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Spectroscopic Analysis of the Energy-Level Structure in Rhenium-190

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Abstract. Investigations of neutron-rich nuclei, particularly those that lie in regions of the nuclear chart known for a high probability of isomeric states forming, are of vital importance to the understanding of nuclear astrophysical processes. Studies of these nuclei, such as ^{190}Re, can be used to validate and improve theoretical models of such processes. A polarised-beam experiment has been performed using the Munich Q3D magnetic spectrograph in order to investigate the energy-level structure of ^{190}Re. An excitation-energy spectrum has been produced, allowing for energies to be assigned to observed states. Through comparison between measured and calculated differential cross-sections and vector analysing powers, the process of assigning spin and parity to newly observed states, and confirming the assignments for previously observed states, is underway.

1. Introduction

The study of neutron-rich isotopes is of great importance to the nuclear physics community as such isotopes are often involved in the rapid neutron-capture process (the r-process). Elucidating more information about these isotopes, such as their mass and energy-level structure, can be used to improve astrophysical models. The isotope ^{190}Re is an example of such a neutron-rich isotope. It is produced in decays from the path of the r-process, specifically from the waiting point due to the magic number at $\mathrm{N} = 126$.

An experiment was performed at the Maier-Leibnitz Laboratory (MLL) in Munich using the Q3D magnetic spectrograph [1]. The $^{192}\mathrm{Os}(\vec{d},\alpha)^{190}\mathrm{Re}$ and $^{194}\mathrm{Pt}(\vec{d},\alpha)^{192}\mathrm{Ir}$ reactions were used to investigate the mass and energy-level structure in ^{190}Re. Previous to this work, the atomic mass of ^{190}Re had an uncertainty of $\pm 70\,\mathrm{keV}$ [2]. Published mass-measurement results arising from this study have already reduced this uncertainty to $\pm 5\,\mathrm{keV}$ [3]. The remainder of the study focuses on the investigations into the energy-level structure of ^{190}Re. Evidence for more than twelve previously unknown energy-levels has been found, in addition to more precise measurements of some of the known energy-levels such as the $J^\pi = (6^-)$, 204 ± 10 keV isomeric state [4], as detailed in this paper.

2. Experimental Procedure

In order to measure α-particle ejectiles from the ^{192}Os($\vec{d}$,α)^{190}Re and ^{194}Pt($\vec{d}$,α)^{192}Ir reactions, a 14 MV tandem Van de Graaff accelerator was used to produce an 18 MeV beam of deuterons. Polarised spin-up and spin-down deuteron beams were utilised in this experiment. This beam was incident on ^{192}Os and ^{194}Pt targets of thickness 45 μg cm^{-2} and 66 μg cm^{-2} respectively, both backed with 7 μg cm^{-2} of carbon. The Q3D magnetic spectrograph was positioned at various angles with respect to the beam line in order to measure the properties of the α-particle ejectiles at various emission angles. This set-up is shown in figure 1.

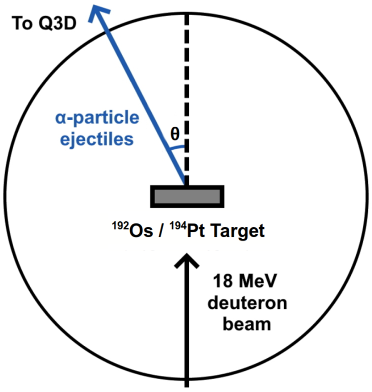

Figure 1. A schematic view of the experimental set-up used in this study. The value of θ was varied in order to extract the angular distributions of excited states in the recoil nuclei.

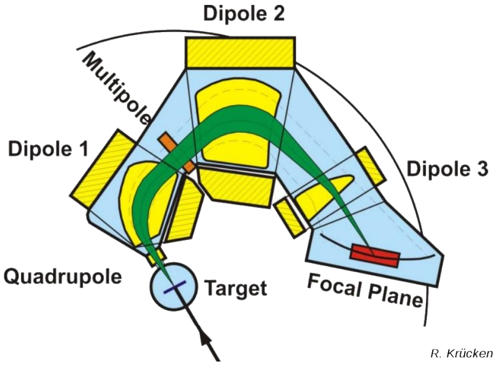

Figure 2. An overview of the Q3D magnetic spectrograph, showing the position of its dipole, quadrupole and multipole magnets as well as its focal plane. Figure from Ref. [5].

The Q3D magnetic spectrograph is shown in figure 2. Particles entering the Q3D were separated based on their charge-to-momentum ratio which, for particles of the same charge, is simply their momentum and, therefore, directly related to their energy. The Q3D can also be used to perform particle identification based on the energy loss of particles within the focal plane detector volume. Thus, clean energy spectra can be produced for the α-particle ejectiles emitted in the aforementioned reactions. To investigate properties of the excited states in ^{190}Re the Q3D was placed at 10°, 15°, 21° and 27° with respect to the beam axis, with polarised spin-up and spin-down beams used at each angle. A run with the Q3D placed at 20° was also performed with an unpolarised beam.

