# SHORT COMMUNICATIONS

## EFFECTIVE TRIPLE ALPHA REACTION RATES IN STARS

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THE triple alpha reaction to produce carbon is the gateway to element synthesis of heavy atomic masses. The radiative width of $7650 \pm 0.2(0^+)$ keV[1], the second excited state of carbon, crucially affects the reaction rates. At temperature $10^8$ K and density $10^5\ \mathrm{g\,cm^{-3}}$, suitable for the triple alpha reaction[2], we expect that the level $7650 \pm 0.2(0^+)$ keV will contribute more to the reaction rates. The temperatures at which the levels, $9330(3^-)$ keV and $10000(0^+)$ keV, contribute substantially to the reaction are supposed to be higher than $10^8$ K. The level, $4420(2^+)$ keV, will contribute substantially at a lower temperature than $10^8$ K. It will be interesting to study how the reaction rates for stars with 50% helium in the core vary with temperature as some hydrogen-deficient carbon stars and R or B variables appear to have an atmospheric composition of 50% helium and 50% carbon. The sum of the masses of three alpha particles is $7274.69 \pm 0.2$ keV and hence the excess energy is 375.31 keV. The second excited state decays to the ground level through $4420(2^+)$ keV state. The width of gamma transition to the ground state cannot be directly measured. There have been a number of measurements for the value[3] $\Gamma_v/\Gamma$. The recent value is $(4.90 \pm 0.2)10^{-4}$. Thus $\Gamma_v$, the radiation width, is found to be $(3.7 \pm 1.1) \times 10^{-3}$ eV. This is about 1.5 times the value used by Duorah and Kushwaha[4]. Further the screening effect of electron clouds also causes enhancement of the reaction. Hence the reaction is restudied.

*Calculation of effective reaction rates*: Utilising the new values of $\Gamma_v$ and $E_r$, the resonance energy, we have deduced from Duorah and Duorah[5], the reaction rate equation,

$$\log\left(\frac{r_{3\alpha}}{\rho^2 X_\alpha^3}\right) = 16.64 - 3\log T_8 - \frac{19.12}{T_8} \quad (1)$$

In equation (1), $r_{3\alpha}$ is the reaction rate in $\mathrm{g^{-1}\,sec^{-1}}$; $\rho$ is the density in $\mathrm{g \cdot cm^{-3}}$; $X_\alpha$ and $T_8$ are the mean fraction of alpha particles by weight and temperature in $10^8$ K unit respectively. The equation is an improved one for the new values of $\Gamma_v$ and $E_r$.

The dimensionless parameters $\Gamma$ (not width here) and $\tau$ have been used to study screened reaction rates[6-8].

$$\Gamma = (z_e)^2/Ta \quad (T \text{ in energy unit}), \quad (2)$$

$$\tau = \left\{\frac{27\pi^2}{4}\frac{M}{T}\frac{(Z_e)^4}{h^2}\right\}^{1/3}, \quad (3)$$

where $a = (3Z/4\pi n_e)^{1/3}$, the mean ionic distance. $M$, $Z_e$ and $n_e$ denote the mass of ions, electronic charge of ions and the number density of electrons respectively. $n_e$ is further given by

$$n_e = \rho/\mu_e H \quad (4)$$

where $$\mu_e = (A/Z) + (m/H), \quad (5)$$

We have

$$m = 9.1 \times 10^{-28}\ \mathrm{g},$$

$$H = 1.660531 \times 10^{-24}\ \mathrm{g},$$

$A/Z = 2$ for helium plasma.

For the triple alpha reaction at $\rho = 10^5\ \mathrm{g\,cm^{-3}}$ and $T_8 = (1\text{–}2)$, the value of $\Gamma$ is between 9·5 and 20. When $\Gamma > 1$, the screening is strong. So we resort to the use of strong screening enhancement factor used by Itoh *et al*[7].

