EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal
to the ISOLDE and Neutron Time-of-Flight Committee

Study of proton-rich Ne isotopes with the ISOLDE Solenoidal Spectrometer

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Requested shifts: 23 shifts
Beamline: XT02 (ISS)

Abstract

The present proposal aims to explore the evolution of single-particle occupancies of *sd*-shell nuclei in the vicinity of the proton drip lines. The novel ISOLDE Solenoidal Spectrometer (ISS) recently commissioned at HIE-ISOLDE will be used to study the evolution of the single particle strength of ^{18,19}Ne with the (d,^{3}He) reaction in inverse kinematics.

1. Introduction

The ideal nuclear picture derived from the shell model considers the nucleus as composed of defined nuclear states fully occupied by nucleons. However in a real nucleus correlation effects [1] lead to the mixing of configurations, reducing the occupancies as the Fermi energy is reached. The degree to which a nuclear state resembles that of single nucleons moving in the average nuclear field is quantified via the spectroscopic factor SF. For stable nuclei the (e.e') data reveals a SF quenching factor around 0.6 with respect to the predictions of the independent particle shell model [2], but the situation in the regions of beta-instability is still greatly unknown. Measured neutron quenching factors for some proton rich nuclei like ^{31}S, ^{32}Cl, and ^{33}Ar decrease to around ~ 0.5 [3]. For the case of ^{32}Ar a small value of ~ 0.25 was reported, showing the strong effect of correlations on neutron subshells N=15,16 far from stability. Results for stable and Ne isotopes (N= 23, 25) are given in [4, 5]. The quenching seems to arise from long-range nuclear correlations and is expected to be larger for the minor nuclear component, eg. SF(n) or SF(p) for p- or n- rich nuclei, respectively [6]. State-of-the-art ab-initio calculations in the coupled-cluster approach were carried out in [7] for neutron-rich oxygen isotopes. The results (Figure 1 left) exhibit a strong variation of SF(π), SF(ν) as a function of the p-n separation energy parameter ΔS. The SF(π) increases from ~ 0.8 for ^{16}O to the maximum value ~ 1 around the neutron dripline. This can be understood as the single-particle correlations increasingly dominate the dynamics of weakly-bound valence nucleons around the Fermi level. The corresponding SF(p) is reduced to about ~ 0.5, which seems a limit for Z=8.

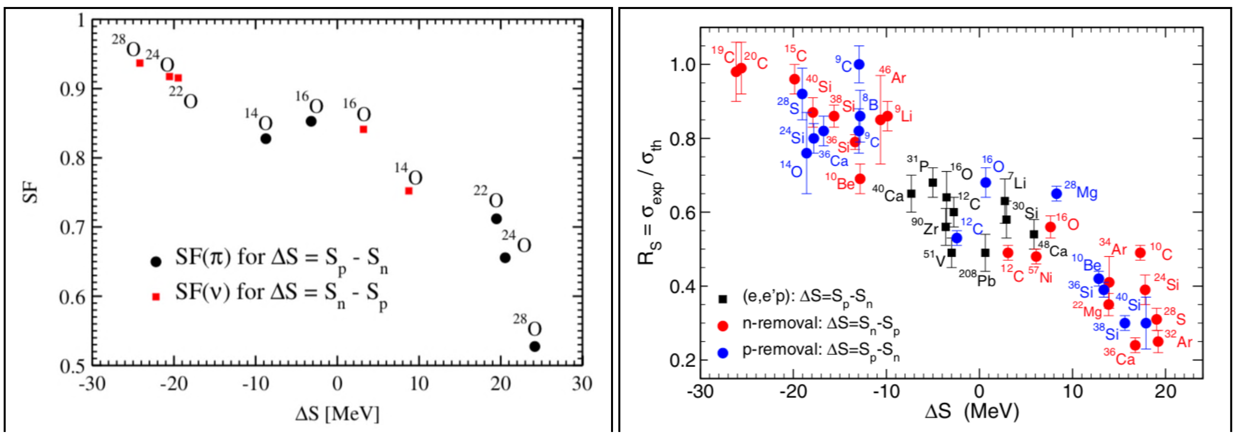

Figure 1. Left: Plot of calculated SFs as functions of the difference between the calculated neutron and proton separation energies [7]. Right: Reduction factor Rs from inclusive one-nucleon-removal cross sections [8].

