Bull. Astr. Soc. India (1996) **24,** 757–761

X-ray burster and nuclear reaction rates

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Abstract. The X-ray burst duration is sufficient to complete certain proton capturing nuclear reaction cycle, at high steller temperature.

Ne-Na cycle like

(a) Ne^{20} (P,γ) Na^{21} $(P,\gamma)Mg^{22}$ $(\beta^+, \nu)Na^{22}$ $(P, \gamma)Mg^{23}$ $(\beta^+, \nu)Na^{23}$ $(P, \alpha)Ne^{20}$

(b) Ne^{20} $(P,\gamma)Na^{21}$ $(\beta^+\nu)Ne^{21}$ $(P, \gamma)Na^{22}$ $(P, \gamma)Mg^{23}$ $(\beta^+, \nu)Na^{23}$ $(P, \alpha)Ne^{20}$

are found to be completed within 10 to 100 secs for a variety of temperatures and density ranging from T_9 $(T/10^9) = .1$ to .3 and ρ 10^2 to 10^4 gm/cc. Considering the cycle to be in equilibrium we have calculated the number density ratios of Ne^{20}, Ne^{21}, Ne^{22} and they are compared with meteoritic samples. It is believed that X-ray burst is likely to take place on the surface of a compact binary companion due to accretion from its larger component with a hydrogen rich outer layer.

1. Introduction

It is accepted that X-ray burst sources belong to binary steller systems. It is believed that X-ray bursts are produced in the accreted layer of a companion neutron star. The accreted layer is primarily composed of hydrogen and helium. Due to heat generation associated with burning of combustible fuel, thermal instability may occur. The source of energy for X-ray burst is attributed to nuclear fusion, while the change in gravitation energy of accreted matter is responsible for quiscent emission (Aller 1961). The rise of temperatures which may be as high as 10^8 K to 10^9 K, due to infall of matter from the binary companion. The density of matter on the neutron star surface is considered around 10^2 to 10^4 gm/cc.

Now we consider the compact binary star in the system as a source of X-ray bursts. X-ray burst is likely to take place due to accretion from its larger companion with hydrogen rich outer layer. On the surface of the neutron star, at high steller temperature rapid proton capturing nuclear reaction cycle can take place.. The X-ray burst duration is sufficient to complete certain proton capturing nuclear reaction.

We have found that Ne-Na cycle like (a) and (b) are completed within time 10 to 100 seconds and in the range of temperature 1.10^8 K to 3.10^8 K for limited density conditions ($\rho \sim 10^2$ to 10^4) gm/cc and shown in fig. 1.

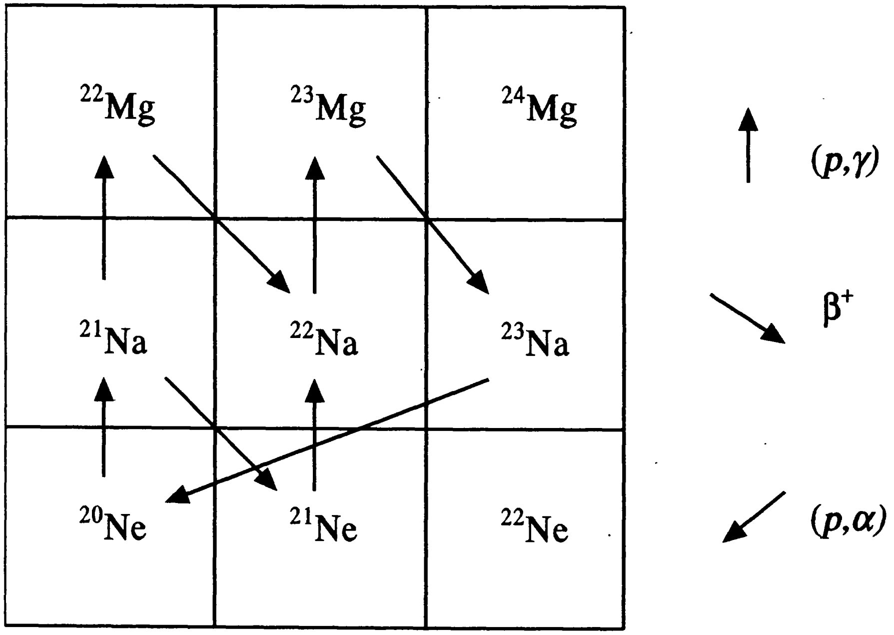

Figure 1. Ne-Na cycles completed within 10-100 sec in the range of temp. 1×10^8 K to 3×10^8 and density range 10^2 gm/cc to 10^4 gm/cc.

