Discussion after the First Part of the Two Talks

Arima (Tokyo): What is the difference between correlations and clusters?

Betts (Argonne): To me they are the same. Of course when we think of clusters we tend to think of spatially correlated nucleons. Pairing correlations are, on the other hand, correlations in momentum space but to me the words can be used interchangeably. It's a choice of language.

Ikeda (Niigata): Clustering correlation is defined as one which acts to form a spatially localized cluster. The spatial localization in the surface region is the essential point different to other correlations. Although this spatial localization is related with the properties of the effective nuclear force, the cluster correlation has rather many body correlation characteristics. This is also different from other correlations which has usually a direct connection with the residual interactions.

Moretto (LBL): I feel that we should not get carried away with the concept of cluster. One hears that α particle, or ^{14}C clusters exist in nuclei just because they are emitted radioactively. I think that emission of a cluster does not imply its preexistence in the parent. If we were to have liquid drop nuclei, where no clusters are present by definition, we could still have radioactive or evaporative emission of clusters.

Betts: The issue is whether or not the observed decay is enhanced or not or in other words what is the spectroscopic factor. If this is large then the concept of a clustered state makes sense. Otherwise not.

Arima: I partly agree with you. As I said already, nuclei are quantum mechanical objects. Therefore any wave function contains some amount of cluster components. A key question, however, is "How much enhanced are the cluster components in certain states?"

Ikeda: In the decays of cluster, the important quantity is the reduced width amplitude in the surface region, which should be compared with the Wigner limit value. However we do not expect the preformation probability especially in the inner region.

Zamick (Rutgers): If, say, ^{24}Mg consisted rigorously as 6 alpha particles, then we would have as a consequence that there are no spin magnetic dipole transitions in ^{24}Mg. A motion of one alpha particle relative to another is a purely orbital motion. In a naive picture of the alpha ($(1s)^4$ configuration) there would be no magnetic excitation of ^4He (or any other closed L-S nucleus). (The above is not quite true because of the tensor force). Thus there are no spin excitations in ^{24}Mg in the extreme alpha cluster model. Experimentally there are substantial spin excitations, however. On the other hand the fact that spin excitations are quenched relative to simple shell model estimates, may indicate a tendency towards alpha clustering. I therefore propose that we consider new classes of experiments e.g. spin excitations, to quantify the degree of alpha clustering.

Arima: You are proposing new kinds of experiments. I am, however, not sure if the quenching of spin excitations can quantify the degree of alpha clustering. It simply tells the spin correlation in nuclei.

Lovas (Debrecen): I would emphasize the standpoint of the cluster models, in terms of which you can define un-ambiguously what a particular type of clustering is. What we can call clustering is just the fact that a nuclear wave function is not orthogonal to the cluster model subspace. The amount of clustering may be defined by the norm square of the projection of the wave function onto this subspace.

Austin (MSU): In heavy ion collisions one observes production of fragments with a probability approximately proportional to m^{-2}. Presumably this occurs at relatively low density. Is it consistent with the importance of cluster phenomena that no special population of α-particle nuclei is observed?

Betts: There are, as far as I know, many possible explanations of this observation. In some of these clustering could play a role. I don't know the data well enough to say what they tell us on this point.

Discussion after the Second Part of the Two Talks

Yamazaki (INS): The Ikeda "energy threshold rule" generally applies to other complex systems, where a new particle is created. As the simplest example, let us take up "pions". The interesting feature here is that a negative pion forms Coulomb-assisted bound states of hybrid character. As far as the pion keeps its identity, deeply bound (1s, 2p, ...) states are expected to be narrow, as shown by Toki and Yamazaki, Phys. Letters, to be published, who proposed "pion transfer" reactions to populate these hybrid bound states. The key issue is what is the pion spectroscopic factor, which will tell us about the internal structure of pion embedded in nuclei.

Arima: Nucleons in nuclei are the best example of clusters. Betts, however, mentioned the interpretation of the EMC-effect in terms of an increase of the nucleon size in nuclei. What is the present status of this as seen by y-scaling in inclusive (e, e')?

Sick (Basel): Indeed the EMC effect could be explained in terms of an increase of nucleon size due to binding. There are, however, many other explanations of the EMC effect as well. The most natural one relates the EMC effect to the binding of nucleons in nuclei. Various calculations indicate that the binding effects explain of the order of 80% of the EMC effect.

The model of an increase of nucleon size due to the nuclear medium is not confirmed. When studying (e, e') and y-scaling, as I will discuss in my talk on Friday, y-scaling allows to set a very stringent limit on the size-change of the nucleon: $\Delta r/r < 3\%$!. The nucleon thus appears as the best (most inert) cluster we know of in nuclear physics.

Cindro (Zagreb): There is something we all know which may help to overcome some of the conceptual difficulties inherent in defining what a cluster is; Clusters are dynamical structures, they come and go. Related to this, let me give you a piece of Chinese wisdom: Barks come out of dogs, but dogs are not composed of barks.

Betts: Eggs come out of chickens and chickens come out of eggs.

Back (Argonne): The recent discovery of ^{14}C natural radioactivity constitutes an interesting phenomenon intermediate between α-decay and spontaneous fission. Will the panel comment on the fact that preformation factors must be taken into account in the calculation of α-decay rates, whereas such factors are absent in fission calculations?

Should such preformation factors be considered for the ^{14}C decay?

Betts: This is a question of the spectroscopic factor again. If we take the best wave functions we have for the parent, daughter and ^{14}C can we reproduce the observed decay rate? If not then we need to modify these wavefunctions by adding more clustering, octupole deformation ... The history of attempts to reproduce absolute alpha decay rates tells us we will not be able to do this. The question is therfore open at this time.

Kajino (Tokyo Metropolitan): Reality of nuclear cluster is observed in several phenomena with low transfer momentum. Theoretical calculations of the clustering state exhibit a dramatic supression of inner oscillations.

My question is how to observe the consequence of the supression of inner oscillations.

Arima: I doubt the meaning of inner oscillations, because after antisymmetrization the relative wave functions between two α's for example with or without oscillations give rise to the same wave function of ^8Be. I thus say there is no way to observe the inner oscillation.

Before we close this session, I would like to ask Professor Wildermuth to tell us his recent application of the Resonating Group method to QED.