A systematic reduction of the SF-quenching (Rs) with ΔS has been observed when comparing experiment and shell-model calculations [8] (Figure 1, right panel). The experimental data are from knockout reactions and the theoretical values from Hartree-Fock calculations. For nuclei close to stability the shell model only reproduces about ~50% of the single particle strength. However, when the N-Z asymmetry is increased away from the stability, the value of Rs for the weakly bound major component reaches ~100% and the tightly bound minor decreases down to ~20%.

The extraction of SF factors from experimental data rely in reaction models, where knockout and nucleon transfer often produce very different results. Knockout reactions tend to involve all the bound and unbound excited states of the residues, whereas the transfer reactions are usually limited to a finite number of single-particle states populated during the reaction process. A systematic analysis of neutron pick-up (p,d) reactions for a large set of stable nuclei was carried out in [9] using a three-body model [10], obtaining Rs ~0.6 and no dependence on ΔS. Similar conclusion was obtained in ref [11] using (p,pn) and (p,2p) knockout reactions with exotic oxygen isotopes. The recent work of ref [12] further confirm a weak dependence of Rs on p/n transfer, mass, reaction type and L transfer.

Therefore, in order to investigate the validity of the shell-model calculations, it is needed to measure the relevant reaction channels involved in the extraction of SFs and use appropriate nuclear reaction models.

2. Physics case

Although knockout reactions have produced abundant spectroscopic information on the ground-sate of exotic nuclei, very few data are available from transfer reactions, particularly on the proton rich side. Transfer reactions has the advantage of being able to select specific final states and individual single particle components of the nuclear wave function, allowing to track their evolution from the stability to the proton drip lines. This information is essential to probe and develop detailed models of nuclear structure in these special regions of extreme isospin and low binding energy, dominated by a strong interplay between nuclear, Coulomb and pairing interactions.

Systematic analysis of Rs for transfer reactions with large ΔS are thus needed to further compare the results obtained with transfer and knockout reactions [10]. From the dynamics point of view, new data in the proximity of the proton drip line is also needed to understand the role of nucleon correlations for developing accurate reaction models. In this mass region strong couplings are expected between elastic, inelastic, transfer channels and the continuum which will affect the values of the extracted spectroscopic factors. In this proposal we aim to investigate the evolution of the single-particle strength across the proton-rich sd-shell nuclei by using transfer reactions.

Among the *sd*-nuclei, the p-rich neon isotopes are of particular interest to trace the evolution of the single-particle components leading to the formation of the proton halo/skin nuclei ^{17}Ne [13,14]. The recent commissioning of the ISOLDE Solenoidal Spectrometer [15] and the intense beams of p-rich neon isotopes presently available (Table 1) provide a unique tool for performing high-precision spectroscopy in a wide range of ΔS with transfer reactions.

We propose to perform a detailed study of ^{18,19}Ne with the (d,^{3}He) reaction at 180 MeV in inverse kinematics, which can be measured using the available HIE-ISOLDE intensities (Table 1**). The goal of the proposed experiment is to determine the single-proton strength of $2s_{1/2}$, $1d_{3/5}$ and $1d_{5/2}$ components of the ground states.** No spectroscopic information is available in the literature. Past measurements have focused on states of astrophysical interest lying above the proton separation threshold [16]. The region of ΔS to be explored is schematically depicted in Figure 2.

ISOTOPE	ISOLDE YIELD (pps)
^{19}Ne	9.6 10^{6}
^{18}Ne	6.9 10^{5}

Table 1. Proton rich Neon isotopes with yields > 10^{5} pps.

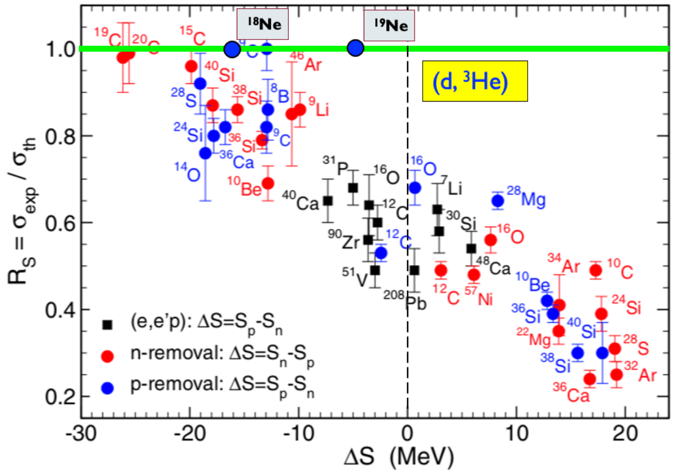

Figure 2. Regions of Δs to be investigated with the ISS spectrometer. Adapted from [8].

