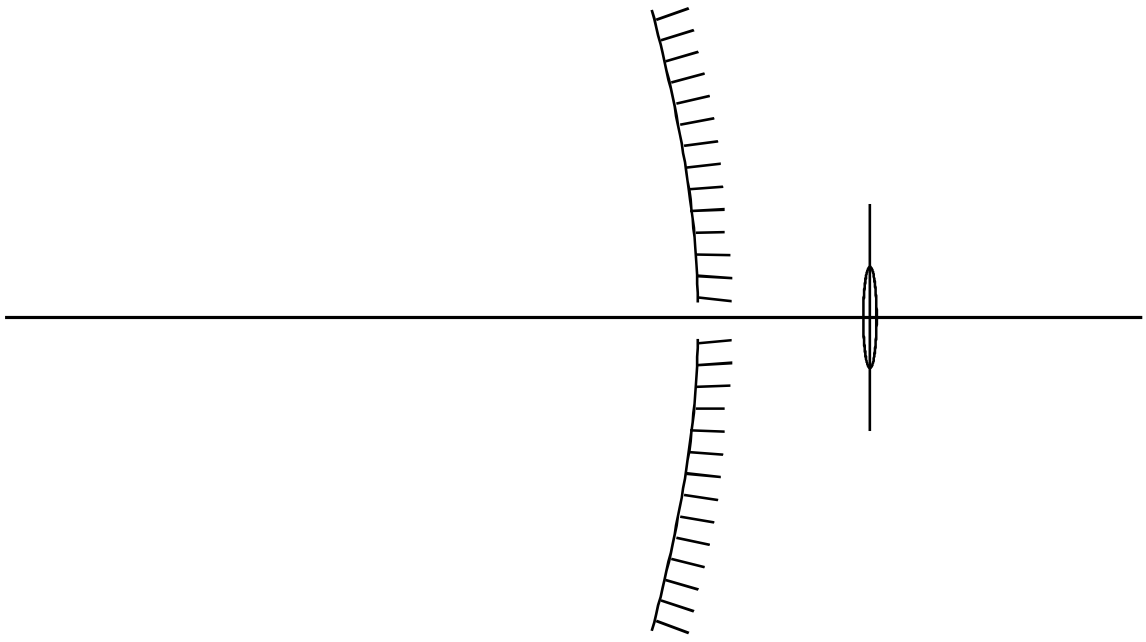
1. The diagram shows the concave mirror of a Cassegrain reflecting telescope, together with the eyepiece lens. Complete the diagram of the telescope and mark on it the focal point of the concave mirror. Draw a ray diagram for two rays from a star, parallel to the principal axis, passing through the telescope and emerging from the eyepiece lens



State, with reasons, **two** optical advantages which the reflecting telescope normally has over a refracting telescope.

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(Total 6 marks)

2. (a) State **two** similarities between a radio telescope and an optical reflecting telescope.

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(2)

(b) The dish of a radio telescope has holes of diameter 20 mm spaced close together in its reflecting surface in order to reduce the weight of the dish. Explain why the performance of this telescope will be far more satisfactory when receiving signals of frequency 7.5×10^8 Hz than when receiving signals of frequency 1.5×10^{10} Hz.

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(3)

(c) Explain why the resolving power of a single dish radio telescope is normally much less than that of a normal optical telescope.

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(2)
(Total 7 marks)

3. (a) A telescope is made from two converging lenses of focal lengths 2.50 m and 0.020 m.

(i) Show, with the aid of a labelled diagram, how the lenses would be placed for normal adjustment. Show, on the diagram, the principal focus of each lens.

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(ii) The telescope is used to observe a planet which subtends an angle of 5.0×10^{-5} rad at the objective. Calculate the angle subtended at the eye by the final image.