We write it as

$$y = \exp\left[1.25\Gamma - 0.11\tau\left(\frac{3\Gamma}{\tau}\right)^2\right]$$

$$= \exp\left[\frac{\tau}{3}\left\{(1.25)\frac{3\Gamma}{\tau} - 0.033\left(\frac{3\Gamma}{\tau}\right)^2\right\}\right]. \quad (6)$$

As $3\Gamma/\tau$ is small, we use also the expression of Alastuey and Jancovici[8] for finding the enhancement rate,

$$y = \exp\left(c - \frac{45}{32}\frac{\Gamma^3}{\tau^2}\right), \quad (7)$$

where $C = 1.0531\Gamma + 2.2931\Gamma^{1/4} - 0.5551 \ln\Gamma - 2{\cdot}35.$ (8)

It is valid for $1 \leqslant \Gamma < 155$. Hence we get the screened rate ($\gamma r^*_{3\alpha}$) from equation (1) after minor simplifications as

$$\log\left(\frac{r^*_{3\alpha}}{\rho^2 X_\alpha^3}\right) = 16{\cdot}64 - 3\log T_8 - \frac{19{\cdot}12}{T_8} + \log y. \quad (9)$$

Using the above equations the enhanced reaction rates

**Table 1** *Reaction rates as functions of temperatures 50 % helium, 50 % carbon, $\rho_5 = 1$*

| $T_8$ | $\Gamma$ | $\tau$ | $3\Gamma/\tau$ | $\log(r_{3\alpha})$ | $\log(r^{*}_{3\alpha})$ | $\log\left(\frac{r^{*}_{3\alpha}}{r_{3\alpha}}\right)$ | $\log(r^{**}_{3\alpha})$ | $\log\left(\frac{r^{**}_{3\alpha}}{r_{3\alpha}}\right)$ |
|---|---|---|---|---|---|---|---|---|
| 1.0 | 19.082 | 328.5 | 0.1743 | 6.615 | 17.212 | 10.598 | 15.65822 | 9.0432 |
| 1.4 | 13.63 | 293.65 | 0.1393 | 11.645 | 19.027 | 7.382 | 18.12641 | 6.48141 |
| 1.8 | 10.601 | 270.05 | 0.1178 | 14.352 | 20.107 | 5.754 | 19.33908 | 5.04702 |
| 2 | 9.541 | 260.731 | 0.1098 | 15.277 | 20.455 | 5.18 | 19.81989 | 4.5429 |

$r_{3\alpha}$ = unscreened reaction rate, $r^{*}_{3\alpha}$ and $r^{**}_{3\alpha}$ = screened reaction rates after Itoh *et al*[7] and Alastuey and Jancovici[8] respectively.

($r^{*}_{3\alpha}$), due to screening effect have been calculated for better value of $\Gamma_v$ becoming available and tabulated in table 1.

At higher temperature the screening effect decreases and yet the effective reaction rates increase tremendously. The mean life which is the inverse of reaction rates will be drastically altered. So a star after exhaustion of 50% of helium will move on to a higher temperature in a very short time in comparison to earlier values of Burbidge[2] *et al* and Duorah and Kushwaha[3].

Table 1 shows that the screened rates after Itoh *et al* and Alastuey and Jancovici are comparable. The screening correction calculated using the methods of Itoh *et al* and Alastuey and Jancovici is not expected to be different as pointed out by latter authors. The difference decreases towards higher temperature warranting that both the rates will almost be the same at higher temperatures. Our results will be suitable for hydrogen-deficient carbon stars and R or B variables as they appear to have an atmospheric composition of 50% helium and 50% carbon.

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## ISOCOUMARIN: SYNTHESIS OF 3-(4′-METHOXYPHENYL)-4-FORMYLISOCOUMARIN

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3-PHENYLISOCOUMARINS possess medicinal properties and are usually obtained by condensing homophthalic anhydride with aromatic hydrocarbons phenols and phenolic ethers using anhydrous, $AlCl_3$ or $SnCl_4$ or PPA[1-3]. This paper reports the synthesis of 3-(4′-methoxyphenyl)-4-formylisocoumarin by the direct condensation of 4-formylisochroman-1,3-dione with anisole in the presence of PPA.

Homophthalic anhydride (I)[4] condensed with ethyl formate in the presence of sodium methoxide to furnish 4-formylisochroman-1, 3-dione(II), which reacted with anisole in the presence of PPA, to give 3-(4′-methoxyphenyl)-4-formyl isocoumarin (III). It reduced Tollen's reagent and gave a 2,4-dinitrophenylhydrazone derivative. Treatment with aqueous sodium hydroxide (10%) yielded 4-methoxy-w(2′-carboxyphenyl)-formyl-acetophenone (IV). Oxidation of III by silver oxide in aqueous sodium hydroxide and subsequent acidification afforded 4-methoxy-w-(2′-carboxyphenyl)-acetophenone (VI) found to be identical with an authentic sample prepared earlier[3]. The IR and UV spectra were found compatible with the structure of the other isocoumarin[5,6].