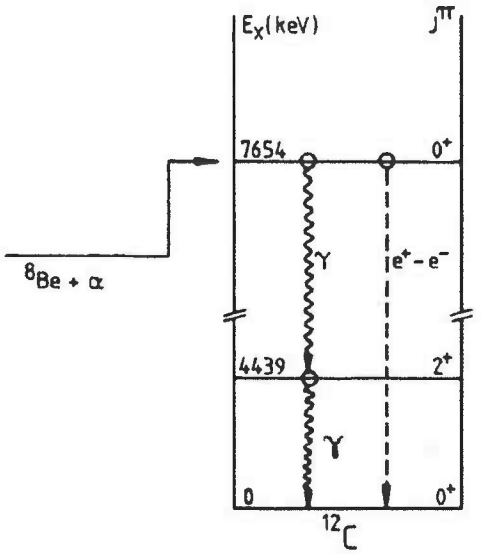
The exam comprises 3 problems. The total number of points is 34. The final grade is obtained by dividing the number of points by 3,4.

Problem 1 (12 pts)

The second step of the triple α-process proceeds through a resonance at $E_r = 7654\ keV$ in ${}^{12}_{6}C$, as shown in the figure below.



a. Determine the temperature of the star at which the production of ${}^{12}_{6}C$ is activated through the reaction ${}^{8}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}C + \gamma$, knowing that the energy of the Gamow peak is $E_0 = 287\ keV$. (4 pts)
b. The temperature of the Sun is currently about $1.5 \times 10^7\ K$. Does helium-burning occur in the sun at present? (2 pts)
c. On which branch of the Hertzsprung-Russell diagram would you find a star burning helium? (4 pts)
d. Which nucleosynthesis process produces the isotope ${}^{13}_{6}C$? (2 pts)

Problem 2 (12 pts)

a. Give the main stellar nuclear reaction and the corresponding burning-stage for the following isotopes: ^{4}He ^{12}C, ^{28}Si and ^{56}Ni. For example, ^{16}O is created by the main reaction ${}^{12}\square C(\alpha, \gamma){}^{16}\square O$ in stars undergoing He-burning. (8 pts)
b. The core of a massive star goes through all fusion burning stages. What is the main end product and why does fusion end up at this element? (4 pts)

Problem 3 (10 pts)

Short answer questions (1 to 2 sentences)

a. Explain why each successive burning stage in a massive star requires a higher temperature. (2 pts)

From Rick Bonhof

b. Explain why a massive star does not experience a Helium flash at the end of the Red Giant Branch. (2 pts)

c. Which principal element is produced in the helium flash? (2 pts)

d. When does a star leave the main sequence? (2 pts)

e. What happens to the core of a large mass star when it can no longer fuse hydrogen? (2 pts)

Formula and other useful stuff

- Gamow energy: $E_G = 2\mu c^2 (\pi \alpha Z_1 Z_2)^2$

  with $\alpha = 1/137$, μ the reduced mass and $c^2 = 931.494\ MeV/u$

- Energy of the Gamow peak:

$$E_0 = \left[E_G \left(\frac{kT}{2}\right)^2\right]^{1/3} = 0.122 (Z_1^2 Z_2^2\, \mu\, T_9^2)^{1/3}\ [MeV]$$

  with $k = 8.617\ 10^{-5}\ eV/K$

- Periodic table