Spectroscopic Information near $N = 14$ and $N = 16$

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I. PHYSICS MOTIVATION

Historically, the concept of independent particle motion, and various mean-field approaches based thereupon, has played and continues to play a fundamental role in studies of quantum mechanical many-particle systems. From a theoretical standpoint, a single-particle (or quasiparticle) picture of states near the Fermi surface offers a good starting point for studies of systems with many interacting particles. The success of the nuclear shell model rests on the assumption that the wave functions used in nuclear structure studies, can be approximated by Slater determinants built on various single-particle states. In a field like nuclear physics, where the average density in nuclei is high and the interaction between nucleons is strong, one expects that correlations beyond the independent particle motion should play an important role in spectroscopic observables. In particular, recent and future experimental programs in low-energy nuclear physics aim at extracting information on the limits of stability of nuclear matter. Correlations which arise as one moves towards either the proton or the neutron driplines, should then provide us therefore with a better understanding of shell structures and single-particle properties of bound, weakly bound and unstable nuclei.

Unfortunately, the consequences of correlations in many-particle systems are normally extremely difficult to measure experimentally and to interpret theoretically. There are rather few observables from which one can extract clear information on correlations beyond an independent particle motion in a nuclear many-body environment.

A quantity which offers the possibility to study deviations from a single-particle picture, and thereby provide information on correlations, is the spectroscopic factor (SF). Although not being an experimental observable *per se* the SFs are defined as the ratio of the observed reaction rate with respect to the same rate calculated assuming a full occupation of the relevant single-particle states. They are thus often interpreted as a measure of the occupancy of a given single-particle state. From a theoretical point of view they represent a measure of what fraction of the full wave function can be interpreted as an independent single-particle or hole state on top of a correlated state, normally chosen to be a closed-shell nucleus.

Recent advances in *ab initio* calculations have resulted in the ability to calculate the properties of nuclei with mass greater than 20, providing precise estimations of properties of nuclei like 48Ca [1], employing properly constrained two- and three-nucleons interactions from effective field theory (and thereby obeying important symmetries of QCD) [2]. These advances allow us now to compute nuclear observables of both stable nuclei and nuclei close to or beyond the driplines, without parameter fitting [3]. Experimental results on nuclei close to the driplines provide thus unique inputs to our basic understanding of correlations in nuclear systems near the limits of stability.

Experimentally there has been quite some emphasis on neutron-rich oxygen isotopes recently. The nucleus ^{24}O is well established as the last bound oxygen isotope. Several recent experiments have provided information on neutron properties close to or beyond the dripline of oxygen isotopes.

However, there is little known about nuclei one to two protons away from the potentially doubly magic ^{22}O and the doubly magic ^{24}O. In the case of ^{22}O, much has been studied experimentally with respect to neutron degrees of freedom, with the primary aim being identifying whether or not the $N = 14$ subshell gap is magic [THI00,STA04,BEC06]. The experimental data, however, is lacking for nuclei that vary by one proton from ^{22}O. For example, since ^{21}N was first observed in 1970 [ART70] only two experiments have been performed to identify excited states of this nucleus [SOH08,ELE10]. In the case of Ref. [SOH08] five excited states were observed by two step fragmentation and were given tentative spin-parity assignments. Similarly, excited states have been measured in ^{23}F three times [ORR89,AZA02,MIC06]. Most recently a series of four reactions were used to populate excited states, including single and multi-nucleon knockout, proton transfer, and inelastic scattering [MIC06]. These measurements resulted in an analysis of the angular distributions of charged particles from the (^{4}He,t) transfer reaction which led to the determination of spectroscopic factors for two of the observed states. For both ^{23}F and ^{21}N, there are no firm spin-parity assignments, and spectroscopic factors are either unknown (^{21}N) or unconfirmed (^{23}F). A more thorough study of the excited states in ^{23}F and ^{21}N, including firm spin-parity assignments and measurements of spectroscopic factors, would provide invaluable input to our understanding of how a single-particle interpretation evolves towards the driplines. Experimental cross sections combined with theoretical *ab initio* calculations of spectroscopic factors can thus shed important information on the evolution of shells and proton and neutron single-particle states close to ^{24}O. Approaching the neutron dripline with ^{24}O, the experimental data becomes more scarce. Although ^{25}F was also first observed in 1970 [ART70] and several gamma rays were observed in the early 2000âs [BEL01,AZA02,ELE04], the first detailed spectroscopy of

