IB · DP · Physics

2 hours 14 questions

Structured Questions

9.4 Resolution

9.4.1 The Rayleigh Criterion / 9.4.2 Rayleigh Criterion Calculations / 9.4.3 Resolvance of Diffraction Gratings

Easy (5 questions)	/51
Medium (5 questions)	/56
Hard (4 questions)	/39
Total Marks	**/146**

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Easy Questions

1 (a) A famous painting has just been displayed in a gallery and is being viewed by hundreds of people every hour from different angles and distances away.

State the Rayleigh Criterion for resolution.

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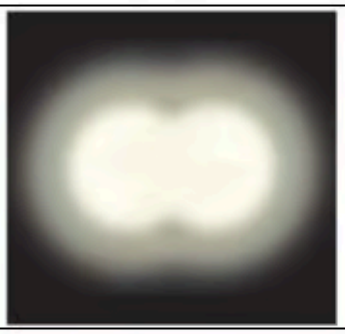
(1 mark)

(b) Viewers at the very back of the room are struggling to make out two white dots on the black background at the top right of the oil painting.

The table shows three different images from three different viewers.

Image	Two dots that are only just resolved	Two dots that show the limiting case of the Rayleigh criterion	Two dots that could not be resolved
			
			
			

Identify the best description of each image by placing a tick (✔) in the correct box .

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(3 marks)

(c) The two dots are 0.004 m apart when viewed by an observer 20 m away.

Calculate the angular separation of the two dots.

(3 marks)

(d) To enhance the viewing experience of the painting it is possible to observe the red dots on the image through a diffraction grating. The wavelength of red light is 700 nm. One viewer has an angle of diffraction through their diffraction grating of 1.4×10^{-5} rad.

Calculate the slit width of the diffraction grating used.

(5 marks)

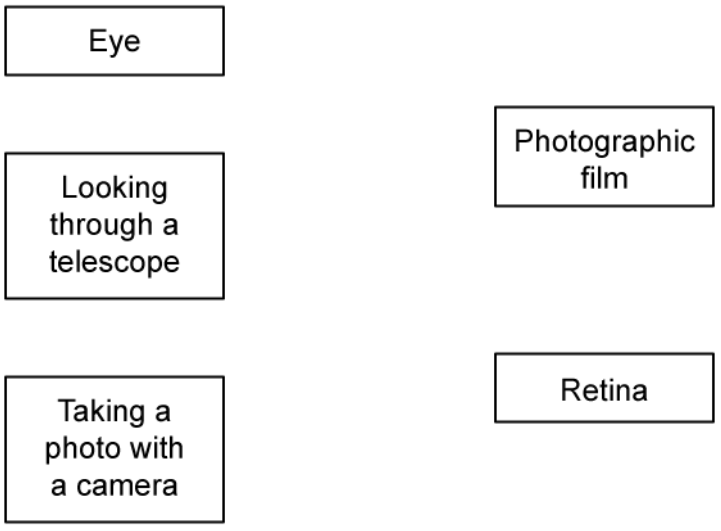
2 (a) A woman is observing two ships on the horizon using different apertures.

Identify by placing a tick (✔) in the correct boxes the apertures Rayleigh's criterion applies to.

Aperture	Rayleigh's Criterion Applies
The pupil of her eye	
The lens of her camera	
The lens of her telescope	
The screen of her phone	

(3 marks)

(b) Link the following apertures and their detectors by drawing a line between them. The same answer may be used more than once.



(3 marks)

(c) Identify the situations, by underlining the correct word, when the two ships will become resolved by the woman's eyes:

(i) The two ships move **closer to / further away from** the woman.

[1]

(ii) The two ships move **closer to / further apart from** each other.

[1]

(iii) **Increasing / decreasing** the diameter of the aperture used by the woman to observe the two ships.