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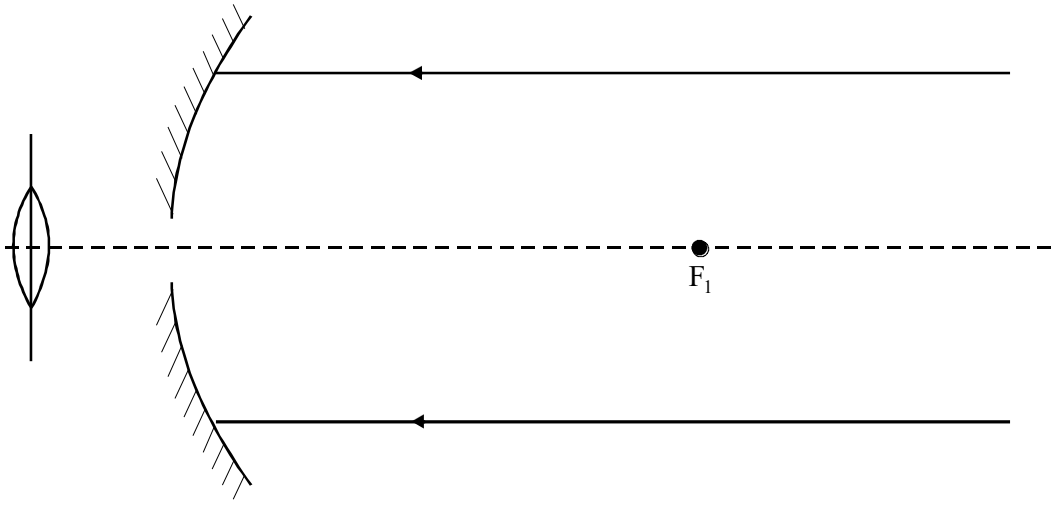
(4)

(b) The diagram (not drawn to scale) shows an incomplete Cassegrain reflecting telescope. F_1 is the principal focus of the concave mirror.



(i) Add to the diagram the second necessary mirror, M.

(ii) Complete the path of the two rays through the telescope when it is in normal adjustment. Show your reasoning in drawing these rays, either on the diagram or below. Label the principal focus, F_2, of the eye lens, and the position of C, the centre of curvature of M.

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(6)

(c) (i) State what is meant by chromatic aberration and explain the effect it would have on the image in an uncorrected refracting telescope.

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(ii) Explain why the Cassegrain telescope would be almost free of chromatic aberration.

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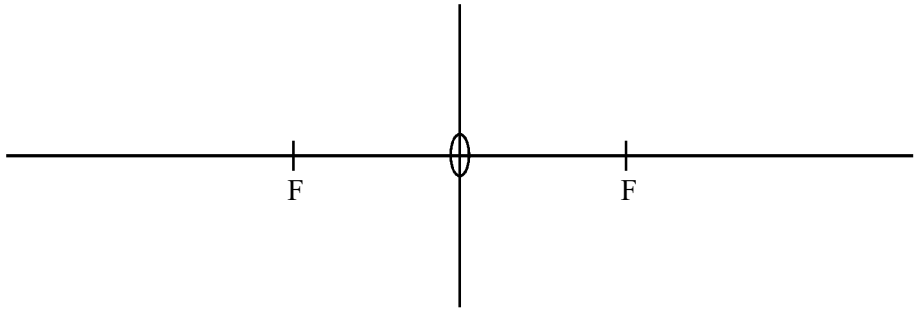
(5)
(Total 15 marks)

4. A converging lens of focal length 100mm is used to produce a magnified image of a small object. The magnification is × 2.

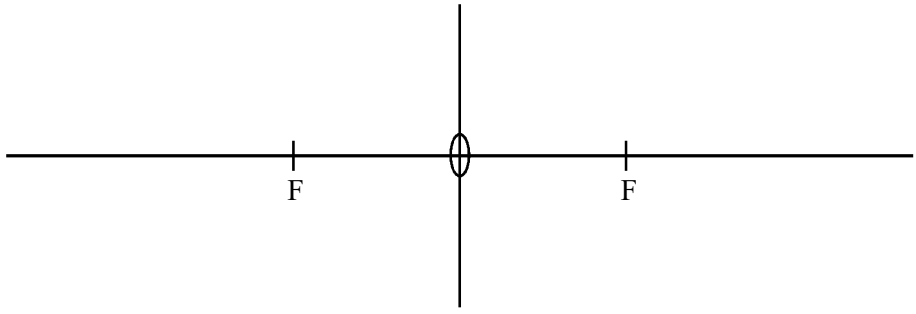
Draw rays on the diagrams to show how the images are produced.
The principal foci are each labelled F. The diagrams need not be drawn to scale.

