Measurement of the ^{197}Au(n,γ) cross section at n_TOF, - a step forward towards a new standard for capture cross section measurements

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The accurate knowledge of the ^{197}Au(n,γ) reaction cross section is of great importance, since this reaction if often used as a reference in capture cross section measurements relevant to Nuclear Astrophysics, as well as for neutron flux determination in nuclear power reactors. With the aim of improving the accuracy of the neutron capture cross section on ^{197}Au, extensive measurements were performed at the n_TOF facility at CERN with two detection systems: a total absorption calorimeter and a set of C_6D_6 detectors. The capture yield and the resonance parameters have been determined in the energy range from 1 eV to 5 keV and compared with evaluated data files. The present capture kernels are on average in good agreement with tabulated data, although sizable differences are observed for several resonances. A few new resonances are also reported.

10th Symposium on Nuclei in the Cosmos
July 27 - August 1, 2008
Mackinac Island, Michigan, USA

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1. Introduction

The main objectives of the experimental activity of the neutron time-of-flight facility n_TOF at CERN are accurate measurements of neutron induced cross sections relevant to nuclear astrophysics [1, 2] and emerging nuclear technologies [3, 4].

Neutron capture cross sections are usually derived relative to a standard (or well known) cross section, for example via the ^{197}Au(n,γ) cross section at thermal energy and in the energy range above 200 keV. Furthermore the first resonance for n+^{197}Au at 4.9 eV is often used to normalize capture yield measurements. In fact, because of its favorable Γ_γ/Γ_n ratio, the value of the capture yield is independent of the resonance parameters when this resonance is saturated.

Accuracte measurements of the (n,γ) cross section of ^{197}Au have been performed at the n_TOF facility with the aim of extending the energy range of this standard using two different detection systems, a set of two C_6D_6 detectors with extremely low neutron sensitivity and a total absorption calorimeter based on BaF$_2$ scintillator crystals.

In spite of its importance, only few measurements of the ^{197}Au(n,γ) cross section have been performed in the resonance region so far. Evaluations are available only in the ENDF/B-VI and ENDF/B-VII libraries, showing 5% discrepancies in the capture kernels.

2. Experiments

At the n_TOF facility [5] [6] neutrons are produced by spallation reactions induced by 20 GeV/c protons from the CERN Proton Synchtotron (PS) in a massive lead target. The high intensity of 7×10^{12} protons/pulse results in a very high instantaneous neutron flux in the energy region: 1 eV - 250 MeV. A 5.8 cm thick water layer around the lead spallation target serves as a coolant and as a moderator, yielding a wide energy spectrum from thermal to 250 MeV. An evacuated neutron flight path leads to the experimental area at a distance of 185 m from the target. The neutron beam is shaped by means of two collimators at 137 and 175 m, which consist of layers of iron and borated polyethylene. Charged particles are removed from the neutron beam by a sweeping magnet located at a distance of 145 m from the target.

The neutron energy is determined by time of flight (TOF). The nominal repetition rate of the pulsed beam is 2.4 seconds, low enough to cover the TOF range down to subthermal energies and to prevent overlapping of slow neutrons from subsequent cycles.

2.1 Capture setup

Neutron capture events are characterized by the emission of γ-rays associated with the deexcitation of the product nucleus to the ground state. In the n_TOF measurements, the *total energy detection system*[8] with two C_6D_6 liquid scintillation detectors as well as a the total γ-ray absorption calorimeter (TAC) have been used. Since the efficiency of the C_6D_6 scintillators are too small to measure the full capture γ-ray cascade, it requires the use of weighting functions to reconstruct the neutron capture yield [7, 8]. The weighting technique, which is only valid for detectors with low efficiency, is indeed well suited for the C_6D_6 setup because the detection probability for 1 MeV γ-rays is only about 3%.

The n_TOF TAC [9, 10, 11] is a 4π detector with nearly 100% detection efficiency for capture γ-ray cascades and an energy resolution of 15% at 662 keV and of 6% at 6.1 MeV. It consists of 40 BaF_2 crystals contained in ^{10}B loaded carbon fibre capsules forming a spherical shell 15 cm in thickness and with an inner diameter of 20 cm. The samples in the center of the TAC are surrounded by a 5 cm thick $C_{12}H_{20}O_4(^6Li)_2$ layer, which moderates and absorbs sample scattered neutrons.