[1]

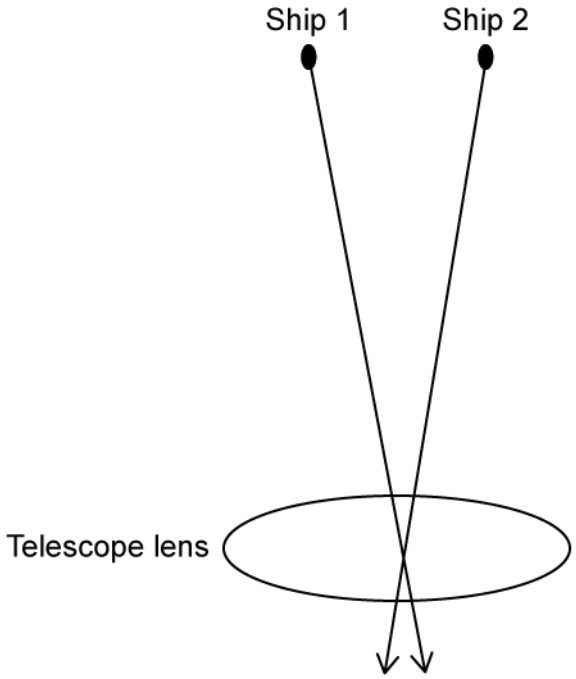
(iv) **Increasing / decreasing** the angle of diffraction between the aperture used by the woman and the two ships.

[1]

(4 marks)

(d) The angle of diffraction between the woman's telescope aperture can be denoted with the letter θ and the diameter of the telescope aperture with the letter b.

Identify, by correctly labelling the diagram with θ and b, the angle of diffraction and the diameter of the aperture.



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(2 marks)

3 (a) An astronomer is observing the light from two distant stars using his telescope.

Identify, by placing a tick (✔) next to, the correct equation for the Rayleigh criterion for a circular aperture.

Equation	
$\theta = \frac{s}{d}$	
$R = \frac{\lambda}{\Delta\lambda}$	
$n\lambda = d\sin\theta$	
$\theta = 1.22\frac{\lambda}{b}$	

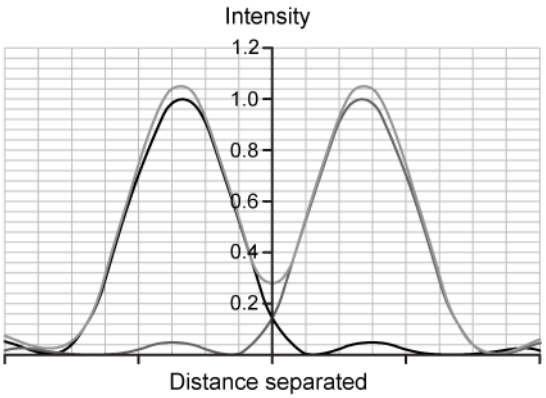
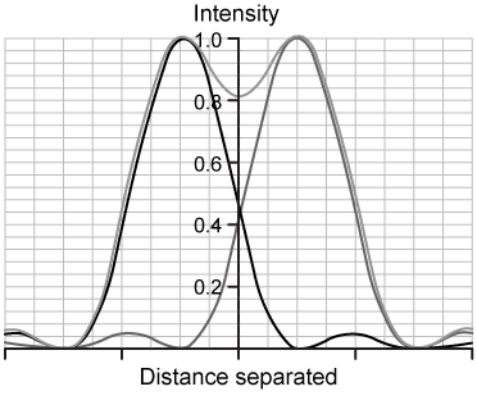
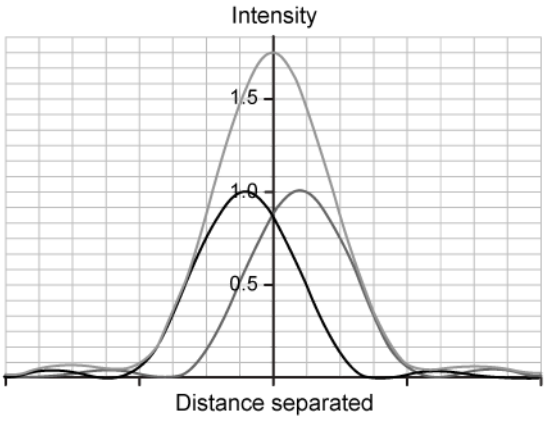
.....

(1 mark)

(b) Three different intensity-distance graphs of the two stars are obtained by the astronomer.

Label each graph, using the phrases below:

Two sources that can be fully resolved.
Two sources that cannot be resolved.
Two sources that are only just resolved.

Graph	Label
	
	
	

(3 marks)

(c) The following statements describing light from the two different stars entering the telescope aperture are false.