(a) real image formation



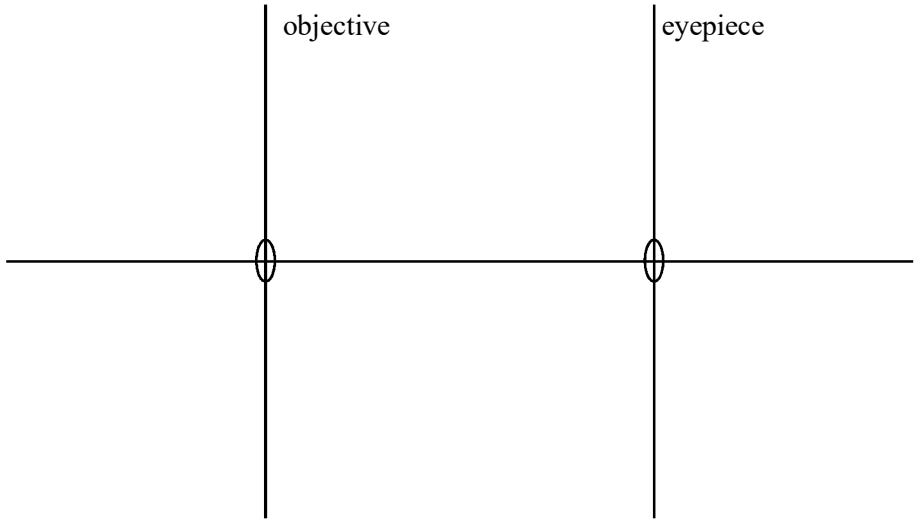
(2)

(b) virtual image formation



(2)
(Total 4 marks)

5. (a) An astronomical telescope consists of two thin converging lenses, as shown. The focal lengths of the objective lens and the eyepiece lens are f and f, respectively. The telescope is used to view the Moon and the separation of the lenses is such that the telescope is in normal adjustment.



(i) Draw rays to show how a magnified image is formed by the telescope. Your ray diagram should show the paths through the telescope of two parallel non-axial rays from a point on the Moon to the observer's eye. Indicate the position of the principal focus for each lens.

(ii) An observer's unaided eye has a resolving power of 120 seconds of arc. If the angular magnification of a telescope is 24, determine the angular separation of two points on the Moon, which the same observer can just resolve with the aid of the telescope.

The angular magnification of the instrument is given by

$$M = \frac{\text{angle subtended at the eye by the image}}{\text{angle subtended at the eye by the object}}$$

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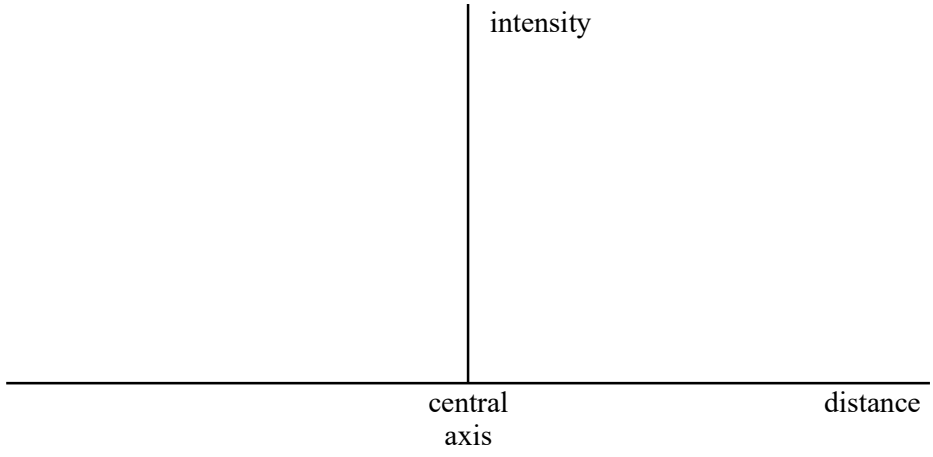
(7)