The TAC is ideal for capture measurements on low mass samples of radioactive and fissile isotopes, because it allows one to select specific reactions via the total energy of the capture γ-ray cascade and to reject γ-rays originating from other processes. The C_6D_6 setup is optimized for cases where the total cross section is dominated by the elastic channel. Thanks to its low neutron sensitivity (defined as the ratio between the detection efficiency for scattered neutrons and for capture γ-rays) reliable results can be obtained even for extremely small Γ_γ/Γ_n ratios. The neutron sensitivity of the C_6D_6 setup is about 10^{-4}, two orders of magnitude smaller than that of the TAC.

2.2 Capture cross section measurement

The main quantity determined in the measurement is the capture yield, defined as the fraction of incident neutrons, $\Phi(E_n)$, that is captured in the sample. It can be expressed as $Y_{exp}(E_n) = \frac{C_{obs}(E_n)}{\varepsilon} \cdot \frac{1}{\Phi(E_n)}$, where C_{obs} is the number of detected reactions and ε the detection efficiency. The capture yield is related to the cross section by the areal density n of the sample, by the total neutron cross section σ_T, and by the radiative capture cross section σ_γ: $Y = (1 - e^{-n\sigma_T}) \frac{\sigma_\gamma}{\sigma_T}$.

In the Resolved Resonance Region the capture cross section of ^{197}Au was described in terms of resonance parameters calculated in the Reich-Moore approximation using the R-matrix code SAMMY [12]. The resonance parameters obtained in the SAMMY fits are the resonance energy, E_R, and the partial reaction widths, Γ_γ and Γ_n. An example of this procedure is given in the left panel of Fig. 1.

3. Results and Conclusions

The n_TOF measurement allowed to extract accurate data for the $^{197}Au(n,\gamma)$ reaction in the resonance region. In the energy range between 1 eV and 5 keV the parameters of 255 resonances could be determined by the combined analysis of separate runs with the BaF_2 TAC and the C_6D_6 detectors. The fact that both data sets are fully consistent with each other confirms the very good performance of the TAC and demonstrates that the $^{197}Au(n,\gamma)$ cross section is suited as a standard in the resolved resonance region. From the resonance parameters capture kernels $K = g(J) \times \Gamma_\gamma \times \Gamma_n/(\Gamma_n + \Gamma_\gamma)$ have been calculated, where $g(J)$ is the statistical spin factor.

Apart from discrepancies for some resonances, these kernels agree on average to 3-4% with the ENDF/B-VII evaluation as illustrated in the right panel of Fig. 1. In addition, a number of resonances could be clearly resolved, which were previously considered to be "doubtful" and, therefore, only partly included in the ENDF/B-VI and ENDF/B-VII evaluations. These cases are summarized in Table 1.

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Table 1: Clearly resolved resonances from this work, which were only partly considered in previous evaluations.

E_R (eV)	209.3	255.7	401.3	561.4	955.2	1022.	1233
ENDF/B-VI	yes	yes				yes	
ENDF/B-VII			yes	yes	yes		yes
n_TOF	yes	yes	yes	yes	yes	yes	yes
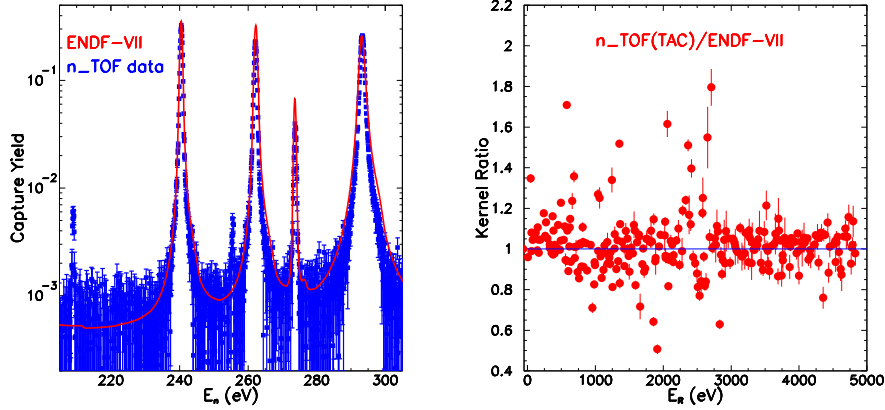
Figure 1: Left panel: Comparison of the experimental yield and the yield calculated with the R-matrix code SAMMY using the resonance parameters listed in ENDF/B-VII. Right panel: Ratio of the capture kernels obtained at n_TOF and listed in ENDF/B-VII, errors from the fit.

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