Determination of α-nucleus potentials by elastic scattering on p-nuclei

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Abundance calculations for the p-nuclei involve an extended network of about 20,000 nuclear reactions of almost 2,000 nuclei. These rates are calculated with the statistical Hauser Feshbach Model (HF-Model). Elastic scattering experimental data provides a test for the global parameterizations of optical potentials that are used in these statistical model calculations.

Recent experiments suggest inconsistencies between the predicted and measured (α,γ) rates which may be due to problems with the α-potential parameters. To explore these parameters the alpha scattering cross sections on $^{120, 124, 126, 128,130}$Te have been measured at energies both close below and above the Coulomb barrier at the FN tandem accelerator of the University of Notre Dame.

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[1] Speaker

1. Introduction

The majority of the heavy elements are synthesized by neutron capture reactions in either the s- or r-process; however, the 35 proton rich stable nuclei lying to the left of the valley of stability are shielded from neutron captures and a different mechanism must account for their formation. The p-process, which is responsible for the synthesis of these proton-rich stable nuclei, mainly involves photodisintegration reactions: (γ,n), (γ,p) and (γ,α) on existing s-process seed nuclei. The synthesis path proceeds via a series of (γ,n) reactions toward the proton rich side until an equilibrium between (γ,n) and (n,γ) reactions is met. At this point, branchings of (γ,p) and (γ,α) occur which lead to the formation of a p-nucleus. The initial abundance of s-seed material is critical as is the timescale and the temperature. The current astrophysical site of synthesis that supports this hot photon bath (T_9=2-3) and these short timescales (~1s) is thought to be in the O/Ne layer of a Type II supernova [1].

2. Modeling the p-process

A p-process network simulation takes into consideration about 2,000 nuclei and 20,000 reactions. One essential component of this simulation is (γ,α) rates. Most α-capture reactions on p-nuclei involve the activation technique. By detailed balance, we arrive at the (γ,α) cross section. The limitation of this method is that the product nucleus must be radioactive and of a measureable half-life. Direct measurements of (α,γ) cross sections at astrophysically relevant temperatures can be very difficult because the corresponding energies are well below the Coulomb barrier and therefore the cross sections very small. Very little data on these reactions at astrophysically relevant energies exist and the current results show a large discrepancy to theory. The vast majority of cross sections are theoretically determined using the H-F statistical model. These theoretically calculated cross-sections are then converted into reaction rates which are then inputs into the network simulation.

The α-nucleus optical potential (which is needed to calculate the transmission probability of the α-particle) is thought to present the largest uncertainty and is thought to account for the current discrepancy of data to theory [2,3]. Global models have been used to parameterize these α-nucleus potentials; however, these models cannot consistently reproduce both (α,γ) and (α,α) data [4,5].

One way to determine the α-nucleus optical potential is by elastic scattering experiments. Below the Coulomb barrier, the cross section is dominated by the electromagnetic interaction and hence extracting nuclear properties of the potential is difficult. If the measurements are done too far above the barrier, then the extrapolation down to astrophysically relevant energies is unreliable; therefore, it is necessary to find a common medium and the scattering data must be very precise in order to ensure an accurate extrapolation. Generally, measurements are done close to the barrier (both below and above). In this work, the measurements were extended to several energy points above the barrier to ensure an accurate determination of the nuclear potential parameters. In this way, the study focuses on getting a local potential that is both energy and mass dependent in order to better understand its behavior and to test the reliability of the H-F model.

3. Experimental set-up and procedure

The experiments were carried out using the FN Tandem accelerator at the University of Notre Dame. Thirty Si pin diode detectors were mounted on a rotatable table which spanned an angular range from 22° to 168° in 2.5° increments. Two monitor detectors were placed at 15° on either side of the beam axis to correct for deviations in the beam spot. Systematic error coming from the uncertainty in the solid angle of 1% dominated at small angles while statistical error played a major role at backward angles.

The solid angles for the monitor detectors were $\approx 1\mathrm{x}10^{-5}$ while those of the rotatable detectors were $\approx 8\mathrm{x}10^{-5}$. The p-nucleus ^{120}Te and its neutron rich isotopes ^{124,126,128,130}Te were measured at 5 energies: 17, 19 (Coulomb barrier), 22, 24.5 and 27MeV. A high energy resolution is desired for a clear identification of the elastically scattered α-particles; therefore, it is necessary to ensure that the α-particles do not deposit too much energy in the target after its interaction with the target nucleus. This is achieved by using relatively thin targets (between 100-300 μg/cm^2) [7]. Since Te oxide has a low melting point (733° C), the degradation of target material is another factor to consider (metallic Te has a melting point of 450° C). The targets were tested prior to measurement and no significant deterioration occurred when exposed to α-beam $\leq$ 250enA.

4. Global Potentials

Current global models as a whole do not take into account both the possible energy and mass dependence of the potentials. In addition, no current model can reproduce both the elastic scattering and the α-capture data. The general trend is that the Fröhlich/Rauscher potential [4] does the best job of reproducing the α-capture data [6]. Figure 1 shows the mass and energy dependence of the potential. For the mass dependence, it is the McFadden/Satchler potential [10] that reproduces the data most accurately; however, this is not the case for the energy dependence which is best represented by the Avrigeanu potential [9].

