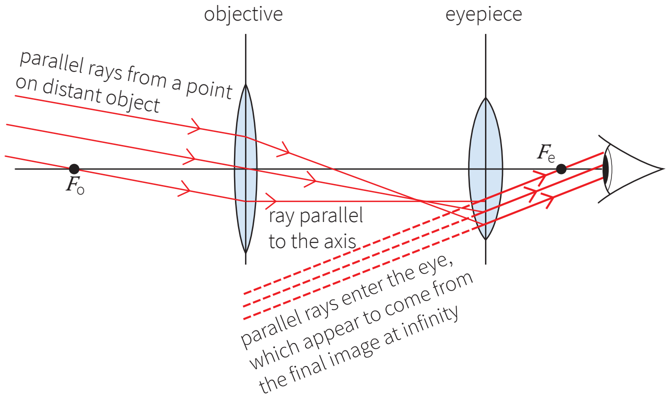
A Level AQA Physics
21 Telescopes – answers

Question	Answers	Extra information	Mark	AO	Spec reference
01.1		Focus of objective where vertical line down from F intersects with line through centre of lens (by eye) 3 parallel rays refracted by objective lens to through focus below F continuing to eyepiece Rays entering eye are parallel to line through focus and centre of eyepiece through lens (by eye)	1 1 1	1	3.9.1.1
01.2	Angular separation $= \frac{\text{diameter}}{\text{distance}} = \frac{1.4\times10^{8}}{9.3\times10^{11}}$ $= 1.5\times10^{-4}$ radians		1	2	3.9.1.1
01.3	$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$ angle subtended by object at unaided eye $\frac{\text{angle subtended by image at eye}}{M} = \frac{1.5\times10^{-4}}{20}$ $= 7.5\times10^{-5}$ rad $\theta = \frac{\text{diameter}}{\text{distance}}$ $\text{distance} = \frac{\text{diameter}}{\theta} = \frac{0.01}{7.5\times10^{-5}}$ = 133 m = 130 m	Angle subtended by object Distance	1 1 1	2	3.9.1.1
01.4	$M = \frac{f_o}{f_e}$ $f_e = \frac{f_o}{M} = \frac{0.98}{20} = 0.049\text{ m} = 49\text{ mm}$	Answer	1	2	3.9.1.1

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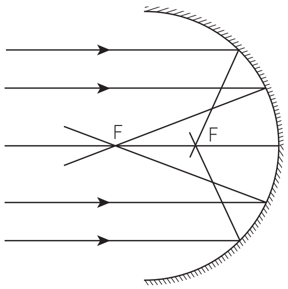
01.5	The angle subtended by Neptune was so small that Galileo viewed it as a point object, like a star Because the resolving power of the telescope was too big		1 1	3	3.9.1.1
02.1	Any two from: • Lenses have to be supported at the edges, but mirrors can be supported from behind • A large lens might break under its own weight • It is easier to produce a large polished surface than a large lens free of imperfections		2	1	3.9.1.2
02.2	 At least two rays at different distances from, and parallel to, the principal axis Law of reflection obeyed at points where rays hit the mirror (by eye) Brought to two separate foci Comment: Light reflected from different parts of the mirror are brought to a focus at different points on the principal axis which will produce a blurred image	1 1 1 1 1	5	1	3.9.1.2
02.3	A parabolic concave primary mirror and a convex secondary mirror		1	1	3.9.1.2

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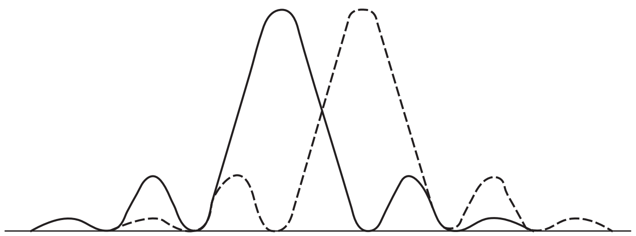
02.4	Angular separation $= \dfrac{\text{diameter}}{\text{distance}} = \dfrac{3.5\times10^{6}}{3.8\times10^{8}} = 0.0092$ radians Rayleigh criterion: angle that is just resolvable $\theta \approx \dfrac{\lambda}{D} = \dfrac{550\times10^{-9}}{0.12} = 4.6 \times 10^{-6}$ radians, which is much smaller than the angle subtended by the moon	Calculation of angle Use of Rayleigh criterion	1 1	2	3.9.1.4
03.1		Two single-slit patterns Arranged so that the maximum of one occurs at the first minimum of the other	1 1	1	3.9.1.4
03.2	Wavelength of light = 550 nm = 550×10^{-9} m $\theta \approx \dfrac{\lambda}{D}$ Angular separation $= \theta = \dfrac{\text{separation of lines}}{\text{distance to lines}} = \dfrac{10^{-3}}{10} = 10^{-4}$ $10^{-4} = \dfrac{\lambda}{D}$ $D = \dfrac{500\times10^{-9}}{10^{-4}} = 5\times10^{-3}$ m = 5 mm	Calculation Answer	1 1	2	3.9.1.4

