Available online at www.sciencedirect.com
ScienceDirect
Progress in Particle and Nuclear Physics 59 (2007) 74–93
Progress in Particle and Nuclear Physics
www.elsevier.com/locate/ppnp

Review

Production of intermediate-mass and heavy nuclei

F.-K. Thielemann[a,*], C. Fröhlich[a], R. Hirschi[a], M. Liebendörfer[a], I. Dillmann[a], D. Mocelj[a], T. Rauscher[a], G. Martinez-Pinedo[b], K. Langanke[b], K. Farouqi[c], K.-L. Kratz[c], B. Pfeiffer[c], I. Panov[d], D.K. Nadyozhin[d], S. Blinnikov[d], E. Bravo[e], W.R. Hix[f], P. Höflich[g], N.T. Zinner[h]

[a] *Department of Physics and Astronomy, University of Basel, Switzerland*
[b] *Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany*
[c] *Institute for Nuclear Chemistry, University of Mainz and Max Planck Institute for Chemistry, Mainz, Germany*
[d] *Institute for Theoretical and Experimental Physics, Moscow, Russia*
[e] *Departament de Física, Universitat Politècnica de Catalunya, Barcelona, Spain*
[f] *Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*
[g] *Department of Physics, Florida State University, Tallahassee, FL 32306, USA*
[h] *Institute for Physics and Astronomy, University of Arhus, Denmark*

Abstract

Nucleosynthesis is the science related to all astrophysical processes which are responsible for the abundances of the elements and their isotopes in the universe. The astrophysical sites are the big bang and stellar objects. The working of nucleosynthesis processes is presented in a survey of events which act as abundance sources. For intermediate-mass and heavy elements, these are stellar evolution, type Ia and core collapse supernovae as well as hypernovae. We discuss successes and failures of existing processes and possible solutions via new (hitherto unknown) processes. Finally an analysis of their role is given in the puzzle to explain the evolution of the elemental and isotopic compositions found in galaxies, and especially the mixture found in the solar system. Different timescales due to the progenitor mass dependence of the endpoints of stellar evolution (type II supernova explosions — SNe II vs. planetary nebulae) or single vs. binary stellar systems (the latter being responsible for novae, type Ia supernovae — SNe Ia, or X-ray bursts) are the keys to understand galactic evolution. At very early times, the role of explosion energies of events, polluting pristine matter with a composition originating only from the big bang, might also play a

* Corresponding author.
E-mail address: F-K.Thielemann@unibas.ch (F.-K. Thielemann).

0146-6410/$ - see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.ppnp.2006.12.019

role. We also speculate on the role of very massive stars not undergoing SN II explosions but rather causing "hypernovae" after the formation of a central black hole via core collapse.
© 2007 Published by Elsevier B.V.

Keywords: Nuclear reactions; Neutrino–nucleus interactions; Nuclear structure; Fission; Stellar evolution; Nucleosynthesis; Type Ia supernovae; Core collapse supernovae; Si-burning; r-process; νp-process; p-process; Chemical evolution of galaxies; Low metallicity stars

1. Introduction

The sites of stellar nucleosynthesis span stable (hydrostatic) stellar evolution and wind ejection [30,62] as well as explosions like novae and both types of supernovae [107,89,54,11,12,90,96,39] hypernovae/gamma-ray bursts [104,72,70,7] or possibly other events, where binary stellar systems are involved. The understanding of each of these environments requires in general hydro (fluid/gas) dynamics, thermodynamics, energy transport [55,12] and last but not least, the knowledge of nuclear physics comprising nuclear reactions, nuclear structure and decay properties [45,51] as well as the nuclear equation of state [52]. Thermonuclear burning, nuclear energy generation and resulting nuclear abundances are determined by thermonuclear and weak interaction rates. Before reviewing hydrostatic burning phases in stellar evolution, the specific burning features of explosive stellar events, astrophysical sites and their contribution to galactic evolution, we want to outline briefly the essential features of thermonuclear reaction rates and the basic equations governing composition change in nuclear reaction networks, and the required nuclear physics input.

In general, when targets j and projectiles k follow specific thermal momentum distributions $\mathrm{d}n_j$ and $\mathrm{d}n_k$ in an astrophysical plasma, leading to relative velocities $\vec{v}_j - \vec{v}_k$, r, the number of reactions per cm^3 and sec, is given by

$$r_{j,k} = \int \sigma(|\vec{v}_j - \vec{v}_k|)|\vec{v}_j - \vec{v}_k|\,\mathrm{d}n_j\,\mathrm{d}n_k.$$

The evaluation of this integral depends on the type of particles (fermions, bosons) and distributions which are involved. For nuclei j and k in an astrophysical plasma obeying a Maxwell–Boltzmann distribution, this simplifies to $r_{j,k} = \langle\sigma v\rangle n_j n_k$. The thermonuclear reaction rates have the form

$$\langle\sigma v\rangle_{j,k} = \left(\frac{8}{\mu\pi}\right)^{\frac{1}{2}} (kT)^{-\frac{3}{2}} \int_0^\infty E\sigma(E)\mathrm{e}^{-E/kT}\mathrm{d}E.$$

Here μ and E denote the reduced mass and center of mass energy of the target-projectile system. When particle k is a photon, the relative velocity is always c and the quantities in the integral are not dependent on $\mathrm{d}n_j$. This simplifies to $r_j = \lambda_{j,\gamma} n_j$. $\lambda_{j,\gamma}(T)$ results from an integration over a Planck distribution for photons of temperature T.

A similar procedure is used for electron captures by nuclei. Because the electron is about 2000 times less massive than a nucleon, the velocity of the nucleus j is negligible in the center of mass system in comparison to the electron velocity ($|\vec{v}_j - \vec{v}_e| \approx |\vec{v}_e|$). The electron capture cross section has to be integrated over a or Fermi distribution of electrons. The electron capture rates are a function of T and $n_e = Y_e\rho N_\mathrm{A}$, the electron number density, where ρ denotes the matter density and N_A Avogadro's number. In a neutral, completely ionized plasma, the electron

Download English Version:

https://daneshyari.com/en/article/1854576

Download Persian Version:

https://daneshyari.com/article/1854576

Daneshyari.com