(b) A parallel beam of monochromatic light, incident on a converging lens and parallel to the axis, fills the lens aperture completely. After transmission through the lens the beam falls on a plane surface placed parallel to the plane of the aperture and approximately 1 m away from it. The plane surface is in the focal plane of the lens.

(i) Sketch a graph, using the axes, to show how the intensity of the light varies with the radial distance from the central axis of the lens, for small radial distances.



(ii) With the aid of another diagram, describe *Rayleigh's criterion* for the resolution of two point sources viewed through the lens.

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(5)

(c) (i) The objective lens of the telescope described in part (a) has a diameter of 15 cm. The telescope is used to view the star Mizar, which is a double star with an angular separation of 7.0×10^{-5} rad. Calculate the approximate value of the resolving power of the telescope for light of wavelength 6.0×10^{-7} m. Hence determine whether the two stars could be resolved by the telescope.

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(ii) If a double star, similar to that described in part (c)(i), cannot be resolved by the telescope, discuss whether or not increasing the angular magnification of this telescope would allow resolution.

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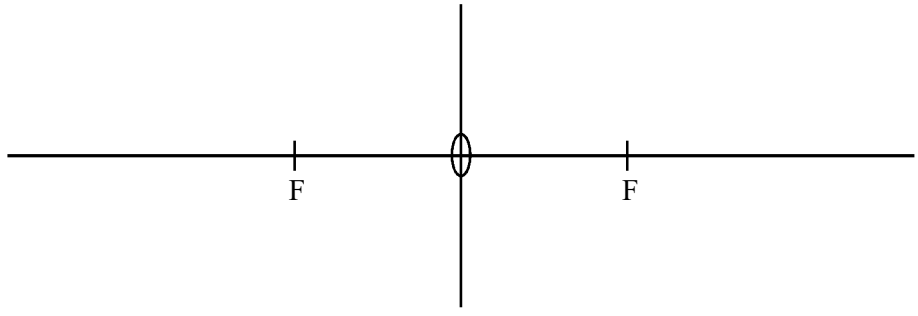
(4)
(Total 16 marks)

6. A converging lens of focal length 100mm is used to produce a real image of an object with a magnification of × ½.

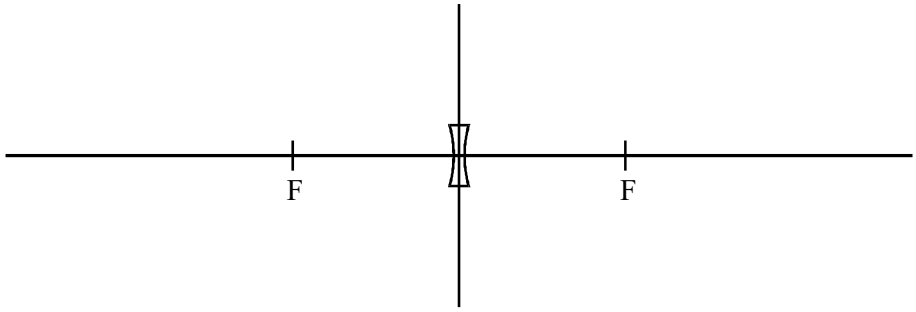
Draw rays on the diagrams to show how the images are produced. The principal foci are each labelled F. The diagrams need not be drawn to scale.

(a)



(2)

(b)



(2)
(Total 4 marks)

7. (a) In the space below, draw a ray diagram for a Cassegrain reflecting telescope. Your diagram should show the paths of two rays from a distant object, which pass through the telescope and emerge from the eyepiece lens.

