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IB DP PHYSICS (2025 SYLLABUS)

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E.5 Fusion and stars

Practice Worksheet — name: ________________________ date: _____________

FORMULAS FOR THIS TOPIC

STELLAR PARALLAX $d(\text{parsec}) = \frac{1}{p(\text{arc-second})}$

STELLAR LUMINOSITY $L = 4\pi R^2 \sigma T^4$

APPARENT BRIGHTNESS $b = \frac{L}{4\pi d^2}$

WIEN'S LAW $\lambda_{\text{max}} T = 2.9 \times 10^{-3}\ \text{m K}$

SECTION A — MULTIPLE CHOICE

A1. Fusion in stellar cores requires extremely high temperatures because:

Ⓐ Nuclei must overcome their mutual electrostatic repulsion to get within range of the strong force

Ⓑ The strong force only operates at high temperatures

Ⓒ Photons must have enough energy to split nuclei

Ⓓ Electrons must be removed from the atoms first

A2. A star has parallax 0.040 arc-seconds. Its distance is:

Ⓐ 25 pc

Ⓑ 40 pc

Ⓒ 0.04 pc

Ⓓ 2.5 pc

A3. On the HR diagram, white dwarfs lie below the main sequence because they are:

Ⓐ Cool and large

Ⓑ Hot but very small, hence dim

Ⓒ Cool and very small

Ⓓ Hot and very large

SECTION B — SHORT ANSWER

B1. Describe the equilibrium that keeps a main-sequence star stable, and what happens when core hydrogen is exhausted. [4 marks]

B2. A star's spectrum peaks at 500 nm and its apparent brightness is $1.4 \times 10^{-9}\ \mathrm{W\ m^{-2}}$ at a distance of 10 pc (3.1×10^{17} m). Determine its surface temperature and luminosity. [4 marks]

B3. Explain why fusion, despite releasing less energy per reaction than fission, releases more energy per unit mass of fuel. [2 marks]

ANSWER KEY

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Section A

A1: Nuclei must overcome their mutual electrostatic repulsion to get within range of the strong force — Positive nuclei repel; only at enormous kinetic energies (temperature) do they approach within ~10^{-15} m, where the attractive strong force can bind them. High density raises the collision rate — both conditions are needed.

A2: 25 pc — $d = 1/p = 1/0.040 = 25$ parsecs (about 82 light-years). Smaller parallax means greater distance — the method fails beyond ~100 pc where the angle becomes unmeasurably small.

A3: Hot but very small, hence dim — Luminosity $L = 4\pi R^2 \sigma T^4$: white dwarfs have high surface temperatures (left side of diagram) but Earth-sized radii, so their luminosity is thousands of times below main-sequence stars of the same temperature.

Section B

B1: Outward radiation pressure from core fusion balances the inward gravitational pressure of the star's own mass. When hydrogen fuel runs out, radiation pressure falls and gravity wins: the core contracts and heats, igniting hydrogen in a surrounding shell (and later helium in the core); the envelope expands and cools — the star becomes a red giant, moving up-right on the HR diagram.

B2: Wien: $T = 2.9 \times 10^{-3}/5.0 \times 10^{-7} = 5800$ K — Sun-like. Luminosity: $L = 4\pi d^2 b = 4\pi(3.1 \times 10^{17})^2(1.4 \times 10^{-9}) \approx 1.7 \times 10^{27}$ W, roughly four times the Sun's.

B3: The binding-energy-per-nucleon curve is steepest at low mass numbers: fusing hydrogen to helium gains ~7 MeV per nucleon, whereas fission gains under 1 MeV per nucleon. Per kilogram of fuel, fusion therefore releases several times more energy.