FINAL STATE INTERACTIONS

By

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"A heavy riddle lies in this..." — J. M. Synge

General aspects of the final state interactions and the main features of the Watson–Migdal theory are discussed. The reactions \( \text{^7Li} + d \rightarrow n + \alpha + \alpha, d + d \rightarrow d + p + n \) and \( N + N \rightarrow d + \pi + \pi \) are analysed as special examples of three body final states.

Anyone who agrees to speak on the subject of Final State Interactions to an audience such as this must clearly possess more courage than sense. The field as a whole presents a maze of traps for the unwary, while promising a rich harvest of largely incomprehensible data to the intrepid physicist who presumes to enter it. It is a field dominated by the prejudices of the workers within it; in which doctrinaire methods of experimental procedure are often followed. The indiscriminate application of limited theoretical models to the physical interpretation of experimental data is also a feature of the enthusiastic chaos which typifies this particular area of scientific endeavour.

Professor Slaus will no doubt have something to say on this point at a later session of this Conference. I also, of course, have my considered prejudices which I now have the welcome opportunity to lay before you.

Zupancic [1] remarked that the study of three particle reactions was proceeding in at least two different directions. On the one hand simple and well-understood limiting situations were being exploited to deduce physical quantities relevant to various fields of physics and with some success. Take, for example, the extraction of nuclear spectroscopic data from three-body final states. On the other hand, a tendency had developed for scientists to penetrate into the unknown land beyond these limiting situations and to encounter problems of considerable conceptual complexity. Many of these problems are still with us, and undoubtedly involve the finer features of three body interactions. The complete analysis of a complex final state in terms of on-shell two body, off-shell two body and perhaps specifically three body effects, plus the interference between them is scarcely possible even today. So let me begin this paper by considering only the limiting cases, in particular those of sequential decay and quasi free scattering.
Sequential decay processes

When a long-lived intermediate system is formed in a collision, its subsequent decay is well-known to be exponential with time and therefore a third particle leaving the interaction region can have a high probability of being found outside the range of nuclear forces, before decay of the intermediate state has occurred. In the case of a two body interaction, however, in which the scattering cross-section does not exhibit true resonance behaviour, the concept of sequential decay requires considerable further examination before it can be used with confidence.

It was observed by Eisenbud [2] that the energy derivative of the phase shift in a scattering process could be interpreted as a time delay. Wigner [3] developed this idea, and showed in particular that for the scattering of one particle by another:

$$\frac{d\delta}{dk} > - R,$$

(1)

where $R$ is the radius of interaction of the two body system and $k$ is the relative wave number of the particle scattered. Outside this radius $R$, the particles could both be considered free.

Zupanic [1] in his consideration of anti-bound states of the isobaric triad $nn$, $np$ and $pp$ used this fact to indicate that although the decay of these systems is not exponential it is possible to consider the average time that they spend together as a function of their relative energy. As their relative position is uncertain to the extent of their relative wavelength, we can define an average life time for the system as:

$$\tau = \frac{1}{v} \left[ r + \frac{1}{k} + \frac{d\delta}{dk} \right].$$

(2)

$r$ is the range of the nuclear interaction, and $v$ and $k$ are the relative velocity and wave number, respectively. Here $(r + 1/k)$ fulfils the role of $R$ in equation (1).

The $nn$ system, for example, which is almost bound, has a low energy phase shift given by the effective range expansion to first order:

$$k \cot \delta = - \frac{1}{a},$$

(3)

where $a$ is the neutron-neutron scattering length. Hence:

$$\tau_{nn} = \frac{1}{v} \left[ r + \frac{1}{k} + \frac{|a|}{1 + a^2 k^2} \right].$$