Neutron Capture Reaction Rates of Unstable Isotopes in the s–Process Branchings

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1 Introduction

Neutron capture rates are an important prerequisite for the study of the formation processes of the heavy elements (A>56) on a slow and rapid time scale (s– and r–process). For the s–process the neutron capture rates of the mainly stable isotopes in the synthesis path have been investigated experimentally in most cases. However, there are about 13 mass regions along the synthesis path with branchings caused by the competition between neutron capture and beta decay rates of unstable nuclei. The s–process branchings are characterized normally not only by one unstable isotope initiating the branching but by a set of two or three succeeding isotopic chains which contain stable and unstable nuclei. As an example, Fig. 1 shows the region of the Os, Ir, and Pt branchings. As the unstable branching isotopes are not yet accessible to direct neutron capture measurements except in a few cases, theoretical calculations using current statistical models have to be applied to supplement the data base for the s–process analysis.

2 Neutron Capture Rates

At the Karlsruhe 3.75 MV Van de Graaff accelerator the Maxwellian average capture (MAC) cross sections of the stable Pt–isotopes could be determined [1] with the cyclic activation method [2, 3]. The results of our measurements [1] are shown in Fig. 2 together with estimates for the isotopes ^{192,195}Pt. In Fig. 2 also a comparison is made between our measured and theoretically calculated Pt cross sections (BR) [1] and previous theoretical results from (AGM) [4], (HWFZ) [5], (Harris) [6], and (CTT) [7].

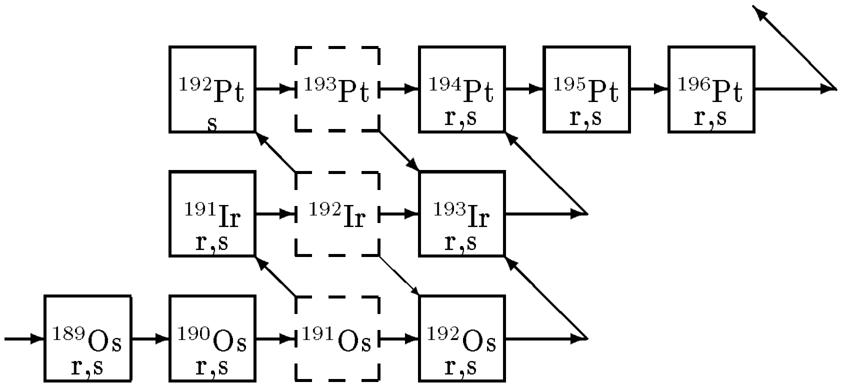

Figure 1: s–process path between Os and Pt (horizontal arrows: neutron capture, inclined arrows: β–decay). The solid boxes are the stable isotopes. The origin of nucleosynthesis (s,r: s– and r–process) is indicated. If there are two contributions, the major contribution is designated first. The dashed boxes are radioactive nuclei.

Additionally, statistical model calculations with an improved version [8] of the code SMOKER [9] have been carried out. The changes in the new version include a different treatment of the level density and updated level information for the known energy levels. The newly determined Pt MAC cross sections can be used to test the reliability of the calculations. Excellent agreement between experimental and theoretical values was found. We further recalculated thermonuclear rates as a function of temperature between kT=5 and 250 keV for stable and unstable isotopes involved in the ^{79}Se, ^{85}Kr, ^{95}Zr, ^{99}Tc, ^{134}Cs, ^{148}Pm, ^{151}Sm, ^{154}Eu, ^{163}Ho, ^{170}Tm, ^{179}Ta, ^{185}W, ^{192}Ir, and ^{204}Tl branchings. The uncertainty for the theoretical values in each branching was estimated by comparing the rates for nearby stable isotopes to experimental data.

3 Conclusions

An s–process analysis of the solar system abundances was carried out with two reaction rate data sets for the unstable branching point isotopes. The second data set was determined using the most recent nuclear parameters in the statistical model calculations. The experimental values for the stable isotopes were supplemented by our newly determined theoretical rates. The neutron densities and temperatures obtained in the SP model (pulsed s-process; burning of one neutron source) [10] are given in Table 1. The quoted errors arise mainly from an estimate of the average deviation of the theoretical cross sections compared to experimental data, as mentioned above.

References

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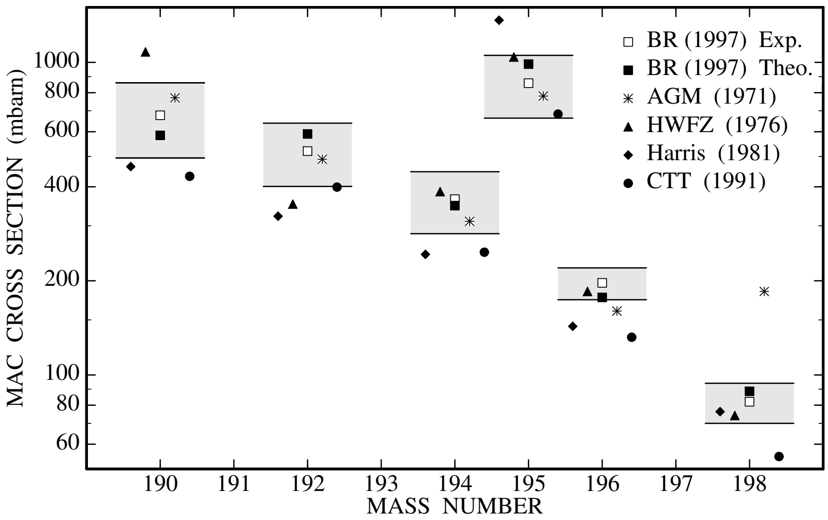

Figure 2: MAC cross sections of the stable Pt-isotopes at kT=30 keV. Comparison of experimentally and theoretically determined values. Experimental values are given with an uncertainty (shaded area). The references of the different abbreviations are given in the text.

Table 1: The s–process calculations with a parametrized model (SP model)[a] to check the influence of the MAC cross sections $\sigma_{\rm BP}$ of the branch point isotopes on the s–process neutron density n_n and temperature kT.

Branch point isotopes $\sigma_{\rm BP}$	$\Delta\sigma_{\rm BP}$	n_n (10^8 cm^{-3})	kT (keV)
Data set 1 (SUPERSEDED)	$^{+100\,\%}_{-50\,\%}$	$2.2^{-1.1}_{+2.5}$	26^{-3}_{+8}
Data set 2 (PRESENT)	$^{+30\,\%}_{-30\,\%}$	$3.7^{-0.8}_{+1.9}$	30^{-2}_{+7}

[a] Ref.[10]

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