In section III the life time of different reactions at different temperatures and densities are studied. In section IV the abundance of Ne^{20} burning products are calculated and compared with the meteoritic samples. Discussion and Conclusion are included in section V.

2. Reaction cycles

In Ne-Na cycle the major reactions are $-Ne^{20}(p, \gamma)Na^{21}$, $Na^{21}(p, \gamma)Na^{22}$ $(p, \gamma)Mg^{23}$ and Na^{23} $(P, \alpha)Ne^{20}$. The slowest reaction of the cycle determines the overall rate of the cycle. The reaction rates are calculated by using the value of cross section of different reaction at different temperature from the tabulated value of (Caughlan and Fowler 1988). We have used the relation for reaction rate (cm^{-3} s^{-1})

$$R_{1,2} = -\frac{\rho^2 N_A}{A_1 A_2} [N_A < \sigma v > X_1 X_2] \text{ cm}^{-3} \text{ sec}^{-1} \tag{1}$$

where A_1,A_2 are the mass numbers of the two reacting nuclei, N_A is the Avogadro number, X_1 and X_2 are the fractional abundances of hydrogen and heavy elements respectively. Expressing the equation (1) in the form of

$$R_{1,2} = N_1 N_2 < \sigma v > \tag{2}$$

and reciprocal of $R_{1,2}/N_2$ gives the life time of the reaction. Life time (τ) verses temperature at different densities are studied Log τ (years) ie., life times of the reaction, are plotted for $\rho = 10^3$ gm/cc in Fig. 2

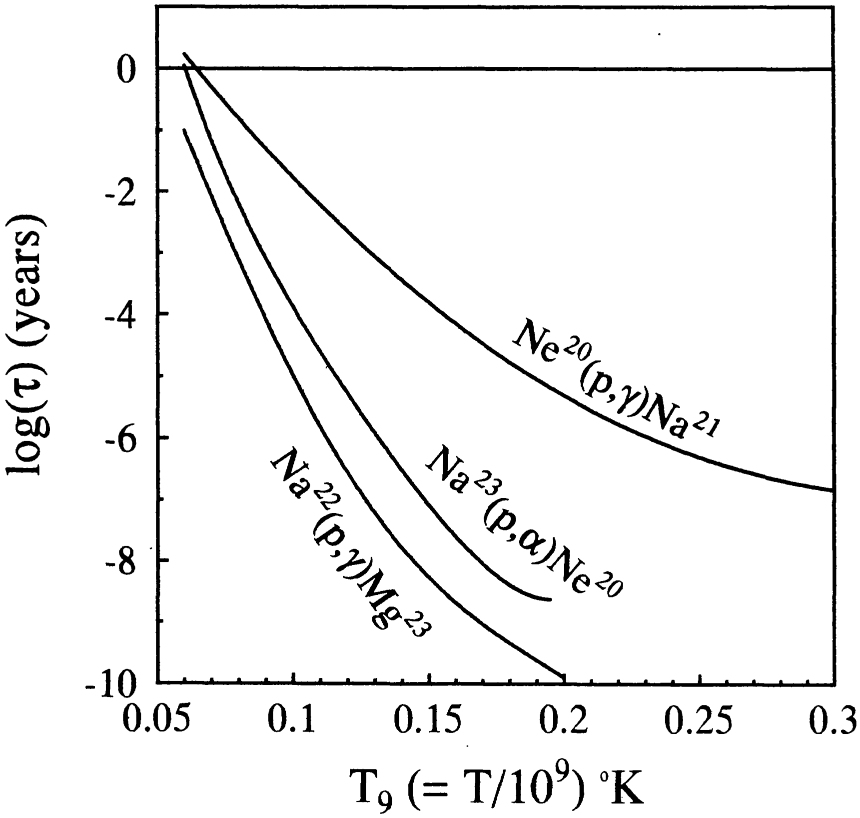

Figure 2. Lifetime of the reactions Ne^{20} (p, γ) Na^{21}, Na^{23} (p, α) Ne Na^{22} (p, γ) Mg^{23} shows against the temperature (t_9 = 0.1 to 0.3) at $\rho = 10^3$ gm/cc.

