9.4 Resolution

Question Paper

Course	DP IB Physics
Section	9. Wave Phenomena (HL only)
Topic	9.4 Resolution
Difficulty	Hard

Time allowed: 50

Score: /39

Percentage: /100

Question 1a

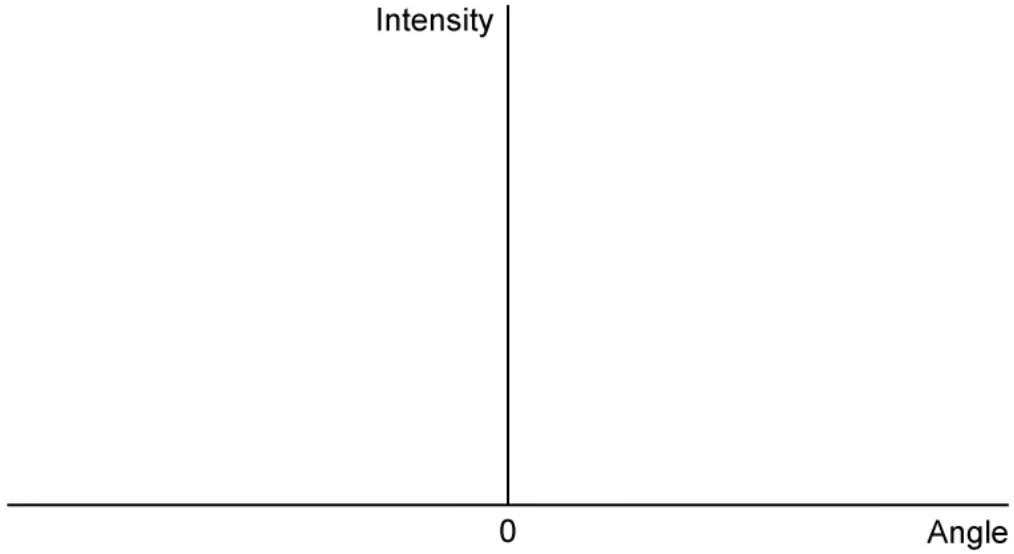
There is a supermassive black hole at the centre of the Andromeda galaxy. It is difficult for astronomers using a telescope to resolve images of the region around this black hole directly.

(a)

(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]

[4 marks]

Question 1b

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.

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

[2]

[2 marks]

Question 1c

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:

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

(c)
(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]

[5 marks]

Question 2a

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

(a)
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]

[2 marks]

Question 2b

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.

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

[3]

[3 marks]

Question 2c

(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]

Question 2d

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

(d)
(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]

[3 marks]

Question 3a

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.

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

[2]

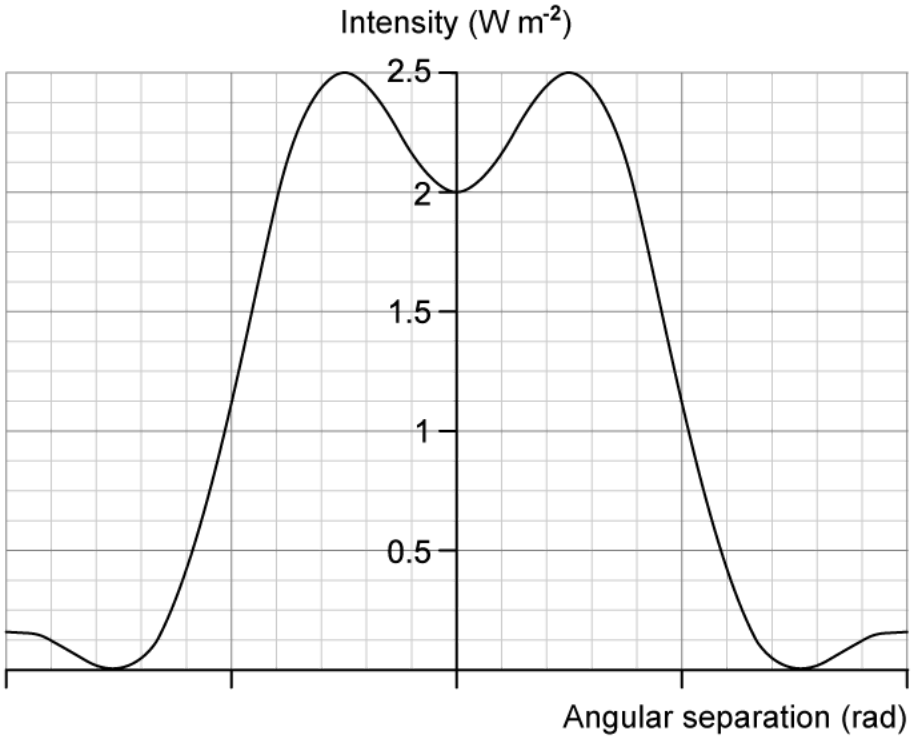
[2 marks]

Question 3b

(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]

Question 3c

(d)
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]

[4 marks]

Question 4a

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.

(a)
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]

[3 marks]

Question 4b

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

(b)
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]

[3 marks]