Production of Samarium in Supernovae

T. Rauscher[1], H. Oberhummer[2], F.-K. Thielemann[3]
[1]Institut für Kernchemie, Universität Mainz, Mainz, Germany
[2]Institut für Kernphysik, TU Wien, Vienna, Austria
[3]Institut für theoretische Physik, Universität Basel, Basel, Switzerland

Correlations of the ^{142}Nd/^{144}Nd ratio with the Sm/Nd ratio in some meteorites have been previously explained by the α-decay of long-lived ^{146}Sm [1]. In order to account for these observations, a necessary production ratio for ^{146}Sm/^{144}Sm in the γ-process of 0.1–0.7 was deduced. The ratio of the rates of ^{148}Gd(γ,n)^{147}Gd and ^{148}Gd(γ,α)^{144}Sm – which plays the dominant role in the production of ^{146}Sm/^{144}Sm – has been re-determined in the present work by improved statistical model calculations.

A detailed study of nucleosynthesis in type II supernovae [2] proposed the existence of the so-called γ-process, by which it was tried to explain the isotopic ratio ^{146}Sm/^{144}Sm. However, the first calculations yielded values which were too low by factors of about 10–50. A crucial point in the determination of the ^{146}Sm/^{144}Sm ratio are the nuclear reaction rates used in the network calculations. In a reexamination of the ^{146}Sm production with revised photodisintegration rates [3], it could be shown that the calculated ^{148}Gd(γ,α)^{144}Sm rate would have to be lower by a factor of about 1/3 in order to reproduce the ^{146}Sm/^{144}Sm ratio derived from observations.

As shown in [3], the ratio ^{146}Sm/^{144}Sm is determined almost entirely by the ratio of the neutron and α-decay branches of the excited ^{148}Gd nucleus. We recalculated the relevant rates in the statistical model (code SMOKER [4]), using updated input parameters. We employed a folding potential in the α-channel for the real part of the optical potential. It was also made use of the most recent mass table [5], and of a theoretical mass formula [6] where experimental information was not available. The level density description gave rise to large uncertainties in previous astrophysical reaction rate calculations. An improved description based on [7], including thermal damping of shell effects, was developed (see also [8]). For the rest of the functions entering into the statistical model calculations we used the same parametrizations and codes as given in [9].

For the reaction rate of ^{144}Sm(α,γ)^{148}Gd we obtain the values 1.27×10^{-15} cm^3 mole^{-1} s^{-1} at a temperature $T_9=2.5$ and 7.56×10^{-13} cm^3 mole^{-1} s^{-1} at $T_9=3.0$. This is three times lower than the value for this reaction given in [3]. The change in the rate is due to the improved α-potential. By using the folding potential the problem with the ambiguity of the effective radius parameter of the equivalent square well potential [3] could also be resolved.

However, in order to treat the rates consistently we also calculated the rate for ^{147}Gd(n,γ)^{148}Gd. We obtain the values 3.16×10^8 cm^3 mole^{-1} s^{-1} and 3.33×10^8 cm^3 mole^{-1} s^{-1} at $T_9=2.5$ and 3.0, respectively. Our ^{147}Gd(n,γ)^{148}Gd rate is smaller by about a factor of 0.4 than the rate used in [3]. The difference in the rates is mainly due to the different level density treatment involved. This is understandable because in [3] a level density description and parameters were employed, which are known to overestimate cross sections and level densities for nuclei close to magic numbers.

Assuming a similar temperature dependence of the rates in the range T_9=2.5–3.0 as in [3], we can derive a temperature averaged ^{146}Sm/^{144}Sm ratio of about 0.1. This is still at the lower limit of the range permitted by observations. The decrease in the ^{144}Sm(α,γ)^{148}Gd cross sections was compensated for by an additional decrease in the neutron capture cross section on ^{147}Gd, thus resulting in a similar abundance ratio as given in [3].

Summarizing, using improved input parameters for the statistical model we were able to obtain a ^{146}Sm/^{144}Sm production ratio (barely) consistent with observational limits. However, only a full network calculation with consistently updated rates for all nuclei involved will be able to give reliable abundances.

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