Exercise walk-through

24.2
Fusion and stars (full E.5)

International Baccalaureate · IB Diploma · Physics · HL

Space · 3.1

Reasoning

For isotropic emission without absorption, flux follows an inverse-square relationship with distance. Observed brightness alone therefore cannot establish luminosity. Keep distance units consistent, identify which quantities are intrinsic to the star, and distinguish observational evidence from a model of stellar evolution. Do not confuse a red giant stage with every possible final remnant.

Luminosity does not determine temperature

1. **Set the model** A star has 100 times the Sun's luminosity and the same effective surface temperature.
2. **Calculate** From $L = 4\pi R^2 \sigma T^4$, the radius ratio is $\sqrt{100} = 10$.

Decision

On an HR diagram, temperature decreases to the right. A bright, cool star must have a large radius; stellar mass controls its later evolution.

Exercises 2.1·2.3

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]

Exercises 2.1·2.3

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

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

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

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

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

Exercises 2.4·3.2

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

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]

Exercises 2.4·3.2

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

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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.

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

Exercises 3.3·3.4

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]

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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 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]

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.