It is also seen that half life of β decay of Na^{21} is 22.5 sec (KRANE 1988). But under assumed circumstances Na^{21} can capture proton and cycle (a) cana proceed.

The temperature of the slowest reaction (Ne^{20} (p, γ) Na^{21}) for 10 to 100 sec at different densities are plotted in Fig. 3.

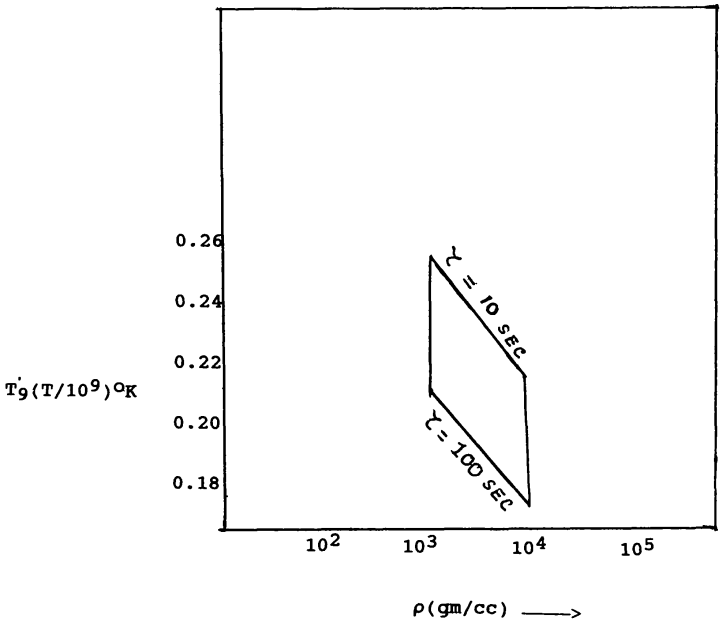

Figure 3. [T – ρ] plane for reaction Ne^{20} (p, γ) Na^{21} within time 10 Sec to 100 Sec.

3. Abundance calculation and comparison

The cycle is considered to be in equilibrium. Then equating the different reaction rates the ratios of Ne^{20}/Ne^{23} and Ne^{20}/Ne^{22} are calculated in the temperature available from Fig. 3. The ratios are independent of densities. The calculated abundance ratios are compared with the observed abundance ratios obtained from meteoritic samples (Lee 1979; Duorah 1965). These are showed in Table 1.

Table 1. Comparison off abundance ratio.

	Abundance ratio					
Element ratio	Calculated			Observed		
	2×10^8 °K	2.5×10^8 °K	3×10^8 °K	SU	CA	C
Ne^{20}/Ne^{21}	19.17×10^3	14.82×10^3	1.14×10^3	3×10^2	3×10^2	3.5×10^2
Ne^{20}/Ne^{22}	7.26	14.20	40.71		< 1.52 (Lee 1979)	

SU : Suess and Urey (1956) Mostly meteritic data.
CA : Cameron's revised values takenfrom Aller (1961).
C : Cameron's revised value (1963).

4. Discussion and conclusions

The density of neutron star surface is considered to be 10^2 to 10^4 gm/cc so that neon burning reaction is completed within the time 10 to 100 secs at temperature range $T_8 = 1 - 3$.

The abundance ratio for these elements show a tendency agreeable for observed universal abundance ratio for the temperature ranging from 1 - 2 x 10^8K (Aller, 1961). It appears that some of these abundances are produced in the x-ray burst events. The matter ejected during the burst and number of such events in certain location in the galaxy need to be determined for full analysis of the abundance ratios of these elements in interstellar matter and in stars. The nuclear physics involved in the rapid proton capturing process is not clearly understood. And many uncertainties are involved in the determination of energy generation in the burst events. More experimental data would be necessary for the proper evaluation of the cycles.

References

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