3. Analysis of Level Structure

3.1. Level Energies

Energy spectra for the α-particle ejectiles were produced for both the ^{192}Os($\vec{d}$,α)^{190}Re and ^{194}Pt($\vec{d}$,α)^{192}Ir reactions with the Q3D placed at 20° with respect to the beam axis. A calibration using the well known energy-level structure of ^{192}Ir [6] enables a correspondence to the excitation energy in the heavy recoiling nuclei, ^{190}Re and ^{192}Ir. As the α-particle kinetic energy decreases with increasing excitation in the heavy recoiling nucleus, the excitation energy of the peaks in the spectra increase from right to left. The resulting calibrated ^{190}Re spectrum, demonstrating this effect, is shown in figure 3. Currently, twelve previously unpublished energy-levels have been observed and assigned excitation energies, as well as observation of five previously known levels. Higher energy levels have also been observed and will be studied further once the first seventeen levels have been fully analysed. For some of the known levels, it is anticipated that the uncertainty in their energies can be reduced through this work.

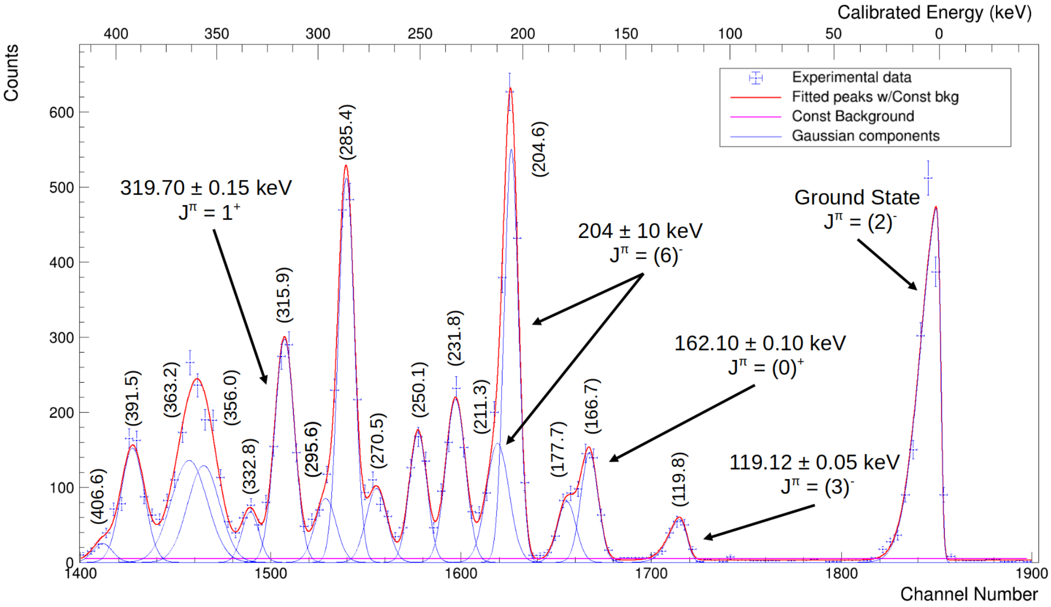

Figure 3. A calibrated α-particle ejectile spectrum corresponding to the energy-level structure in ^{190}Re. Initial energy assignments for the excited states are shown in brackets in units of keV. Beyond ~ 150 keV the calibration is an extrapolation and the energies have an uncertainty of ~ 6 keV. This will be improved upon before full publication of the energies. Previously observed states [7] have been labelled (due to the large uncertainty in the 204 ± 10 keV state, further work is needed to unambiguously assign a peak to this state).

3.2. Level Spins and Parities

Individual ^{190}Re spectra were also produced for measurements taken with the Q3D placed at 10°, 15°, 21° and 27°, all with both spin-up and spin-down polarised beams. This allows for the differential cross-section $\frac{d\sigma}{d\Omega}(\theta)$ and vector analysing power $A_y(\theta)$ to be extracted as follows:

$$\frac{d\sigma}{d\Omega}(\theta) = \frac{\sigma_+(\theta) + \sigma_-(\theta)}{2}, \tag{1}$$

$$A_y(\theta) = \frac{2}{3P_y} \frac{\sigma_+(\theta) - \sigma_-(\theta)}{\sigma_+(\theta) + \sigma_-(\theta)}, \tag{2}$$

where $\sigma_\pm$ are the measured spin-up/spin-down cross sections and P_y is the vector polarisation of the beam [8]. These extracted values can then be compared to calculated values for a variety of spin/parity configurations in order to determine what the spin and parity of each of the excited states in ^{190}Re are. This then allows interpretation of the underlying nuclear structure.