Rewrite each statement below so it is correct.

(i) The two stars are situated far apart from each other, so they are viewed through the telescope by the astronomer as a single unresolved source of light.

[1]

(ii) The two stars are close to the Earth, so they are viewed through the telescope by the astronomer as a single unresolved source of light.

[1]

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(2 marks)

(d) The sentences below describe how light from the distant stars will pass through the aperture of the telescope.

Complete the sentences using the correct words from the textbox.

circular	**diffract**	**detector**
rectangular	**refract**	**receptor**

Light from the distant stars passes through the _____ aperture of the telescope. The light will then _____ before creating a diffraction pattern upon the _____ inside.

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(3 marks)

4 (a) Diffraction gratings have a wide range of different uses.

Identify some of these uses by placing a tick (✔) next to those that use a diffraction grating.

	Place a tick (✔) next to the uses of a diffraction grating
Spectroscopy	
Loudspeakers	
Lasers	
Mirror coatings	

(2 marks)

(b) A student is using a diffraction grating to resolve emission spectra from different elements.

He observes the emission spectra of two wavelengths of sodium:

$\lambda_1 = 588.99$ nm

$\lambda_2 = 589.59$ nm

Calculate the difference in meters between the two wavelengths of sodium.

(3 marks)

(c) Calculate the average wavelength, λ in meters of the sodium light.

(3 marks)

(d) Calculate the resolvance of the diffraction grating used in this experiment.

(2 marks)

5 (a) A helicopter engineer is improving the design of helicopter headlights. He is first investigating the angular separation of the lights.

Identify, by placing a tick (✔) in the box, the correct information about the angular separation and Rayleigh criterion.

Information	Place a tick (✔) in this box if the information is correct
The angular separation is measured in degrees	
The angular separation is the angle between the diffraction aperture and the light rays coming from the two sources	
The angular separation, $\theta \geq 1.22\frac{\lambda}{b}$ when the two sources can be fully resolved	
Decreasing the angular separation between two objects means they can be resolved	

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(2 marks)

(b) The engineer is using a diffraction grating to observe the headlights at different distances away. A second-order spectrum is created by a diffraction grating with 9000 lines.

Calculate the resolving power of the diffraction grating.

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(2 marks)

(c) The engineer collects the following data on the separation of and the light intensity from the two helicopter headlights.

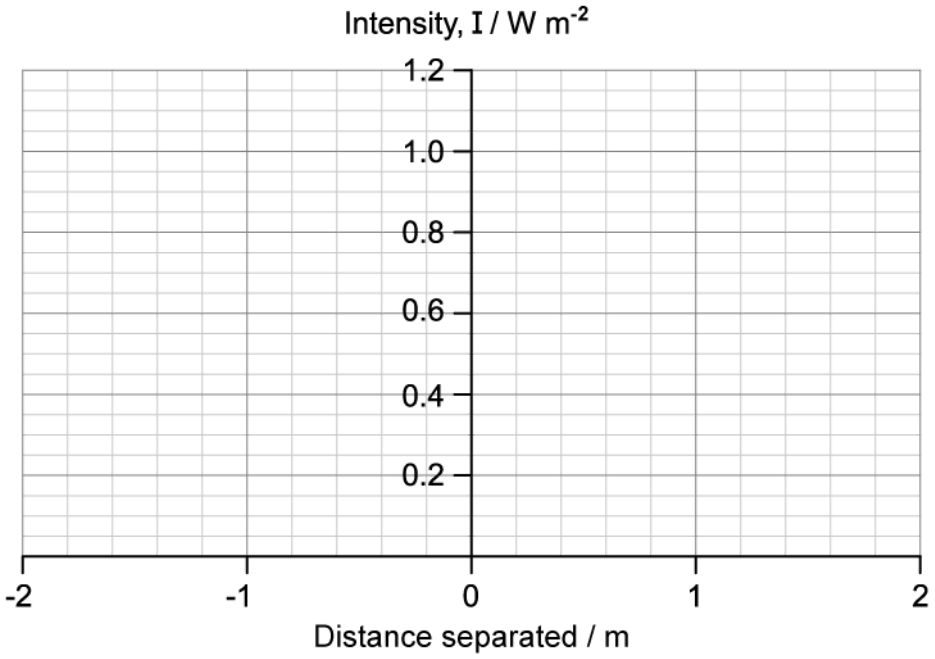
For headlight 1:

Distance separated, /m	Intensity, I / W m^{-2}
−1.80	0
−0.80	1
0.20	0

For headlight 2:

Distance separated / m	Intensity, I / W m^{-2}
−0.20	0
0.80	1
1.80	0

Plot a graph of the results on the axes below to show the combined intensity of the light from the two headlights.



