer possible. Thus the high-energy phonons behave 'ballistically' with a mean free path of many centimetres, and their velocity and energy can be determined.

Baird *et al.* used a very simple and elegant device of a heater at a constant fixed distance below a bolometer, with the heater in the liquid and the bolometer in the space above it. The system could be raised or lowered to vary the liquid and vapour paths, keeping the total path constant. A collimator orifice was fixed just below the liquid surface, to ensure that the ballistic phonons of interest and the ejected atoms of interest travelled along the same straight line. It was, in effect, a time-of-flight spectrometer.

From the time taken for the phonons to go from heater to surface and for the ejected atom to go from the surface to bolometer, and from knowledge of the binding energy, it was found that the phonon energy equalled the sum of the binding energy plus the kinetic energy of the ejected atom.

The results were checked by adding a small number of ^3He atoms to the otherwise very pure ^4He , with the knowledge that ^3He atoms sit on a superfluid ^4He surface. The evaporated ^3He atoms, with their binding energy known, also had the correct kinetic energy.

Baird, Hope and Wyatt have thus clearly established that there is a one-to-one phonon-atom quantum evaporation, and that we can speak of a phonokinetic effect which is the analogue of the photoelectric effect. □

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