To simulate values of both the differential cross-section and vector analysing power, the program DWUCK4 [9] was used. This program calculates scattering and reaction observables using the distorted-wave Born approximation. To obtain outputs for various spin and parity configurations and compare these to calculated values, a python program named PyDwuck was created. PyDwuck generates input files and runs DWUCK4 for a desired set of spin/parity configurations and determines the optimal configuration based on a minimisation routine. An example of this is shown below in figure 4, where various spin/parity configurations are compared to the measured differential cross-sections for the ~ 119 keV state. It is highly likely that this peak is the previously measured $E = 119.12 \pm 0.05$ keV, $J^\pi = (3)^-$ state.

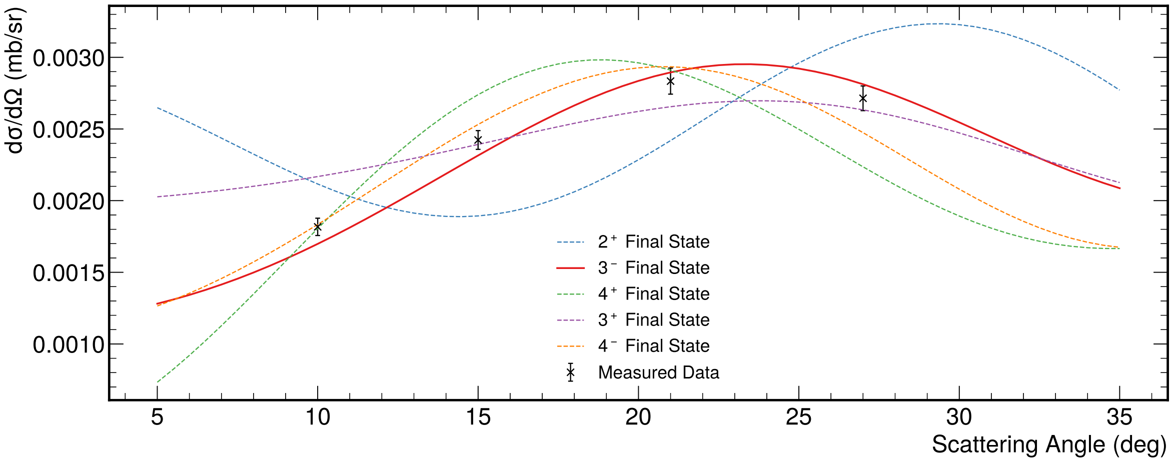

Figure 4. A plot showing the measured differential cross-section for ∼119 keV state in the ^{190}Re energy spectrum compared to calculated differential cross-sections for various spin and parity assignments. The calculation that best fits the measured data, corresponding to a $J^\pi = 3^-$ state, is shown as the clearest line with the other lines dashed.

As can be seen in figure 4, the spin/parity configuration that best fit the data is $J^\pi = 3^-$, in agreement with the current literature assignment for this level [7], with the $J^\pi = 4^-$ assignment also showing good agreement. While this is a promising result, such agreement is not currently observed for the vector analysing power of any of the peaks suggesting an error in the extraction of measured quantities or in the calculation input.

4. Summary and Outlook

An experiment was performed at the Maier-Leibnitz Laboratory using the Q3D magnetic spectrograph with the aim of reducing the uncertainty in the atomic mass of ^{190}Re and improving on current knowledge of its energy-level structure. Through use of an ^{192}Ir calibration energies have been assigned to observed states in the ^{190}Re spectrum, confirming the observation of previously reported levels. Before publication, each energy level will be assigned spin and parity configurations by comparing measured differential cross-sections and vector analysing powers to calculations. This has been successful for the differential cross-sections but more work is needed on the vector analysing powers before confident configuration assignments can be made.

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References

[1] Löffler M, Scheerer H J and Vonach H (1973) *Nucl. Instr. and Meth.* **111** 1 – 12
[2] Wang M *et al.* (2017) *Chinese Phys. C* **41** 030003
[3] Griffiths M R *et al.* (2020) *J. Phys. G: Nucl. Part. Phys.* **47** 085104
[4] Reed M W *et al.* (2012) *Phys. Rev. C* **86** 054321
[5] Dollinger G and Faestermann T (2018) *Nucl. Phys. News* **28** 5–12
[6] Baglin C M (2012) *Nucl. Data Sheets* **113** 1871–2111
[7] Singh B and Chen J (2020) *Nucl. Data Sheets* **169** 1–390
[8] Wirth H F *et al.* (2004) *Phys. Rev. C* **70**(1) 014610
[9] Kunz P D and Rost E (1993) *The Distorted-Wave Born Approximation* (Springer New York) pp 88–107