(3 marks)

(d) Identify the type of resolution shown by the two headlamps in the graph in part c.

(1 mark)

Medium Questions

1 (a) A woman is rowing a boat towards two ancient statues situated on an island. The woman can just resolve the images of the two statues.

Describe whether the Rayleigh criterion applies to this scenario.

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(3 marks)

(b) The pupils in the woman's eyes have a diameter of 2.3 mm. The average wavelength of the sunlight is 570 nm.

She can just resolve the images of the two statues when her distance from them is 10 km.

(i) Calculate the angular separation of the two statues when the images can just be resolved.

[2]

(ii) Determine the distance between the two statues.

[1]

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(3 marks)

(c) Around the other side of the island, there are two further statues. These are situated at a distance apart of 0.73 m.

Determine how far the woman can row away from the island before she can no longer resolve these two statues.

(2 marks)

(d) The sun begins to set and the average wavelength of light is now 500 nm. The woman's pupils dilate to give a wider diameter of 3.1 mm.

Determine the new distance at which the woman can resolve the second set of statues.

(3 marks)

2 (a) Two distant stars are detected on earth using a telescope with a circular receiving dish.

Outline the criteria to enable light from the two stars to be just resolved.

(3 marks)

(b) The stars are both situated in a galaxy 5.4×10^{25} m from the Earth and are 3.7×10^{20} m apart.

The wavelength of light received from the stars is 9.3 μm.

Calculate the minimum size of the circular receiving dish required to resolve the image of the two stars.

(2 marks)

(c) The same telescope is used to observe a different galaxy at a distance of 3.8×10^{27} m from Earth. The astronomer wishes to resolve two stars with a separation of 2.3×10^{22} m.

Determine whether the telescope is able to resolve the light from the stars.

(2 marks)

(d) The astronomer working with the telescope wishes to determine if sodium is present in the stars. To do this they use a diffraction grating to split the light from the star.

The two wavelengths of light they wish to resolve are 589.0 nm and 589.6 nm.

Determine the resolving power of the diffraction grating required to resolve these wavelengths.

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(3 marks)

3 (a) Monochromatic light of wavelength 610 nm is incident normally on a single narrow slit. A diffraction pattern is formed on a screen.

Sketch a graph to show the variation of relative light intensity with angle, measured from the centre of the slit.

(3 marks)

(b) The single narrow slit is replaced by a diffraction grating.

Describe how the Rayleigh criterion allows the new diffraction pattern to be predicted.

(4 marks)

(c) A second monochromatic light source of 630 nm is placed alongside the original monochromatic light source of wavelength 610 nm. The width of the beam of light from these sources is 2.0 mm.

(i) Calculate the resolving power of the diffraction grating.

[3]

(ii) Calculate the minimum number of lines per mm required to resolve the two light sources for the second order maximum.

[2]

(5 marks)

(d) The diffraction grating is replaced with with 200 lines per mm.

Calculate the resolving power of the new grating under the same conditions

(2 marks)

4 (a) A binary star system is observed using a telescope with a circular lens. The images of the two stars can just be resolved according to the Rayleigh criterion.

Outline what is meant by the statement "just resolved according to the Rayleigh criterion" in this context.

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(2 marks)

(b) The circular lens has a diameter of 4 mm. The distance from the Earth to the binary star system is 6.2×10^{16} m, and the average wavelength of light emitted by the stars is 470 nm.

Determine the separation of the two stars.

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(2 marks)

(c) The telescope is directed at a different area of the sky to detect further binary systems, using a larger diameter lens. A potential binary system with the same average wavelength of light, and the same separation between the stars is detected at 9.1×10^{18} m distance from the earth.

Determine the diameter of the new lens.

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(2 marks)

(d) The light from the binary system is passed through a diffraction grating with 430 lines per mm. The difference in wavelength between the two stars is 1.3 nm.