3. Theoretical calculations and simulations

Figure 3 shows a selection of levels and couplings possibly participating in the ^{18,19}Ne(d,^{3}He) reaction. Finite-range DWBA calculations for proton pickup has been carried out using FRESCO, assuming SF=1. The results are shown in Figure 4. We used global deuteron and ^{3}He scattering parameters [18, 19]. The d/^{3}He overlap uses the binding potential and SFs matched to shell model calculations [20]. The $2s_{1/2}$ component will produce peaks at θ_{Lab} = 0°, 30°, 70° (red lines), whereas the $1d_{3/2,}$ $1d_{5/2}$ components give a smoother behavior with maxima at θLab ≃ 25°, 55°, 85° (blue and green lines). The total cross sections are in the range of ~ 5 - 30 mb.

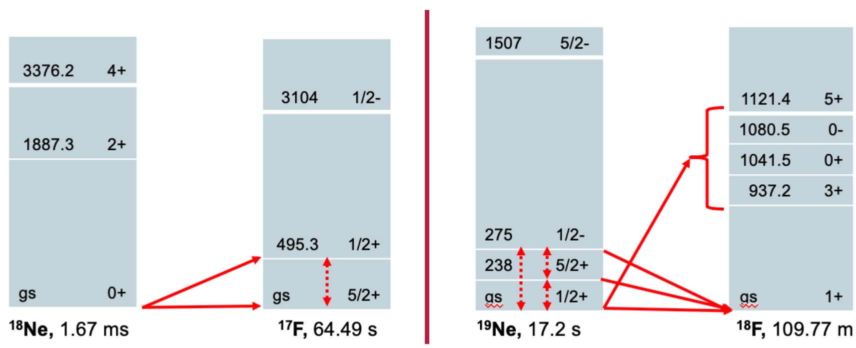

Figure 3. A selection of levels (energy in keV) and couplings in ^{18,19}Ne and ^{18,19}F in (d,^{3}He) reactions.

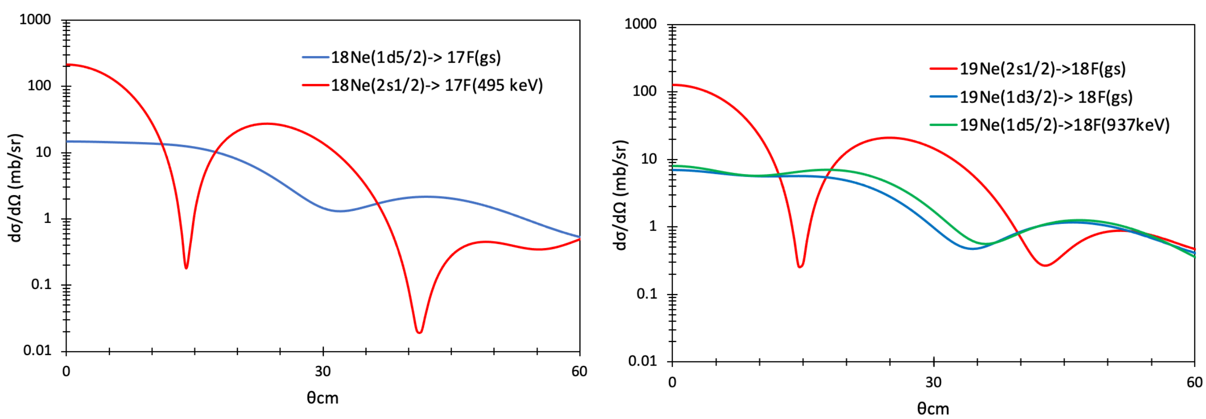

Figure 4. Left: Result of DWBA calculations for ^{2}H(^{19}Ne,^{3}He)^{18}F (left) and ^{2}H(^{18}Ne,^{3}He)^{17}F (right) at 180 MeV, from $2s_{1/2}$ and $1d_{3/2}$, $1d_{5/2}$ single-particle components to ground and excited states of the recoiling nucleus.

The left panel of Figure 5 shows a simulation of the expected ^{3}He angular distribution of ISS for the reaction ^{18}Ne(d,^{3}He)^{17}F at 180 MeV. The simulations were carried out using the code NP-Tool. The kinematics of the reaction is shown in the right panel. The energy of ^{3}He ejectiles after the thick 300 μg/cm^2 target varies from ~ 400 keV to ~ 8 MeV in the angular range 25° - 55 ° Lab. The total detection efficiency is ~ 55%. Similar results are obtained for the reaction ^{19}Ne(d,^{3}He)^{18}F.

