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The Gamow-state description of the decay energy spectrum of neutron-unbound ^{25}O

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Abstract

We show the feasibility of calculating the decay energy spectrum of neutron emitting nuclei within the Gamow-state description of resonances by obtaining the decay energy spectrum of ^{25}O. We model this nucleus as a valence neutron interacting with an ^{24}O inert core, and we obtain the resulting resonant energies, widths and decay energy spectra for the ground and first excited states. We also discuss the similarities and differences between the decay energy spectrum of a Gamow state and the Breit–Wigner distribution with energy-dependent width.

Keywords: Exact solutions; Single-particle levels; Nuclear structure models; ^{25}O strength function

1. Introduction

Ever since the discovery of the exotic ^{11}Li nucleus [1], there have been many experimental [2–4] and theoretical [5–7] studies of nuclei far from the beta stability line. On the experimental side, new techniques were developed to produce and study the properties of rare isotopes.

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On the theoretical side, new models were developed to guide and explain the experimental findings. The theoretical and experimental understanding of unstable nuclei will continue to be one of the main goals of the nuclear physics community [8], as testified by the construction and updating of a number of facilities around the world [9–12].

Experimentally, one method of studying unstable nuclei is by means of their decay energy spectrum, which measures the number of decays per unit of energy versus energy (see for example Refs. [13,14]). In particular, by using techniques such as invariant-mass spectroscopy, it is possible to obtain the experimental decay energy spectrum of some unstable nuclei that decay by neutron emission (see for example Refs. [3,15–17]). Hence, it is important to be able to calculate such spectra theoretically.

In Refs. [18,19], the resonant (Gamow) state was used to obtain a theoretical expression for the decay energy spectrum of an unstable system decaying into the continuum. The purpose of the present paper is to use the formalism of Refs. [18,19] to obtain the energy spectrum of the ^{25}O nucleus, which decays by neutron emission.

Dripline Oxygen isotopes are currently of great interest, both theoretically and experimentally. From the excited states of ^{19}O [20] to the isotopes well beyond the neutron drip line [21], there are several Oxygen isotopes whose energies, widths, and decay energy spectra can be used as a test bench for different theories. The heavier neutron drip line nucleus that has been observed experimentally is ^{24}O, which was found to be doubly magic [22]. An excited state of ^{24}O was found [23] to decay sequentially to ^{22}O. In addition, other low-lying neutron-unbound excited states of ^{24}O have been measured [24]. The energy and width of the unbound ground state of ^{25}O were investigated in Refs. [25–28], and strong evidence for the first excited state of ^{25}O was found in Ref. [28]. The ground state [27,29], excited states and decay modes [17,26] of ^{26}O have also been studied.

In our analysis, we will use the neutron-unbound ^{25}O because its decay energy spectrum has been measured experimentally [25–28]. Since ^{24}O is doubly magic, we will treat ^{25}O as a valence neutron in an ^{24}O core, and we will describe the valence neutron by a Gamow state. This two-body model is able to reproduce the experimental ground state of ^{25}O, $3/2^+$. However, our two-body model yields $7/2^-$ as the first excited state, instead of the one found experimentally, $1/2^+$.

The structure of the paper is as follows. In Sec. 2, we summarize the formalism needed to calculate the theoretical decay energy spectrum. In Sec. 3, we assess the validity of the code. In Sec. 4, we apply the code to the ^{25}O nucleus. We will model the interaction between the valence neutron and the ^{24}O core by the Woods–Saxon and the spin-orbit potentials, and obtain the energies, widths and decay energy spectra of the ground and first excited states. We will compare our results with those obtained by the Continuum and the Gamow Shell Models [6,7]. We will also compare the theoretical decay energy spectrum with the experimental ones [25–28]. In addition, we will discuss the similarities and differences (both quantitative and phenomenological) between the Gamow-state decay energy spectra and the Breit–Wigner distributions with energy-dependent width. In Sec. 5, we summarize our main results and present an outlook of future applications.

2. Formalism

In order to be self-contained, in this section we outline the main ingredients needed to calculate the decay energy spectrum of ^{25}O.