(i) Determine the resolving power of the diffraction grating

[1]

(ii) Hence calculate the width of the beam of light received from the stars to produce resolution of the two stars in the 3rd order spectrum

[2]

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(3 marks)

5 (a) A man stands on an airstrip at night as a car approaches him. His pupils have a diameter of 3.2 mm and the wavelength of the light is 490 nm. He can just resolve the light from the headlights of the car into two distinct points.

The car is moving at 20 m s^{-1} and the headlights are 1.6 m apart.

(i) Calculate the Rayleigh criterion for this situation.

[1]

(ii) Determine the time the man has to leave the airstrip before he is hit by the car.

[2]

(3 marks)

(b) Draw a labelled sketch of the variation of intensity of light with angle, θ, as it falls on the man's retina at the point where the two headlights can just be resolved.

(3 marks)

(c) Hovering above the airstrip is a helicopter on which the man can just resolve two light sources. The helicopter is hovering at 25% of the distance at which the car lights were able to be resolved, and the separation between the lights is 0.45 m. The pupil diameter of the man remains unchanged.

Determine the wavelength of the light emitted by the helicopter's lights.

(3 marks)

(d) The man is holding blue lights in each hand to guide the helicopter to a safe landing. He switches to using red lights whilst maintaining the same separation.

Explain the effect on how the helicopter pilot observes the lights

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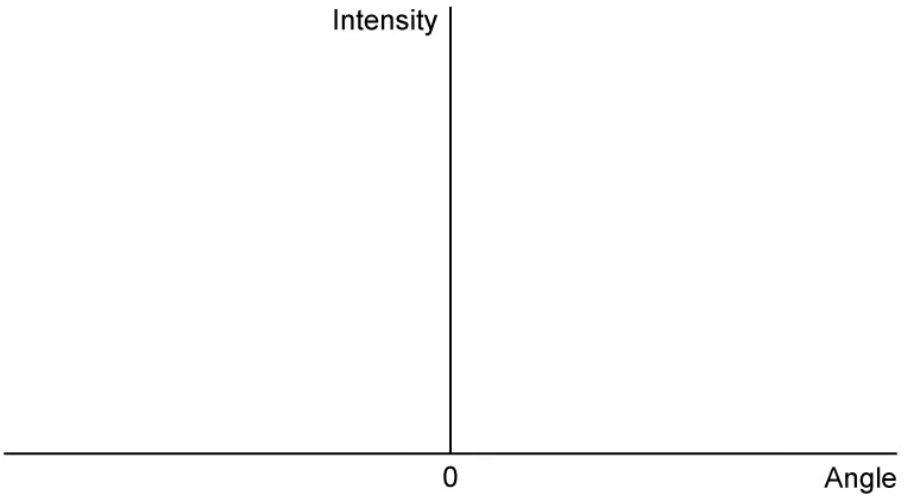
(3 marks)

Hard Questions

1 (a) There is a supermassive black hole at the centre of the Andromeda galaxy. It is difficult for astronomers using a telescope to resolve images of the region around this black hole directly.

(i) Sketch on the axis the variation in the intensity of the diffraction pattern produced when light from a point object passes through a circular aperture.

[2]



(ii) Explain the meaning of the Rayleigh criterion. Draw a diagram to aid your explanation.

[2]

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(4 marks)

(b) Astronomers investigating the supermassive black hole at the centre of the Andromeda galaxy detect radio waves at a frequency of 240 GHz. By correlating the information from several radio telescopes, they can obtain the same resolution as a single radio telescope with a diameter of 4500 km.

Calculate the angular separation of the black hole as detected by the telescope on Earth.

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(2 marks)

(c) The centre of the Andromeda galaxy is 27 000 light years away from the Earth and the black hole at its centre has a mass equal to 9×10^{36} kg. The following equation can be used to calculate the radius of a black hole:

$$R_s = \frac{2GM}{c^2}$$

(i) Compare the limit of resolution of the telescope from (b) and the angle subtended by the radius of the black hole to the perpendicular distance of the black hole from the Earth.

[3]

(ii) Identify and give a reason for whether the entire black hole can be seen through the telescope.

[2]

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(5 marks)

2 (a) The Hale telescope in Palomar California was designed and built by the California Institute of Technology in the 1940s.