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03.3	Suitable suggestion, e.g. It would reduce random errors, eliminate systematic errors by finding a line of best fit Measure distance from lines, L, for a range of distances between lines, x $\frac{x}{L} = \frac{\lambda}{D}$ so plot x against L, gradient $= \frac{\lambda}{D}$ so $D = \frac{\lambda}{\text{gradient}}$	Suggestion Correct data to be measured Correct data to be plotted Algebraic expression for D	1 1 1 1	2	3.9.1.4
03.4	Brightness $\propto$ aperture^2 Relative brightness $= \frac{0.1^2}{(5 \times 10^{-3}\,\text{m})^2}$ = 400 times brighter	Use of relationship, explicit or implied Answer	1 1	3	3.9.1.4
04.1	The signals may come from any part of the electromagnetic spectrum, and ground-based telescopes do not detect all wavelengths		1	1	3.9.1.3
04.2	Both of them involve parabolic reflectors The radio telescope has a detector at the focus, and a reflecting telescope has another mirror at the focus		1 1	1	3.9.1.3
04.3	Assuming angular separation is the same $\theta \approx \frac{\lambda}{D}$ so $\frac{\lambda_{\text{radio}}}{D_{\text{radio}}} = \frac{\lambda_{\text{optical}}}{D_{\text{optical}}}$ $D_{\text{radio}} = \frac{\lambda_{\text{radio}} D_{\text{optical}}}{\lambda_{\text{optical}}} = \frac{0.52 \times 0.22}{470 \times 10^{-9}} = 2.4 \times 10^5\,\text{m}$ This is very large, and much too large to build a single dish of this size	Assumption about angular separation clearly stated Ratios compared Answer Comment	1 1 1 1	2	3.9.1.4
04.4	Any correct suggestion and measure, e.g., Interference from microwave ovens/mobile phones/radio or TV transmissions, so build radio telescopes away from cities/towns	Suggestion measure	1 1	1	3.9.1.3

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05.1	The Rayleigh criterion is the minimum angle at which two points with an angular separation can be seen as distinct. A more powerful telescope can resolve objects that are closer together, i.e. have a smaller angular separation Power is related to angle and not to watts / not rate of energy transfer	Explanation of resolving in terms of Rayleigh criterion Link to angle not watts	1 1	1	3.9.1.4
05.2	Telescopes have objective lenses with different focal lengths; A has the smallest focal length, C has the biggest focal length A telescope with a larger focal length will produce an image that subtends a bigger angle to the eye		1 1	2	3.9.1.1
05.3	Length of pixel = 2×10^{-6} m, Area of pixel = $(2 \times 10^{-6}\text{ m})^2 = 4 \times 10^{-12}\text{ m}^2$ Number of pixels = $\frac{1.2 \times 10^{-4}}{4 \times 10^{-12}\text{ m}^2}$ $= 3 \times 10^7$ pixels = 30 megapixels	Area of pixel Answer	1 1	2	3.9.1.4
05.4	Quantum efficiency is the percentage of incident photons that cause electrons to be liberated This is about 70–80 % in a CCD and about 1% in the human eye	Description of quantum efficiency Comparison	1 1		3.9.1.4
06.1	The top part of the lens acts like a prism, which disperses white light/splits light into different colours/wavelengths Blue/violet light is refracted more than red light so the focus for blue/violet is closer to the lens than the focus for red light The image has multi-coloured blurred edges	Shape of lens discussed Variation of refraction with wavelength used to explain Appearance of image	1 1 1	1	3.9.1.2
06.2	$n = \frac{c}{c_s}$; $c_s = \frac{c}{n} = \frac{3 \times 10^8}{1.45} = 2.1 \times \text{ m s}^{-1}$		1	2	3.3.2.3