5. Local Potentials

The potential for ^{120,124,126,128,130}Te was calculated assuming a Double Folding parameterization in the real part and a Volume and Surface Woods-Saxon term in the imaginary part. The analysis of the experimental cross section is done with the code A0 [11]. It proceeds by performing a χ^2 minimization, and adjusting the parameters of the potential systematically. The code calculates the scattering matrix S for a certain nuclear potential. Only those terms which contribute to the elastic scattering are taken into account. Figure 2 below shows the local potential of ^{130}Te preliminary fit compared to experimental data. We see good agreement. In the case of ^{120}Te, the agreement is not as accurate as in the case of ^{130}Te. ^{120}Te is deformed in the ground state and this could be one reason for the less precise agreement [12].

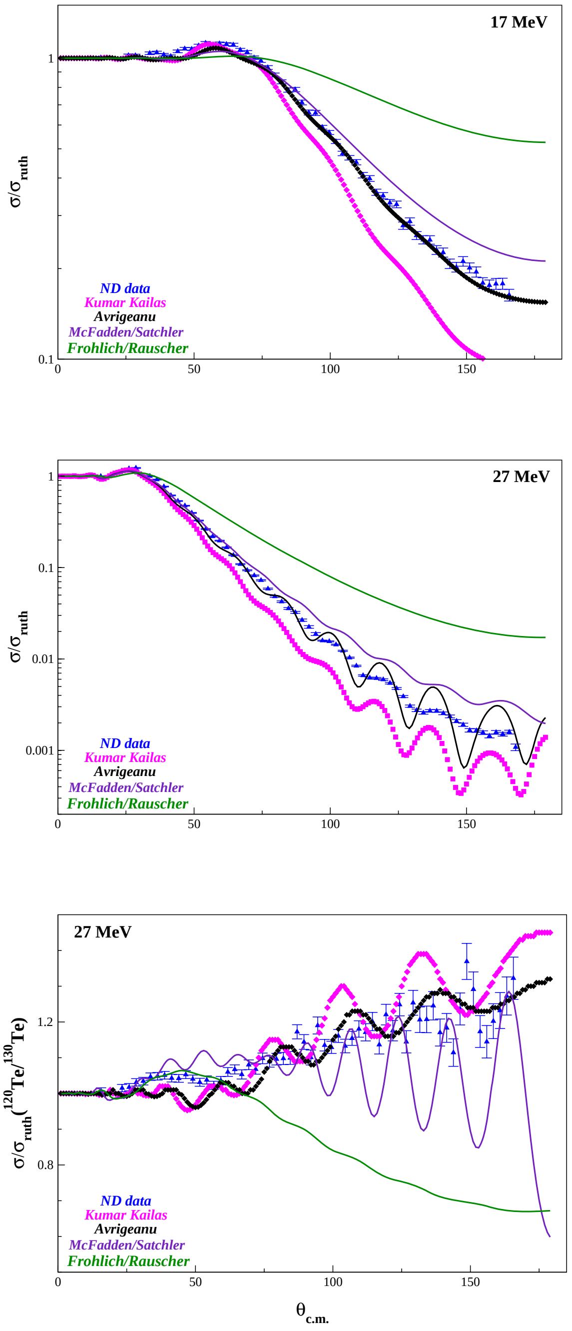

Figure 1: The energy and mass dependence of the potential is tested: the experimental Rutherford normalized cross section (this work) of ^{120}Te at 17 MeV and at 27 MeV (top) is compared to standard global potentials: Kumar Kailas (pink) [8], Avrigeanu (light blue) [9], McFadden/Satchler (green) [10], and Fröhlich/Rauscher (purple) [4]. The third figure shows the mass dependence.

6. Conclusion

The energy and mass dependence of the α-nucleus potential has been studied on the p-nucleus ^{120}Te and along its isotopic chain. In addition, the charge dependence of the potential can be studied by α-scattering on ^{118}Sn. Future work is needed to apply these parameterizations to the H-F calculations of (γ,α) rates and to test the reliability.

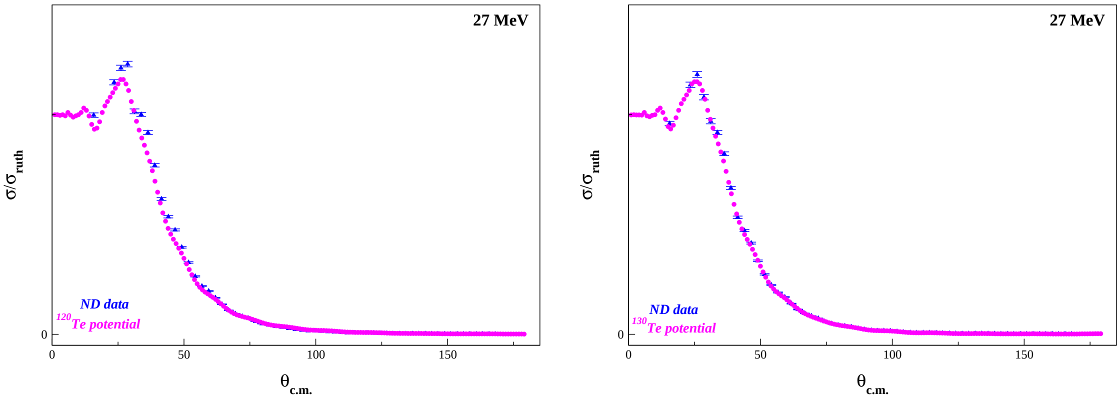

Figure 2: Preliminary fit of the local potential of ^{120}Te compared to the Rutherford normalized cross section (this work) of ^{120}Te at 27 MeV (left) and that of ^{130}Te (right).

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