InkPhysics

ANSWER BOOK

Telescopes across the spectrum

Astrophysics · Year 13

AQA 3.9.1.3, 3.9.1.4

20 questions · 57 marks

NAVY EDITION

SECTION A · Warm-up

A1 The atmosphere absorbs ultraviolet and X-rays high above the ground, so they never reach a ground-based instrument (1). It is transparent to radio wavelengths, so a dish at sea level receives them day and night, even through cloud (1). [2]

A2 The sources are just resolved when the central maximum of one diffraction pattern falls on the first minimum of the other (1): their angular separation is then $\theta \approx \lambda/D$, with θ in radians (1). [2]

A3 Quantum efficiency is the fraction (or percentage) of the photons arriving at the detector that are actually registered (1). A CCD achieves about 80%; the eye manages about 1% (1). [2]

A4 A surface reflects cleanly provided its irregularities are small compared with the wavelength (1). Radio wavelengths are centimetres to metres, so mesh serves, while visible light at about 5×10^{-7} m demands a far smoother surface (1). [2]

A5 Visible light (1) and radio waves (1). [2]

A6 Radio waves pass through cloud (1), and observing can continue in daylight, because the daytime sky is not bright at radio wavelengths (1). [2]

SECTION B · Standard

B1 [2]

$\theta \approx \lambda/D = 5.5 \times 10^{-7}/5.0$ (1)

$\theta = 1.1 \times 10^{-7}$ rad (1)

B2 [4]

Eye: $\theta \approx 5.0 \times 10^{-7}/(5.0 \times 10^{-3})$ (1)

$\theta = 1.0 \times 10^{-4}$ rad (1)

Dish: $\theta \approx 0.21/64 = 3.3 \times 10^{-3}$ rad (1)

The eye's angle is the smaller, so the eye resolves the finer detail (1)

B3 [2]

Collecting power $\propto D^2$, so the ratio $= (10/2.0)^2$ (1)

Ratio = 25 (1)

B4 [4]

$\theta \approx \lambda/D = 5.5 \times 10^{-7}/2.4$ (1)

$\theta = 2.3 \times 10^{-7}$ rad (1)

Smallest feature $\approx \theta d = 2.3 \times 10^{-7} \times 3.8 \times 10^{8}$ (1)

≈ 87 m (1)

B5 $\theta \approx \lambda/D = 5.5 \times 10^{-7}/0.130$ (1) $= 4.2 \times 10^{-6}$ rad (1). This is larger than the stars' separation of 2.2×10^{-6} rad, so the telescope cannot resolve them (1). [3]

B6 Collecting power $\propto D^2$ (1), so the smaller telescope gathers light $(0.50/0.25)^2 =$ 4 times more slowly (1). Exposure needed = 4 × 1.0 = 4.0 hours (1). [3]

B7 Blue: $\theta \approx 4.0 \times 10^{-7}/0.30 = 1.3 \times 10^{-6}$ rad (1). Red: $\theta \approx 7.0 \times 10^{-7}/0.30 = 2.3 \times 10^{-6}$ rad (1). The blue angle is the smaller, so the blue filter resolves the finer detail (1). [3]

B8 CCD: $0.80 \times 6.0 \times 10^4 = 4.8 \times 10^4$ photons (1). Eye: $0.01 \times 6.0 \times 10^4 = 600$ photons (1). [2]

SECTION C · Stretch

C1 Optical: $\theta \approx 5.0 \times 10^{-7}/0.15 = 3.3 \times 10^{-6}$ rad (1) [4]
Radio: $D = \lambda/\theta = 0.21/(3.3 \times 10^{-6})$ (1)
$D = 63$ km (1)
A single dish 63 km across cannot be built, which is why radio astronomers link widely separated dishes to act as one large aperture (1)

C2 Its quantum efficiency is far higher, about 80% against about 1% (1); it can accumulate light over an exposure of minutes or hours while the eye refreshes many times a second (1); it produces a permanent, shareable record whose brightness can be measured (1); and it responds beyond the visible, into the infrared and ultraviolet (1). [4]

C3 Infrared: sited on high, dry mountains or in space because water vapour absorbs infrared (1), and the detectors are cooled so the instrument's own warmth does not swamp the signal (1). X-ray: placed in orbit, and focused by grazing-incidence nested mirrors, because X-rays penetrate an ordinary mirror surface instead of reflecting (1). [3]

C4 Optical: $\theta \approx 5.5 \times 10^{-7}/0.20 = 2.7 \times 10^{-6}$ rad, smaller than 3.0×10^{-6} rad, so the optical telescope just resolves the pair (1). Radio: $\theta \approx 0.21/25 = 8.4 \times 10^{-3}$ rad, far too coarse (1). Required dish: $D = \lambda/\theta = 0.21/(3.0 \times 10^{-6})$ (1) = 70 km, which is why single dishes never match optical resolution (1). [4]

C5 Linked pair: $\theta \approx 0.060/(3.2 \times 10^5) = 1.9 \times 10^{-7}$ rad (1). Single dish: $\theta \approx 0.060/64 = 9.4 \times 10^{-4}$ rad (1). Improvement factor $= 3.2 \times 10^5/64 = 5000$ (1): the linked pair resolves detail 5000 times finer (1). [4]

C6 $\theta \approx \lambda/D = 5.0 \times 10^{-7}/(4.0 \times 10^{-3}) = 1.25 \times 10^{-4}$ rad (1). The lamps are just resolved when they subtend this angle, so $d \approx s/\theta$ (1) $= 1.5/(1.25 \times 10^{-4}) \approx 1.2 \times 10^{4}$ m, about 12 km (1). [3]