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06.3	Correct suggestion, e.g. The first lens changes the direction of the light by an amount that varies with frequency When it leaves the first lens, the amount of glass that the red light travels through is greater than the amount of glass that the blue light travels through, slowing the red light more So when it is refracted on leaving the flint glass it is brought to a focus at the same point	The effect of the first lens remains the same The effect of the second piece of glass Effect on crossing boundary between flint glass and air	1 1 1	3	3.3.2.3
06.4	Correct suggestion and explanation, e.g. Lens A because it has a shorter focal length, so is likely to be thicker, so the top of it behaves more like a prism		1 1	3	3.3.2.3
07.1	To reduce interference from artificial sources of radio waves such as microwaves/mobile phones		1	2	3.9.1.3
07.2	$\theta \approx \frac{\lambda}{D}$ A pair of more distant objects have a smaller angle between them Largest frequency means smallest wavelength, which produces the smallest limit of resolution, so 3.0 GHz	Use of equation, explicit or implicit Largest frequency	1 1	3	3.9.1.3
07.3	An electron moves from a higher to a lower energy level		1	1	3.2.2.3
07.4	$E = hf$ $f = \frac{E}{h} = \frac{5.87\times10^{-6} \times 1.6\times10^{-19}}{6.63\times10^{-34}}$ $= 1.41\times10^{9}\text{ Hz} = 1.41\text{ GHz}$ This is between 70 MHz and 3 GHz, so can be detected	Calculation of frequency Explicit link to range of frequencies	1 1	2	3.2.2.1

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07.5	The diameter is larger, so the area over which photons are collected is larger, and there are more photons per unit area		1	3	3.9.1.3
08.1	$F = \frac{GMm}{r^2} = -\frac{mv^2}{r}$ $v = \frac{2\pi r}{T}$ $v^2 = \frac{4\pi^2 r^2}{T^2} = \frac{GM}{r}$ $r = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$	Use of Newton's law of gravitation and equation for centripetal force, explicit or implied Correct expression	1 1 1	2	3.7.2.1
08.2	$r = \sqrt[3]{\frac{6.67\times10^{-11} \times 5.97\times10^{24} \times (95.42 \times 60)^2}{4\pi^2}}$ $= 6.92 \times 10^6$ m	Answer	1	2	3.7.2.1
08.3	Change in potential energy $\Delta E = \left(-\frac{GMm}{r_{\text{orbit}}}\right) - \left(-\frac{GMm}{r_{\text{Earth}}}\right)$ $= 6.67\times10^{-11} \times 5.97\times10^{24} \times 11\,110 \left(-\frac{1}{6.92\times10^6}\right) - \left(-\frac{1}{6.37\times10^6}\right)$ $= 5.52\times10^{10}$ J	Use of two values of gravitational potential energy Answer	1 1	2	3.7.2.3
08.4	Some of the wavelengths of electromagnetic radiation are absorbed by the atmosphere		1	1	3.9.1.3
08.5	They are difficult to repair when they break/the instrumentation or software cannot be easily updated		1	1	3.9.1.3
08.6	Gamma rays pass through glass and metal/they are not refracted by glass or reflected by metal		1	1	3.9.1.3

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08.7	Height of HST above surface = (6.92 – 6.37) $\times 10^6$ m = 5.5×10^5 m Angular separation $\theta = \frac{\text{separation}}{\text{distance}}$ $= \frac{25}{(355\,600\,000 - 550\,000)}$ $= 7.0 \times 10^{-8}$ radians Minimum angular resolution of HST $\theta \approx \frac{\lambda}{D} = \frac{500 \times 10^{-9}}{2.4} = 2.1 \times 10^{-7}$ radians Relevant comment, e.g. The resolution of the HST is not good enough to resolve the astronauts	Distance Angular separation Resolution of HST Comment	1 1 1 1	3	3.9.1.3

Skills box answers

Question	Answer
1	Using Rayleigh criterion and rearranging, minimum diameter $D = \frac{\lambda}{\theta} = \frac{5.7\times10^{-7}\text{ m}}{(1.1\times10^{-5}\text{ rad})} = 0.052$ m
2	Angular separation $\theta = \frac{\lambda}{D} = \frac{0.21\text{ m}}{76.2\text{ m}} = 2.8\times10^{-3}$ m
3	To obtain the same resolution for radio waves (wavelengths ~10^{-1} m) as for visible light waves (wavelengths ~10^{-7} m) requires a much larger aperture. In reality, radio astronomers use several smaller telescopes that are spread over a wide area and combine the observations mathematically to obtain the equivalent of a very large aperture.