Draw a diagram to show the path of two rays emerging from stellar objects, parallel to the axis, through the Hale telescope, as far as the eyepiece.

(2 marks)

(b) The Hale telescope was one of the first telescopes to use a diffraction grating. The diameter of the diffraction grating is 12.5 cm with 250 lines per mm. The wavelength of the incident light is 2.5 μm.

Calculate the resolving power of the diffraction grating.

(3 marks)

(c) (i) Calculate the smallest difference in frequency in GHz in the light that the grating can detect.

[2]

(ii) State the type of radiation that can be detected by the Hale telescope.

[1]

(3 marks)

(d) To reduce atmospheric absorption problems the telescope was built in the Palomar Mountain Range.

(i) Identify the component of the atmosphere that absorbs the most infrared radiation.

[1]

(ii) The spectrum of light from objects observed by the telescope can be used to predict their temperature.
Explain why this absorption can lead to errors in the temperature value.

[2]

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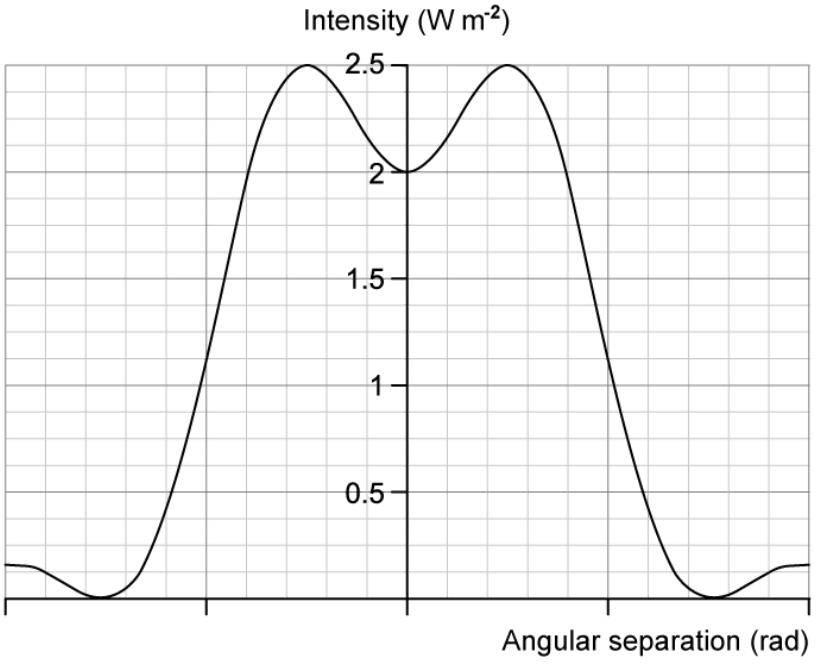
(3 marks)

3 (a) A binary star system in Alpha Centuri can be observed from Earth. Alpha Centuri A and B are 4.35 light years away from Earth and are 23 AU from each other.

Calculate the angular separation of the two stars from Earth. Give your final answer to one significant figure.

(2 marks)

(b) (i) Complete the graph to show the individual angular separation and intensities for Alpha Centuri A and B when they can just be resolved by an observer on Earth.



[2]

(ii) Label the x-axis with the appropriate values for angular separation.

[3]

(5 marks)

(c) State and explain the changes that would be observed on the graph from your answer to (b) part (i) if Alpha Centuri A and B both moved further away from the Earth by an equal amount.

(4 marks)

4 (a) The James Webb Space Telescope has a mirror diameter of 6.5 m and operates with a wavelength range of 0.6 μm to 28 μm.

Determine whether it can resolve two binary stars 3.6×10^{10} m apart at a distance of 3.19×10^{17} m away.

(3 marks)

(b) The James Webb Space Telescope (JWST) was launched with the criteria to "see further" than the Hubble Space Telescope (HST). The following information is available:

	James Webb Space Telescope	**Hubble Space Telescope**
Mirror Diameter	6.5 m	2.5 m
Distance from Earth	1.5×10^6 km	547 km
Range of Observable Wavelengths	0.6 μm to 28 μm	0.1 μm to 2.5 μm

Evaluate how each of the factors given in the table will enable the James Webb Space Telescope to be effective in meeting its criteria.

(3 marks)