bridge) on primaeval black holes formed very early on in the history of the Universe. It seems that these very small holes will not grow to gargantuan proportions (that is $10^{16}\ M_{\odot}$) as had been previously suspected by Zeldovich and Novikov. G. Gibbons (University of Cambridge) outlined some possible quantum mechanical effects associated with very small ($\ll 10^{-10}$ cm) holes, first proposed by S. W. Hawking (University of Cambridge) in collaboration with whom both the above pieces of work were carried out. Of special importance is the question of whether they can possess charge.

After this discussion of gravitational collapses it was peculiarly fitting that S. Chandrasekhar (University of Chicago), the man who in a sense started off the subject with the discovery of the upper limit to the mass of a cold degenerate newtonian configuration which bears his name, should have received the highest award of the Polish Academy of Sciences—the Smoluchowski medal—at this conference. It was also characteristic of his breadth of interests that it was for his work on Brownian motion that he received his award.

NUCLEAR PHYSICS

## Continuum Shell Model

from our Nuclear Theory Correspondent

UNTIL fairly recently, nuclear structure and nuclear reaction studies developed almost independently, with occasional connections between the two. It was found most convenient to use a harmonic oscillator potential to generate the wave functions for shell model calculations because of its simple and useful analytical properties. These wave functions are indeed good approximations to the real ones, especially for light nuclei. But this potential arises to an infinite value outside the nucleus, which ensures that the nuclear wave functions soon fall to zero so that the nucleus is prevented from interacting with anything else.

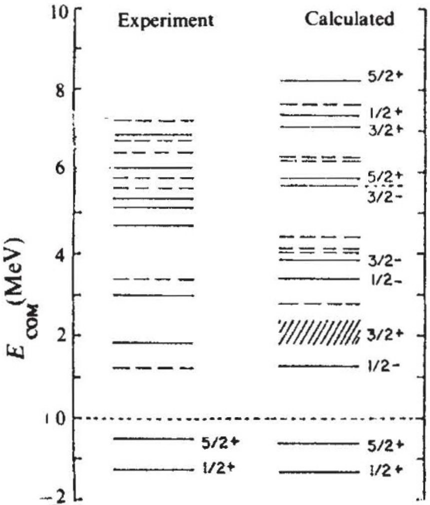

**Fig. 1** Comparison between the calculated and experimental energy spectra of $^{15}$C.

Nuclear reaction studies, on the other hand, have most frequently used one-body potentials like the optical potential to represent the interaction between an incident particle and the nucleus. Such potentials are essentially energy averaged, so that the particular structural characteristics of each nucleus are largely washed out and the potential is almost the same for all nuclei. Thus, paradoxically, nuclear structure theory allowed no reactions, and nuclear reaction theory was almost independent of nuclear structure.

In particular, the shell model calculations, although very sophisticated, could only give the properties of bound states and states that are in reality unstable to particle emission had to be treated as if they did not decay. Reaction calculations, on the other hand, did not include important features of the structure of the interacting nucleus and were then unable to give an adequate account of the increasingly detailed experimental data. This barrier is now being broken down by nuclear structure calculations that include unbound or scattering particles and by nuclear reaction theories that take detailed account of the structure of the interacting nuclei.

A recent example of the former is the continuum shell model calculations of the structure of $^{15}$C carried out by Philpott (*Nucl. Phys.*, **A208**, 236; 1973). This is a fully microscopic shell model treatment of the structure of $^{15}$C taking account of continuum states as well as bound states and including configuration mixing, finite range and spin-dependent forces and using fully antisymmetrised wave functions. This gives not only the usual shell model states but also a wide range of resonance phenomena, including broad single-particle and narrow many-body resonance in both elastic and inelastic scattering.

To do this the total wave function is expanded as a sum of states, some localised and some describing the separation of a nucleon from the nucleus. If this is inserted into the Schrodinger equation the usual separation procedure gives a set of coupled differential equations for the bound and unbound wave functions, and these can be solved subject to the appropriate boundary conditions.

These equations include matrix elements depending on potentials that have to be specified explicitly before they can be evaluated. These potentials have one-body and two-body components. The one-body component represents the interaction between each active nucleon and the core, and is conveniently provided by a Saxon-Woods potential whose parameters are adjusted to fit the observed single-particle energies in $^{13}$C. The two-body component represents interactions among the three active nucleons outside the $^{12}$C core, and this was taken from a previous shell model calculation in which a standard central Gaussian two-body force was used to fit energy levels in $^{14}$N and $^{14}$C.

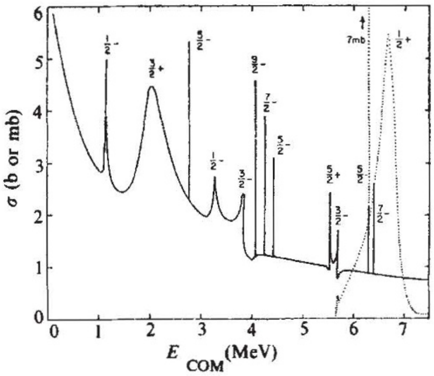

**Fig. 2** Calculated total elastic and reaction cross sections for the interaction of neutrons with $^{14}$C. ——, $\sigma_E$ (b); - - -, $\sigma_R$ (mb).

The resulting energy level spectrum (shown in Fig. 1) is naturally very similar to the conventional shell model for the bound states, but the unbound states now have widths corresponding to their decay probabilities. It is also possible to calculate the total elastic and reaction cross sections for the interaction of neutrons with $^{14}$C; these are shown in Fig. 2. There is a large variation in the widths of the states, depending on their individual structure. In addition, the form factors for single nucleon transfer reactions can be calculated within the shell model framework, since the wave functions behave correctly beyond the nucleus.

There is not yet sufficient experimental data on any one nucleus to make a detailed test of this theory, and indeed in its present form it is premature to expect more than qualitative agreement. Its importance is that it provides a way of unifying structure and reaction data, and further theoretical development, together with the use of more realistic forces, will give more reliable predictions that can be compared with new experimental data.

PALAEOMAGNETISM

## Réunion Event Defined

from our Geomagnetism Correspondent

ALTHOUGH the boundaries of the major intervals (epochs) of the geomagnetic polarity-time scale for the past four million years or so are now fairly well defined, the number and precise ages of the much shorter polarity reversal events are still the subject of investiga-