(3)

(b) (i) With the aid of a ray diagram, explain what is meant by *spherical aberration* of a curved mirror. State how a reflecting telescope can be designed to overcome spherical aberration.

(ii) State what is meant by *chromatic aberration.* Explain why a reflecting telescope does not suffer from chromatic aberration.

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(6)
(Total 9 marks)

8. A converging lens of power 10 D produces a magnified image of a small object. The image is 0.25 m from the centre of the lens and is the same way up as the object.

(i) State **one** other property of the image.

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(ii) Determine the focal length of the lens.

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(iii) Show that the object should be placed approximately 0.07 m from this lens for the image to be formed.

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(iv) Draw a ray diagram below to show how this image is formed. Mark the positions of the object, image and the principal foci of the lens.

A scale diagram is **not** required.

(Total 7 marks)

9. (a) (i) Draw the diffraction pattern produced when light from a star passes through a circular aperture.

(ii) Explain what is meant by the "Rayleigh criterion" for the resolution of **two** stars. Draw a diagram to help if you wish.

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(3)

(b) The star Arich in the constellation Virgo is two stars separated by an angle of 1.1×10^{-5} radians when viewed from Earth. Calculate the minimum diameter of a telescope objective which would just allow the two stars to be resolved. Assume the light from the star has a wavelength of 5.7×10^{-7} m.

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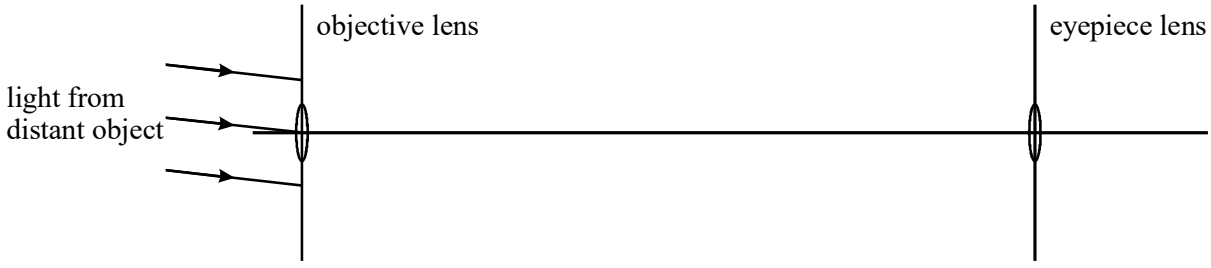
(2)
(Total 5 marks)

10. (a) Complete the ray diagram for an astronomical refracting telescope in normal adjustment. Your diagram should show the paths of the three non-axial rays, through both lenses. Label the positions of the principal foci of the two lenses.



(3)

(b) In 1656 Huygens made an astronomical telescope with an angular magnification of approximately 100. The distance between the two lenses was approximately 3.5 m when in normal adjustment.

(i) Estimate the focal length of the objective lens and the focal length of the eyepiece lens used to make this telescope.

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(ii) Using this telescope, Huygens discovered Titan, a satellite of Saturn. At this angular magnification, the image of Titan subtends an angle 4.0×10^{-3} radians when it is approximately 1.3×10^{9} km from the Earth. Calculate the diameter of Titan.

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(3)

(c) Most modem large optical telescopes use mirrors rather than lenses. State and explain **two** optical advantages reflecting telescopes have compared with refracting telescopes.

advantage 1 .....

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advantage 2 .....

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(2)
(Total 8 marks)

11. The charged coupled device (CCD) camera is often used with telescopes because of its high *quantum efficiency.*

(a) State what is meant by quantum efficiency and give a typical value for the quantum efficiency of a CCD.

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(2)

(b) Describe the mode of action of a CCD.

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(5)
(Total 7 marks)

12. (a) A converging lens of focal length 4.0 cm is used to form an inverted image of a small upright object. The image produced is the same size as the object.

(i) State the distance of the lens from the object for this image to be formed.

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(ii) Draw a ray diagram to show how the image is formed. Mark the positions of the object, image and the principal foci of the lens.

