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PAIRING IN EXOTIC He ISOTOPES*

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Data obtained in experiments with the exotic helium isotopes, ^{6,8}He, are reanalyzed to learn about correlations between the valence neutrons. The results indicate strong pairing of the two valence neutrons in ^{6}He, similar to that found in ^{18}O. For ^{8}He, the observed effect is still strong but weaker than that for ^{6}He.

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1. Introduction

The existence of bound multineutron systems in nuclear matter, such as the dineutron or tetraneutron, is currently attracting considerable attention in nuclear physics. Recent experimental studies suggest that the

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tetraneutron can exist as a system of correlated dineutron pairs [1]. In this contribution, we explore the question as to how strong are the pairing forces in the exotic helium isotopes, ^{6,8}He.

Information about correlations between the valence nucleons can be obtained from studies of nucleon-transfer reactions. If the valence nucleons are not correlated into pairs, the transfer of two nucleons proceeds mainly as a two-step process by the sequential transfer of single nucleons. Thus, if the probability for a single transfer (a single step) is P_1, the probability of the two-step process is the square of this value. In the case of a correlation, the transfer is most likely to be a one-step process and the probability of the two-nucleon transfer is enhanced compared to the two-step value and can be written as

$$P_2 = \mathrm{EF}\ P_1^2 \,, \tag{1}$$

where EF is an enhancement factor that can serve as a measure of the correlation (pairing) [2].

2. Data analysis

Suitable scattering experiments with ^{6,8}He beams on lead targets at energies around the Coulomb barrier have been recently performed [3, 4]. An experiment with an 18 MeV ^{6}He beam scattered from a ^{206}Pb target was performed at Louvain-la-Neuve [3], while at GANIL a 22 MeV ^{8}He beam was scattered from a ^{208}Pb target [4]. In both experiments, in addition to elastically scattered particles, angular distributions of α-particle and ^{6}He yields (for ^{6}He and ^{8}He beams, respectively) were measured. These reaction products could be produced either by breakup of the loosely-bound incident particles or one- and two-neutron stripping reactions.

Particles from breakup could be separated from the total yields as they are located at the most forward angles. For transfer reactions, the optimum Q values are similar for the one- and two-neutron transfers. These values are slightly negative [3, 5] and the reaction products peak at backward angles. In the experiments discussed here, transfers of one and two neutrons could not be separated, therefore, in this work model calculations are used, following the method in Ref. [3], in order to perform the separation. Thus, the results of the distorted-wave Born approximation (DWBA) and coupled-reaction channels (CRC) calculations of the one-neutron transfer reactions published in Ref. [3, 4] were used to extract the two-neutron transfer contributions from the total α or ^{6}He yields (see Fig. 6 of Ref. [3] for the α yield). Transfers to the following single-particle states in the final nuclei were included: 0.0, 2.73, 4.40, 4.64, 5.14, 5.13 MeV (^{207}Pb) and 0.0, 0.78, 1.42, 1.57, 2.03, 2.49, 2.54 MeV (^{209}Pb). The calculations are described in detail in Ref. [3, 4] where all the parameters are also given.

For ^{6}He + ^{206}Pb, this extraction was done for laboratory angles larger than 100° and for ^{8}He + ^{208}Pb for angles larger than 50°.

The two-neutron transfer data obtained in this way may be presented in terms of the transfer probabilities, $P_{2n}(\theta_{\rm lab})$,

$$P_{2n}(\theta_{\rm lab}) = \frac{\sigma_{2n}}{\sigma_{\rm Ruth}}(\theta_{\rm lab})\,, \tag{2}$$

where $\sigma_{\rm Ruth}$ is the Rutherford cross section. The transfer probabilities, in turn, can be presented as a function of the classical distance of closest approach,

$$D = \frac{Z_a Z_A\, e^2}{2E_{\rm cm}} \left(1 + \frac{1}{\sin(\theta_{\rm cm}/2)}\right)\,, \tag{3}$$

where Z_a and Z_A are the charge numbers of the projectile and target, respectively.

