I would like, for a moment, to consider the many-body problem in the nucleus in the light of what we now know about an analogous many-body problem, that of electrons in metals. In ordinary metals, it is found experimentally that the low-lying excitations of the system possess an essentially individual particle character. The specific heat depends linearly on the temperature, and the Fermi surface is well-defined, as is evidenced by the de Haas-van Alphen effect. The main problem which faces the theoretical physicist is that of reconciling these facts with the rather strong long-range Coulomb interactions between the electrons. This may be done, however, by taking into account properly the polarization effects produced by the Coulomb interactions. When this is done, (by, for instance, introducing the plasma field to describe the polarization waves), one obtains a system of “effective” electrons, which interact through a screened Coulomb interaction with a range of the order of the inter-particle spacing. The “effective” electrons consist of the original electrons plus their associated screening clouds. It is then feasible to show that the elementary excitations of the “effective” electron system possess the desired individual particle character, although a completely satisfactory mathematical proof of this fact does not yet exist.

This situation is rather similar to that obtaining with the shell model for the nucleus, and one might hope for a similar happy ending here. I do not, however, believe that we will find it in just this form. To see why, let us consider the “unusual” metals, the superconductors.

Recently Bardeen, Cooper and Schrieffer 1) have proposed a theory

---

1) National Science Foundation Senior Post-Doctoral Fellow, 1957-58; Permanent address: Princeton University, Princeton, N.J.
of superconductivity which is satisfactory in all major respects. They propose that the following criterion distinguishes between superconductors and ordinary metals: in superconductors the effective interaction between the electrons near the Fermi surface is attractive. Thus the phonon-induced electron interaction, which is attractive for electrons near the Fermi surface, must be more attractive than the screened Coulomb interaction is repulsive. This criterion may be shown to work quite well in practice.

They then consider the consequences of an effective averaged attractive interaction between electrons near the Fermi surface. They show that the wave functions of the system are markedly altered. They find for the ground state an essentially many-body wave function which corresponds to the coherent virtual excitation of all pairs of electrons of opposite spin and momentum near the Fermi surface. Further, they show it takes a finite amount of energy to excite any individual electron out of the coherent assembly, that is, the infinite system possesses an energy gap in its excitation spectrum which shows up in an exponentially varying specific heat at sufficiently low temperatures. Bardeen, Cooper and Schrieffer then go on to calculate a number of other superconducting properties, including the specific heat, Meissner effect, and phase transition, finding in each case good agreement with experiment.

What Bardeen, Cooper and Schrieffer have derived is, in fact, quite general, and should apply to any system of fermions for which the averaged interaction between the particles near the Fermi surface is attractive. In their theory, no matter how weak the attractive interaction may be, it will give rise to coherent many-body states for the particles near the Fermi surface and an energy gap in their excitation spectrum. I think that we will all agree that the effective interaction between nucleons in the nucleus is attractive. We might accordingly expect the BCS theory to apply to nuclei.

I should therefore like to suggest that nuclei resemble superconductors, in that the attractive interaction between the nucleons makes necessary the introduction of coherent many-body states and gives rise to an energy gap in the nuclear excitation spectrum. I believe that this effect must be taken into account in any proper treatment of the nuclear many-body problem. Bohr and Mottelson and I have been discussing these matters during the past summer in Copenhagen, and they will have more to say on this topic later in the meeting.
Reference

1) J. Bardeen, L. N. Cooper and J. R. Schrieffer, Phys. Rev. 106 (1957) 162

Discussion

A. Bohr: The important point from the nuclear point of view which is brought out by the work of Bardeen et al. is the major modification occurring at the Fermi surface of a Fermi gas in which there are attractive interactions. This modification extends over a certain energy region, representing a characteristic interaction energy. In the nuclear case it is quite possible that this interaction energy is small compared to the Fermi energy and therefore it should not effect, say, the calculation of the average binding energy of the particles in the nucleus. However, it is of course of great relevance for such problems as the justification of the shell model. Such a change of the Fermi surface would imply for instance that as we go to heavier and heavier nuclei there would finally be no shell structure because the distance between the shells would go to zero as the nucleus became heavier and it would finally be smaller than the region for which the whole spectrum was modified. Of course one should say that these effects are to some extent another way of talking about the configuration interactions which take place between neighbouring single particle levels and which have already been considered for some time, but this way of talking throws an interesting light on the problem. It is also possible—this remains to be seen—that one may be able to use some of the methods suggested in the electron problem to treat configuration interactions in the nucleus from a different point of view. In particular, the emphasis on correlations in which the particles remain in pairs is rather interesting. It is also somewhat suggestive that the gap in the energy spectrum which Bardeen and his collaborators obtained may have something to do with the gap existing in the intrinsic spectra of nuclei which is discussed in another session †.

Brueckner ‡‡ pointed out a difference in character between interactions in a superconductor and in a nucleus. In the superconductor the interaction between pairs was repulsive except for a very small region near the Fermi surface, whereas in a nucleus the interaction was attractive everywhere. There was no group of states in a nucleus where the interaction was of opposite sign from the bulk of the states. This might cause difficulty in carrying over the deductions of Bardeen to the nuclear case.

Eden asked how big the energy gap was likely to be in the case of a nucleus, in order to enable one to estimate the effect on calculations.

Mottelson: It is probably of the order of 1 MeV, and therefore not of first significance in calculating the total energy of the nucleus. But it will be very important for the discussion of the nuclear levels that lie within an energy interval of that order of magnitude.

† B. R. Mottelson, Lecture in session on unified model and discussion following.
‡‡ Editor's note: Brueckner has stated that on later examination these remarks seemed to be incorrect; however he thought they could remain in the proceedings.