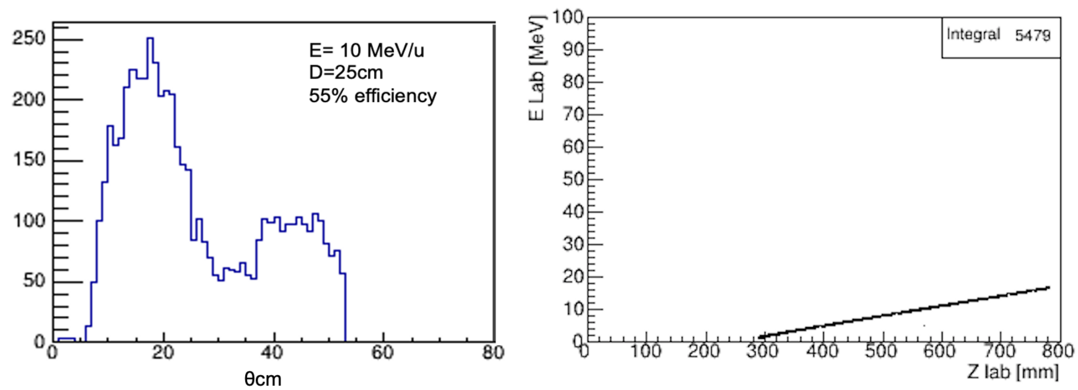

Figure 5. Left: Simulation of the ^{3}He angular distribution as a function of the scattering angle (cm) for the reaction ^{18}Ne(d,^{3}He)^{17}F at 180 MeV with 300 μg/cm² CD_2 target (NPTool). Right: kinematics of ^{3}He ejectiles.

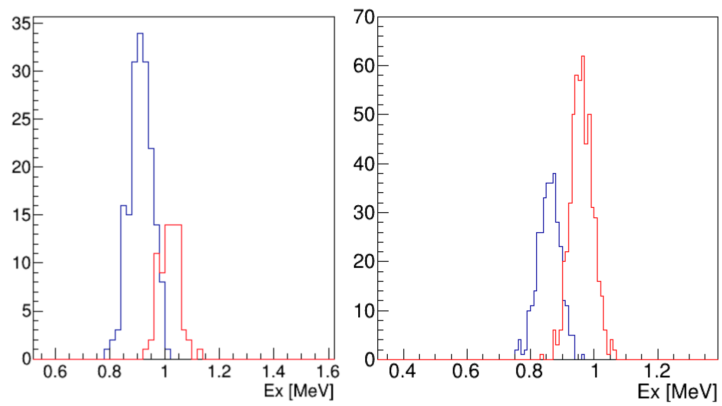

Figure 6. Simulation of the excitation energy distribution at 40°±0.5° lab (Left) and 45°±0.5° lab (Right) for the reaction ^{19}Ne(d,^{3}He)^{18}F* at 180 MeV populating the levels 937 keV(3+) (blue) and 1041 keV(0+) (red) with a 300 μg/cm² CD_2 target (NPTool).

Ground and excited states of fluorine recoils can be populated by proton-pickup up to the proton separation threshold. In the case of ^{18}Ne transfer to ^{17}F(gs) and the first level at 495.3 keV are possible. Because of angular momentum conservation, the former can only proceed through the $1d_{5/2}$ component of the ^{18}Ne(gs), and the latter through its $2s_{1/2}$ component. In the exit channel, coupling between ^{17}F(gs) and the first level at 495.3 keV should be included using coupled reaction channel calculations (CRC). In a similar manner ^{18}F(gs) can only be populated from the $2s_{1/2}$,$1d_{3/2}$ components of the ^{19}Ne (gs) w.f., the first 3+ excited state at 937 keV from its $1d_{5/2}$ component, and the 0+ excited state at 1041 keV from the $2s_{1/2}$ component. The states at 1080 keV (0-) and 1121 keV (5+) cannot be reached due to angular momentum and parity conservation. The separation of the 937 keV and 1041 keV levels is only 104 keV, at the limit of the energy resolution of the spectrometer. The simulations for 40° and 45° lab are shown in Figure 6. In principle, the relative contributions could be extracted using a fitting procedure. However, the angular distributions for the *s* and *d* transfer are very different, and the SF's can be extracted by fitting the angular distribution of the peak-sum with the theoretical calculations. In the entrance channel, the levels at 238 keV and 275 keV can be excited and coupled to the transfer process. Couplings effects have been observed in (d,^{3}He) reactions with stable neon isotopes [17]. The energy difference is below the energy resolution of the ISS, but the total angular distribution and its effect on the transfer process can be studied by CRC calculations. Thus, together with the experimental data, comprehensive reaction models can be developed to extract the SFs and to investigate the dynamical effects behind the quenching ratios.