(3)

(b) (i) The lens in part (a) is replaced by another converging lens of focal length 12.0 cm, the distance between the lens and object staying the same. Calculate the distance between the image formed and the lens.

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(ii) State **three** properties of this image.

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(3)
(Total 6 marks)

13. (a) Draw a ray diagram to show the paths of **two** rays travelling parallel to the principal axis through a Cassegrain telescope, as far as the eyepiece.

(3)

(b) With the aid of a ray diagram explain what is meant by *spherical aberration* when applied to a concave mirror.

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(2)

(c) With the aid of a ray diagram explain what is meant by *chromatic aberration*.

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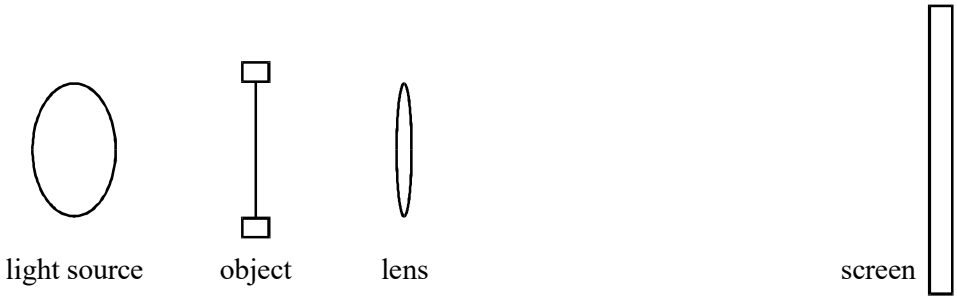
(2)
(Total 7 marks)

14. Whilst performing experiments on lenses, a student makes a simple projector using a light source, a converging lens, an object and screen as shown in the diagram below.



(i) A magnified focused image is produced on the screen. State **two** other properties of this image.

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(ii) In the space below, draw a ray diagram to show how the lens forms this image. Mark the positions of the object, image and a principal focus of the lens.

(iii) A focused image is formed on the screen when the lens is placed 0.17 m from the object and 1.62 m from the screen. Calculate the power of the converging lens.

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(Total 6 marks)

15. (a) Draw a ray diagram to show the path of two rays, parallel to the axis, through a Cassegrain telescope, as far as the eyepiece.

(2)

(b) The UKIRT is a Cassegrain telescope capable of detecting both infrared and visible radiation. It has an objective diameter of 3.8 m.

(i) Calculate the resolving power of this telescope for infrared light of wavelength 2.0 μm.

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(ii) Explain why the resolving power of this telescope is better in the visible region than in the infrared region.

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(4)

(c) To reduce atmospheric absorption problems, the telescope was built at the top of Mount Mauna Kea in Hawaii.

(i) What, in the atmosphere, is responsible for absorbing infrared radiation?

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(ii) The spectrum of light from a star can be used to determine its temperature. Explain why this absorption can lead to errors in the value.

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(3)
(Total 9 marks)

16. (a) Draw a ray diagram for an astronomical refracting telescope in normal adjustment. Your diagram should show the paths of three non-axial rays through both lenses.
Label the principal foci of the two lenses.

(3)

(b) **Figure 1** shows an astronomical telescope made from two cardboard tubes of slightly different diameter, two convex lenses of focal lengths 0.10 m and 0.50 m respectively and some modelling clay.

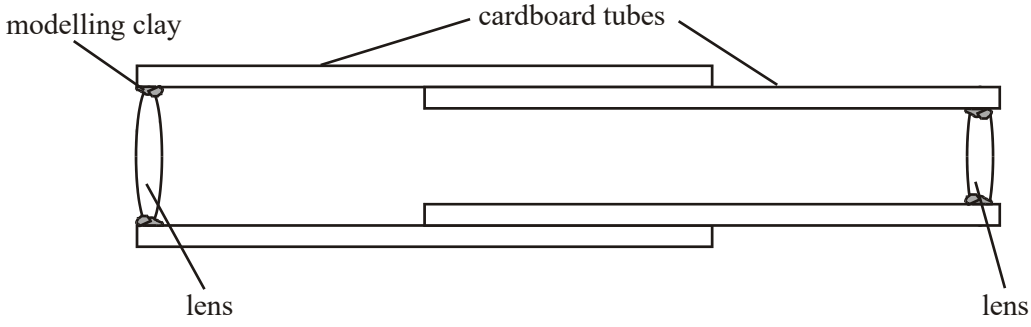

Figure 1

(i) Calculate the distance between the two lenses when the telescope is in normal adjustment.