The two-neutron transfer reaction data, ^{206}Pb(^{6}He,α)^{208}Pb and ^{208}Pb (^{8}He,^{6}He)^{210}Pb, obtained from the total α and ^{6}He yields by subtracting the calculated one-neutron transfer contribution and transformed into probabilities using the above equations, are plotted in Figs. 1 and 2. The calculated one-neutron transfer cross sections were transformed into probabilities in the same way and compared to the two-neutron ones by means of Eq. (1). The dashed curves plotted in Figs. 1 and 2 represent results corresponding to EF

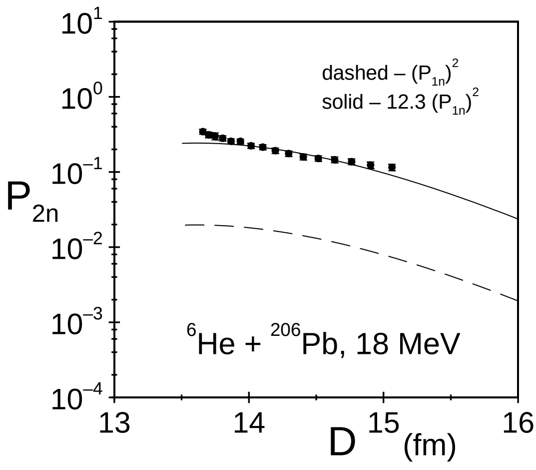

Fig. 1. Transfer probabilities for the ^{206}Pb(^{6}He,α)^{208}Pb reaction at a bombarding energy of 18 MeV as a function of the distance of the closest approach. Solid points: values extracted from experimental data [3]. The curves correspond to the predictions according to Eq. (1) (dashed curve with EF = 1.0, solid curve with EF = 12.3), with P_{1n} obtained from the DWBA calculations of Ref. [3].

factors of unity. They underpredict the experimental points, suggesting a pairing correlation of the valence neutrons. The solid curves correspond to EF factors equal to 12.3 and 6.7 for ^{6}He and ^{8}He, respectively.

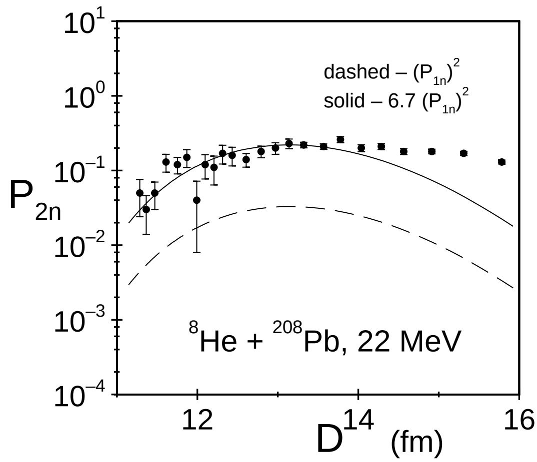

Fig. 2. Transfer probabilities for the ^{208}Pb(^{8}He,^{6}He)^{210}Pb reaction as a function of the distance of the closest approach. Solid points: values extracted from the experimental data [4]. The curves correspond to predictions according to Eq. (1) (dashed curve with EF = 1.0 and solid curve with EF = 6.7), with P_{1n} obtained from the CRC calculations of Ref. [4].

3. Summary

From a reanalysis of the data sets obtained in ^{6}He+^{206}Pb and ^{8}He+ ^{208}Pb experiments [3, 4], it is found that the valence neutrons in the exotic helium isotopes, ^{6}He and ^{8}He, are strongly correlated. For ^{6}He, the paring of the valence neutrons is comparable to that published recently for ^{18}O [6], while for ^{8}He, the effect is somewhat weaker. To the best of our knowledge, this is the first study of this type performed for radioactive neutron-rich nuclei. The results obtained are model-dependent but this work builds on the experience gained from a previous analysis of the one-neutron stripping reaction for a weakly-bound nucleus incident on a lead target, the ^{208}Pb(^{7}Li,^{6}Li)^{209}Pb reaction using a polarized lithium beam [7]. One should note, however, that the method applied in the present study may lead to an overprediction of the enhancement factors for ^{6,8}He due to the too low values of the one-neutron transfer cross sections adopted from the previous model calculations [3, 4]. In these calculations, only the transfers to the ground states of ^{5,7}He were taken into account. An earlier study of the ^{6}He$(p,d)^5$He reaction has shown that the transfer can also proceed to the resonant state of ^{5}He at 1.27 MeV enhancing the total calculated value of the one-neutron transfer cross section [8]. In order to obtain model-independent values of the enhancement factor, future experiments should be designed so that the contributions of the one- and two-neutron transfer reactions can be separated.

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