4. Experimental setup

The goal of the experiment is to determine the single-proton strength of $2s_{1/2}$, $1d_{3/5}$ and $1d_{5/2}$ components of the ground states of ^{18,19}Ne isotopes. For this propose we will measure the angular distribution of the elastic and inelastic deuterons, and the ^{3}He ejectiles from the reaction ^{18,19}Ne(d,^{3}He)^{17,18}F at 180 MeV in inverse kinematics, covering the angular range 25°-55° lab (~ 5°- 55° cm) and up to ~2 MeV excitation energy in the recoiling nuclei. We will use the ISOLDE Solenoidal Spectrometer (ISS) to analyse the ^{3}He and deuterium ejectiles. The ISS silicon array will be placed at 25 cm from a CD_2 target of 300 µg/cm^{2}, and the recoil detector in front where ^{3}He ions will go over the top. The beam energy and target thickness has been chosen according to the following criteria:

- Maximum yield of ground and low-lying states of the recoiling fluorine isotopes.
- Minimum kinetic energy of ^{3}He ejectiles ~ 400 keV.
- Maximum energy straggling ~ 50 keV.
- Maximum angular straggling ~ 1° lab.

5. Beam requirements

The beam time request is summarized in Table 2. The shift number is estimated for 5000 counts total in the angular range of interest, assuming a 10% beam transmission and 55% efficiency for ISS. One shift of stable ^{20}Ne (~ 10^{6} pps) is needed for the detector setup, and another 2 for changing beams to ^{19}Ne - ^{18}Ne.

ISOTOPE	Intensity on target	SHIFTS
^{18}Ne	6.9 10^{4} pps	18.5
^{19}Ne	9.6 10^{5} pps	2.5
Beam change		2
	Total	23

Table 2. Beam time request.

6. Safety

Use of Cryogenic fluid (LHe) and strong magnetic fields (2.5 T).

Summary of requested shifts:

2.5 x ^{19}Ne, 18.5 x ^{18}Ne, 2 x beam change

Stable beam: 1 x ^{20}Ne

References:

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: *The experimental setup comprises: ISOLDE solenoidal spectrometer)*

Part of the Choose an item.	Availability	Design and manufacturing
[if relevant, name fixed ISOLDE installation: MINIBALL + only CD, MINIBALL + T-REX]	☐ Existing	☐ To be used without any modification
ISOLDE solenoidal spectrometer	☒ Existing	☒ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[Part 2 experiment/ equipment]	☐ Existing	☐ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]		

HAZARDS GENERATED BY THE EXPERIMENT

(if using fixed installation) Hazards named in the document relevant for the fixed [MINIBALL + only CD, MINIBALL + T-REX] installation.

Additional hazards:

Hazards	*[Part 1 of the experiment/equipment]*	*[Part 2 of the experiment/equipment]*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure			
Vacuum			
Temperature	4 K		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid	LHe, ~1650 l, LN2 , ~200 l, 1.0 Bar		
Electrical and electromagnetic			
Electricity	0 V, 300 A		
Static electricity			
Magnetic field	2.5 T		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	[material]		

Beam particle type (e, p, ions, etc)	Ions// 20,19,18Ne		
Beam intensity (on target)	^{18}Ne, 6.9 10^{4} pps ^{19}Ne, 9.6 10^{5} pps ^{20}Ne ~ 10^{6} pps		
Beam energy	180 MeV		
Cooling liquids			
Gases			
Calibration sources:	☐		
• Open source	☒ Alphas -callibration		
• Sealed source	☐ [ISO standard]		
• Isotope			
• Activity			
Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance	[		
• Isotope			
• Activity			
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chemical agent], [quantity]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chemical agent], [quantity]		
Corrosive	[chemical agent], [quantity]		
Irritant	[chemical agent], [quantity]		
Flammable			
Oxidizing			
Explosiveness			
Asphyxiant	Helium		
Dangerous for the environment	[chemical agent], [quantity]		
Mechanical			
Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		
Vehicles and Means of Transport	[location]		
Noise			
Frequency	[frequency],[Hz]		
Intensity			
Physical			
Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		
Manual handling	[location]		
Poor ergonomics	[location]		

0.1 Hazard identification

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*

5 kW