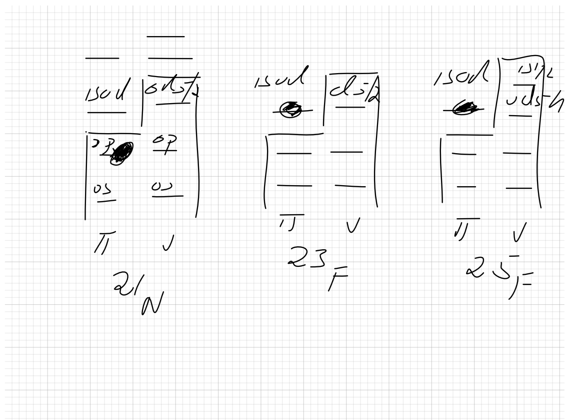

Figure 1. Possible proton states above and below the Fermi levels of ^{23}F, ^{21}N, and ^{25}F. A schematic single-particle picture has been adopted. Whether this picture is meaningful or not, is a central aim of this proposal.

excited states in ^{25}F was not published until 2014 [VAJ14]. In Ref [VAJ14] seven gamma-rays are identified corresponding to five excited states. The states are given tentative spin-parity assignments, but due to the nature of the fragmentation reaction employed, spectroscopic factors were not determined. Performing single proton knockout reactions with beams of radioactive ^{24,26}Ne and ^{23}O will provide a critical means to further develop the current understanding of the structure of neutron rich isotopes near $N = 14$ and $N = 16$. By probing the largely mysterious proton shell structure in this region in a systematic way, as a function of changing isospin, we will gain valuable, currently unknown, knowledge on the structure of the excited states of ^{23}F, ^{21}N, and ^{25}F, as well as information concerning the ground state configuration of the potentially doubly magic ^{22}O, as shown in Fig. [**?**]. Information about the possible single-proton nature below and above the Fermi level of ^{22}O can thus be extracted from the structure of the excited states of ^{23}F and ^{21}N. Furthermore, the evolution of eventual single-proton states above the Fermi leves of the doubly magic nuclei ^{22}O and ^{24}O, can in turn be extracted from the spectroscopic information from ^{23}F and ^{25}F, providing us with a complete picture of proton and neutron degrees of freedom close to the dripline of the oxygen isotopes. Figure [**?**] shows the schematic single-particle interpretation which can tested.

II. GOALS OF THE PROPOSED EXPERIMENT

The primary goal of this experiment is to measure the spectroscopic factors and spin-parities of states in ^{23}F, ^{21}N, and ^{25}F near the $N = 14$ and $N = 16$ magic numbers. By measuring proton knockout from radioactive ^{24,26}Ne we will be able to determine the spectroscopic factors of the low lying states in ^{23,25}F. This information is crucial to the further development and predictive power of ab initio models aiming to correctly describe the behavior of the oxygen, and near oxygen isotopes as they approach the dripline. In addition to the knockout from Ne, proton knockout reactions will also be performed using a radioactive ^{22}O beam, and a stable ^{16}O beam. The aim of these reactions will be to understand the underlying structure of the oxygen isotopes. These measurements will further allow us to characterize the nature of the ground state of the potentially doubly magic ^{22}O isotope. At the same time, we will be able to identify excited states in ^{21}N, and make spin-parity assignments and determine spectroscopic factors to these states. Information on these neutron dripline nuclei, combined with *ab initio* theoretical studies, will provide crucial information for our understanding and interpetration of nuclei close to the limits of stability.

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