24.2 Fusion and stars (full E.5)

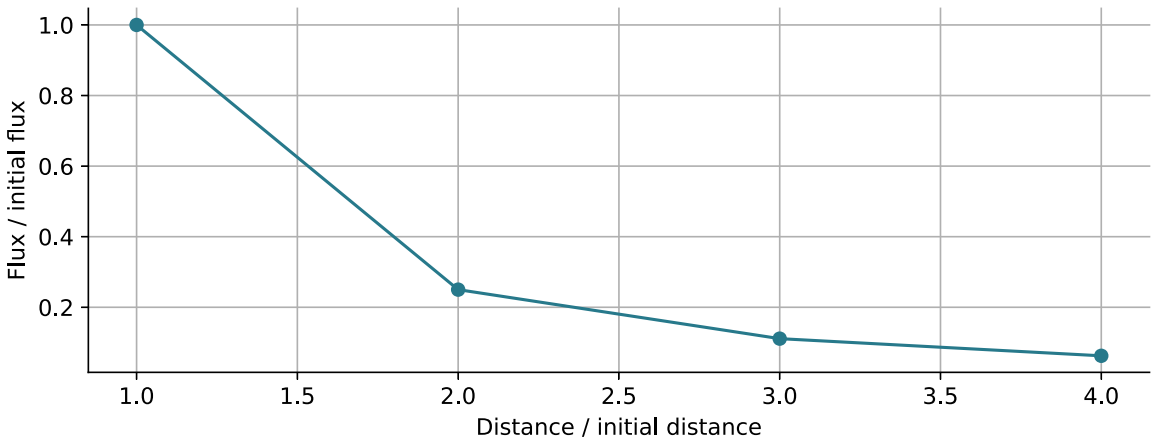
Name: _____ Class: _____ Date: _____ **Total: 22 marks**

KEY WORDS fusion • main sequence • red giant • stellar parallax • Hertzsprung-Russell diagram

Objective

Practise the full guide E.5 toolkit: stellar stability as the balance of radiation pressure and gravity, fusion and its density–temperature conditions with energy calculations, the effect of stellar mass on evolution, the main regions of the Hertzsprung–Russell diagram, stellar parallax $d(\text{pc}) = 1/p(\text{arcsec})$ with AU–ly–pc conversions, and stellar radii from luminosity and temperature. Original practice; not an official IB paper.

1 Key knowledge and worked examples



■ **The E.5 rule set**

$$d(\text{pc}) = \frac{1}{p(\text{arcsec})} \qquad L = 4\pi R^2 \sigma T^4 \qquad 1\ \text{pc} = 3.26\ \text{ly}$$

HR diagram: luminosity up, temperature right-to-left (hot left). Main sequence diagonal; red giants and supergiants top right (bright, cool, huge); white dwarfs bottom left (hot, dim, small); instability strip between.

■ Worked example: a giant by arithmetic

A star shines at 100 solar luminosities with the Sun's surface temperature. $L \propto R^2T^4$, so at equal T: $R = \sqrt{100} = 10$ solar radii. On the HR diagram it sits at the Sun's temperature but 100× higher – on a constant-radius line well into the giant region. Two habits: convert parallax to parsecs before any other unit, and compare with the Sun as a ratio so σ cancels.

2 Practice

2.1 State the two pressures whose balance keeps a main-sequence star stable. [2]

2.2 State the two conditions a plasma needs for sustained fusion, with the physical reason for each. [2]

2.3 On an HR diagram, where do white dwarfs sit, and what does that position imply about their size? [2]

2.4 A star shows a parallax of 0.050 arcsec. Calculate its distance in parsecs and light years. [2]

3 Exam-style questions

3.1 Describe the evolution of a star of one solar mass from main sequence to final state, naming each stage. [4]

3.2 In the Sun's core, four hydrogen nuclei (total mass 4.0313 u) fuse into one helium nucleus (4.0026 u). Calculate the energy released per helium nucleus in MeV. [3]

3.3 Explain why red giants are more luminous than main-sequence stars of the same temperature, using $L = 4\pi R^2 \sigma T^4$. [3]

3.4 A star has a surface temperature of half the Sun's and a radius 100 times the Sun's. Calculate its luminosity in solar units, and locate it on the HR diagram. [4]

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

2.1 Outward radiation pressure from the core; inward gravitational pressure.

2.2 Very high temperature, so nuclei move fast enough to overcome their electric repulsion; very high density, so collisions are frequent enough to sustain the reaction rate.

2.3 Bottom left – hot but dim; high temperature with low luminosity forces a small emitting area: tiny stars, Earth-sized.

2.4 $d = 1/p = 1/0.050 = 20$ parsecs $= 65$ light years.

3.1 Hydrogen fusion on the main sequence until the core runs low; the core contracts and the outer layers swell into a red giant while helium fuses; the outer layers drift off as a planetary nebula; the core remains as a white dwarf, slowly cooling.

3.2 $\Delta m = 4.0313 - 4.0026 = 0.0287\ u$; $E = 0.0287 \times 931.5 = 26.7$ MeV.

3.3 At equal temperature the T^4 factor matches, so $L \propto R^2$; a giant's radius is far larger; with the same surface brightness over a much larger area, its luminosity is greater by R^2 – hence its position at the top right.

3.4 $L/L_\odot = (R/R_\odot)^2(T/T_\odot)^4 = 100^2 \times (1/2)^4 = 10^4 \times 1/16 = 625$; cooler than the Sun and 625× brighter, it sits in the red-giant region, upper right of the HR diagram.