InkPhysics

ANSWER BOOK

Black-body radiation and spectral classes

Astrophysics · Year 13

AQA 3.9.2.3, 3.9.2.4 · CIE 25.2.1, 25.2.2, 25.2.3 · OCR A 5.5.2(e), 5.5.2(i), 5.5.2(j), 5.5.2(k)

19 questions · 57 marks

NAVY EDITION

SECTION A · Warm-up

A1 Stefan: $P = \sigma A T^4$, with A the surface area and T the surface temperature in kelvin (1). Wien: $\lambda_{max} T = 2.9 \times 10^{-3}$ m K, the constant carrying the product unit metre kelvin (1). [2]

A2 O B A F G K M, hottest to coolest (1). The Sun, at about 5800 K, is a class G star (1). [2]

A3 The star radiates as a black body (1), and the light travels to the telescope without absorption on the way, by dust or by atmosphere (1). [2]

A4 A body that absorbs all the electromagnetic radiation incident on it (1). It is therefore also the best possible emitter, radiating a spectrum that depends only on its temperature (1). [2]

A5 Class O stars are blue; class M stars are red (1). Class M spectra show molecular absorption by titanium oxide, TiO (1). [2]

A6 The peak moves to a shorter wavelength (Wien's law) (1), and the curve rises at every wavelength, so the total power radiated (the area under the curve) increases (1). [2]

SECTION B · Standard

B1 [3]

$\lambda_{max} = 2.9 \times 10^{-3}/10\,000$ (1)

$\lambda_{max} = 2.9 \times 10^{-7}$ m (1)

In the ultraviolet, so the star looks blue-white (1)

B2 [3]

$T = 2.9 \times 10^{-3}/(9.7 \times 10^{-7})$ (1)

$T = 2990$ K (1)

Just below 3500 K, so a red class M star (1)

B3 [4]

$A = 4\pi r^2 = 4\pi \times (1.39 \times 10^9)^2$ (1)

$A = 2.43 \times 10^{19}$ m^2 (1)

$P = \sigma A T^4 = 5.67 \times 10^{-8} \times 2.43 \times 10^{19} \times 9000^4$ (1)

$P = 9.1 \times 10^{27}$ W (1)

B4 Balmer absorption needs hydrogen atoms already excited to the n = 2 level (1). In cool stars almost all atoms sit in the ground state, so the lines are weak; in the hottest stars the hydrogen is ionised, so no bound electrons remain to absorb (1). Class A, 7500 to 11 000 K, is the productive middle (1). [3]

B5 $P \propto T^4$ at fixed area (1), so the power rises by a factor of $3^4 = 81$ (1). [2]

B6 $\lambda_{max}T$ is constant, so the 400 nm star is twice as hot as the 800 nm star (1). With equal areas $P \propto T^4$ (1), so the ratio is $2^4 = 16$, the hotter star radiating 16 times the power (1). [3]

B7 $A = 4\pi r^2 = 4\pi \times (7.0 \times 10^6)^2 = 6.2 \times 10^{14}$ m² (1). $T^4 = P/\sigma A$ (1) $= 1.1 \times 10^{24}/(5.67 \times 10^{-8} \times 6.2 \times 10^{14})$ (1), so $T = 1.3 \times 10^4$ K (about 13 000 K) (1). [4]

B8 Power per unit area $= \sigma T^4 = 5.67 \times 10^{-8} \times 5800^4$ (1) $= 6.4 \times 10^7$ W m^{-2} (1). [2]

SECTION C · Stretch

C1 $A = P/\sigma T^4 = 3.9 \times 10^{28}/(5.67 \times 10^{-8} \times 3480^4)$ (1) [5]
$A = 4.7 \times 10^{21}$ m² (1)
$r = \sqrt{(A/4\pi)}$ (1)
$r = 1.9 \times 10^{10}$ m (1)
≈ 28 solar radii (1)

C2 X, below 3500 K, peaks towards the infrared and looks red (1); Y, between 7500 and 11 000 K, peaks towards the ultraviolet and looks blue-white (1). With equal areas, $P \propto T^4$, so Y out-radiates X by a factor of tens to around a hundred (1). [3]

C3 Measure the wavelength at which the star's black-body spectrum peaks (1); Wien's law $\lambda_{max}T = 2.9 \times 10^{-3}$ m K then gives the surface temperature directly (1). [2]

C4 Wien: $T_J = 2.9 \times 10^{-3}/(6.9 \times 10^{-7}) = 4203$ K and $T_K = 12609$ K (1). $A = P/\sigma T^4$ and $r = \sqrt{(A/4\pi)}$ (1). $r_J = 1.4 \times 10^9$ m (1); $r_K = 2.9 \times 10^8$ m (1). Star J is about 5 times larger in radius, despite its smaller power output: its low temperature must be offset by area (1). [5]

C5 Measure the wavelength at which the star's spectrum peaks; Wien's law $\lambda_{max}T = 2.9 \times 10^{-3}$ m K gives the surface temperature (1). Measure the radiant flux at Earth and, knowing the star's distance, use the inverse square law to find the total power radiated (1). Stefan's law $P = \sigma AT^4$ then gives the surface area (1), and $A = 4\pi r^2$ converts area to radius (1). This assumes the star radiates as a black body (1) and that no light is absorbed between the star and the telescope, by dust or atmosphere (1). [6]