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Broad resonances and beta-decay

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Abstract

Beta-decay into broad resonances gives a distorted lineshape in the observed energy spectrum. Part of the distortion arises from the phase space factor, but we show that the beta-decay matrix element may also contribute. Based on a schematic model for p-wave continuum neutron states it is argued that beta-decay directly to the continuum should be considered as a possible contributing mechanism in many decays close to the driplines. The signatures in R-matrix fits for such decays directly to continuum states are discussed and illustrated through an analysis of the beta-decay of ^{8}B into 2^+ states in ^{8}Be.

Keywords: Beta-decay; R-matrix fit; Broad resonance

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1. Introduction

The concept of a resonance is pervasive in quantum physics as applied e.g. on nuclear, particle, atomic and molecular phenomena. However, a closer look at the literature shows that there is no unique way of defining a resonance. When applied in data analysis, varying definitions can give different results for broad resonances [1–3] or may even at some point become impossible to apply. There are two distinct aspects of a resonance, the first being as a state of a (continuum) system in analogy with a bound state, the second as characterizing an enhanced response to a disturbance. We shall here mainly be concerned with the first aspect.

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We shall focus in this paper on beta-delayed particle emission processes that traditionally are considered to proceed through (resonance) states in the beta-decay daughter and shall argue that beta-decays directly to the continuum should be taken into account in more situations than was done so far. Before dealing specifically with beta-decay we shall in Section 2 remind the reader about some aspects of the description of resonances and how well they perform when applied to broad resonances. This will be illustrated in Section 3 through simple model calculations. One goal is to clarify whether parameters taken from analyses of beta-decay data can be used in modeling of other nuclear processes proceeding through the same "reaction channels", we show in Section 4 that loosely bound initial states may require special considerations. In the limit of very broad resonances it is not possible to decouple the population of the resonance from its decay. The properties of the resonance, its position and width (or more generally its shape), will differ when populated via different mechanisms. Since analyses of decays through broad levels are often made via R-matrix fits we shall discuss (Section 4.3) what effects may occur there. Finally, Section 5 discusses how our results may be generalized and Section 6 presents our conclusion.

It may be appropriate first to recall that a resonance as such does not correspond directly to any physical observable. However, the resonance concept can be very useful in describing the evolution of a system, e.g. as a response to an external probe, namely by employing resonances as basis states in the description. We are of course never forced to use a specific set of basis states, but narrow resonances in particular seem a natural choice. In the opposite limit of very broad structures the alternative description in terms of "pure" continuum states (a basis defined by the asymptotic behavior of the wavefunctions) may seem the natural one. It is important to note that both descriptions are valid and, at least for structures of intermediate width, can be used in practice. A practical example can be found in the calculation [4] of the dipole strength function for ^{11}Be where a basis combining resonances and continuum contributions is used and it is demonstrated explicitly how the number of included resonances can be varied without changing the result. (The complex scaling method [5] used in this work can be related to the Berggren decomposition of the continuum [6,7].)

From such general considerations it appears that it is to some extent a matter of convenience whether one interprets an experimental spectrum in terms of resonances or not. This point has been made very clearly by Dalitz, see [8] and the contribution to [9]. The two possible descriptions, emphasizing resonances or continuum states, may be thought of as complementary, and the question of whether a process happens resonantly or not will as noted earlier [10,11] not always have a unique, or meaningful, answer. Nevertheless it is worthwhile to explore how far the resonance concept may be taken, to see how different resonance definitions relate to experimental observables, and to determine when corrections must be included.

2. Limits for resonant behavior

Most resonance definitions are conceptual or formal, but do agree in the case of narrow resonances. Resonances may also be identified in experimental spectra, and a standard requirement has been that several different observables should give consistent (energy and width) parameters for a given resonance, the point being that resonances should be an intrinsic property of the system studied and ideally not influenced by the ways of exciting it. For increasingly broader resonances the deduced parameters can no longer be expected to be identical for the different conceptual definitions or different observables.

Blatt and Weisskopf [12] start their exposition of nuclear resonances by considering the relative amplitude of wavefunctions inside and outside the nucleus. A resonance corresponds to an