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(ii) The Moon is 380 000 km from the Earth and has a diameter of 3 500 km. Calculate the angle subtended by the image of the full Moon when viewed through the telescope.

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(iii) The telescope suffers from chromatic aberration. Describe how this affects the appearance of the image.

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(4)
(Total 7 marks)

17. A converging lens can be used to produce both a magnified real image and a magnified virtual image of an object.

(a) Draw ray diagrams to show how each image is formed. Label the principal foci of the lens in each case.

(4)

(b) Calculate the object distance required to produce a magnified image 0.25 m from a lens of power +10 D when the image is

(i) real,

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(ii) virtual.

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(4)
(Total 8 marks)

18. (a) Describe what is meant by an Airy disc and explain its significance in determining the resolving power of a telescope.

You may be awarded marks for the quality of written communication in your answer.

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(3)

(b) The Arecibo telescope is the largest radio telescope in the world. It can be used to investigate distant galaxies by detecting the 1.4 GHz radio signal produced by molecular hydrogen.

(i) When the telescope was being built, any surface irregularities had to be less than 0.01 m in order for it to detect the molecular hydrogen signal. Verify this value using an appropriate calculation.

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(ii) The diameter of the Arecibo telescope is 305 m. Calculate its resolving power when detecting the molecular hydrogen signal.

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(3)

(c) Describe a problem associated with spherical reflecting telescopes and state how telescopes are designed to prevent it.

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(2)

(Total 8 marks)

19. The last refracting telescope that could be called „the largest optical telescope in the world" was one with an objective lens of diameter 0.90 m. It was superseded in 1889 by a reflecting telescope with an objective mirror of diameter 1.52 m.

(a) Calculate

(i) the ratio $\frac{\text{resolving power of the reflector}}{\text{resolving power of the refractor}}$,

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(ii) the ratio $\frac{\text{the amount of light energy that can be collected per second by the reflector}}{\text{the amount of light energy that can be collected per second by the refractor}}$.

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(3)

(b) Spherical aberration can be a problem with reflecting telescopes.

(i) Draw a ray diagram to show how spherical aberration arises in a reflecting telescope.

(ii) State how this problem can be prevented.

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(2)

(c) The image produced by a refracting telescope can be clearer than that of a similar diameter reflector because of the position of the secondary mirror.

(i) Sketch a diagram to show the position of the mirrors in a Cassegrain telescope.

(ii) Give **two** reasons why the secondary mirror in the Cassegrain telescope affects the clarity of the image.

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(3)

(Total 8 marks)

20. Charge coupled devices (CCDs) are commonly used in astronomy because of their high *quantum efficiency*.

(a) Describe the structure and operation of a CCD.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

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(4)

(b) Explain what is meant by quantum efficiency, and state a typical value of the quantum efficiency of a CCD.

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(2)
(Total 6 marks)

21. A converging lens can be used to produce both a magnified real image and a magnified virtual image of an object.

(a) Draw ray diagrams to show how each image are formed. Label the principal foci of the lens in each case.

(4)

(b) Calculate the object distance required to produce a magnified image 0.25 m from a lens of focal length 0.10 m where the image is virtual.

Object distance = ...

(2)

(Total 6 marks)

22. Modern astronomy relies on the analysis of radiation from many different parts of the electromagnetic spectrum. Compare the main features of telescopes used to detect radio waves with those of optical reflecting telescopes. Explain the differences in their resolving and collecting powers.

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(Total 6 marks)