Theme 5: Light - Reflection and Refraction

Prior Knowledge

It is recommended that you revise the following topics before you start working on these questions.

- Rectilinear propagation of light - formation of shadows, umbra-penubra, opacity of materials
- Reflection off a plane surface - plane mirrors, incident and reflected ray, normal
- Refraction and refractive index of materials - how and why does refraction occur, the normal to a surface, refractive index of air, glass, water, etc.

Direct To Home (DTH)

The DTH technology for TV content reception was proposed in India in 1996 and approved by the government in 2000. It promised better picture quality and completely changed how TV content was delivered to individual homes. It replaced the local players (referred to as *cable operators, cable guys, cable wala*, etc.) by a selected set of big companies.

What lies at the heart of this technology is a dish antenna installed in each house, which receives signals directly from the satellite and a cable then runs down into the house, transmitting the signals received from the satellite. This dish antenna has to maximise the signals it catches but should be portable enough for each house to have their own antenna. Typical dish antennas are around 60 cm in diameter and are called "dish" because they are similar to the cooking/eating dishes we use - a shallow paraboloid. Let us dig deeper and understand what is so special about the "dish" shape.

Case Study A - Reflection from a Dish

In a dish antenna, the dish captures the signals and reflects all of them to one point (its focal point), called the feed horn, from where it is further sent to the house through a cable. The dish antenna has the same shape as the reflecting surface of a solar cooker. In a solar cooker, the food being cooked will be placed at the focal point.

Fig. 5.1, Dish antenna

Fig. 5.2, Solar cooker

Question 1

Be it the feed horn or the stand on which the food container is placed, its location has to be determined based on the shape of the reflecting dish. If you want this point to be further away from the dish, what changes would you make to the dish?

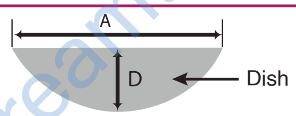


Fig. 5.3, Schematic of the dish with diameter A and depth D

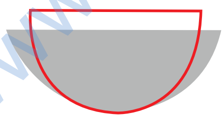


Fig. 5.4, Answer option a

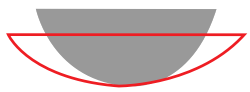


Fig. 5.5, Answer option b

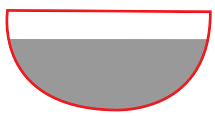


Fig. 5.6, Answer option c

No change to the dish, just place it at a higher altitude

Answer option d

a. Make it deeper, i.e. increase D and decrease A, as in Fig. 5.4
b. Make it shallower, i.e. increase A and decrease D, as in Fig. 5.5
c. Increase the aperture, i.e. increase A and D, as in Fig. 5.6
d. No change to the dish, just place it at a higher altitude

Answer

Question 2

Here is a simple model of the dish antenna / solar cooker reflector, where we model a curved mirror, using a bunch of flat mirrors. The flat mirrors are mounted along the perimeter of a semicircle. The focus of this curved mirror is obtained by joining the reflected ray from each mirror, where the incident ray is parallel and close enough to the principal axis.

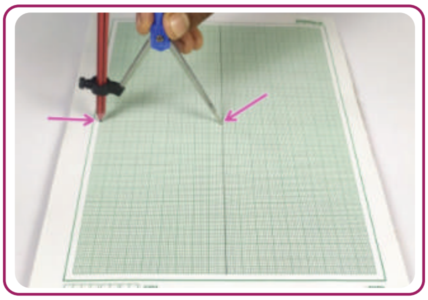


Fig. 5.7, Draw a circle of radius 9 cm on a graph sheet

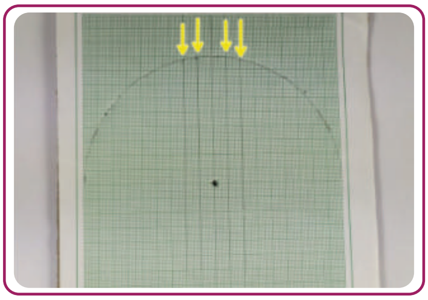


Fig. 5.8, Draw two lines parallel to the principal axis on both sides of the principal axis

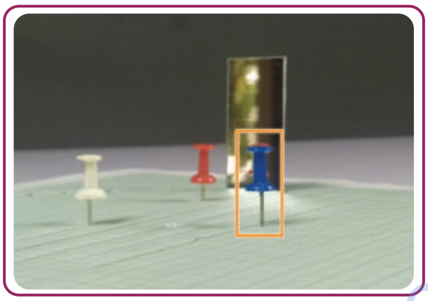


Fig. 5.10, Fix a flat mirror along the curve and place a third pin such that it hides the reflection of the two pins

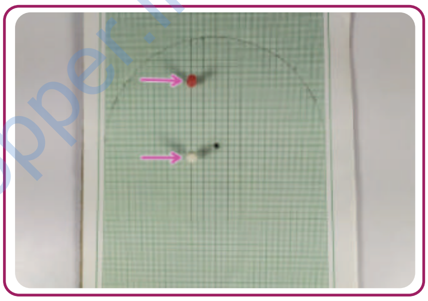


Fig. 5.9, Pierce two board pins on one of the parallel lines

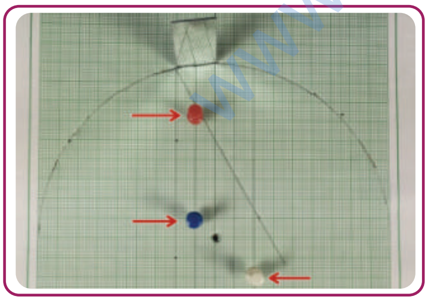


Fig. 5.11, Draw the reflected ray and shift the position of the mirror to the next incident ray and repeat the process

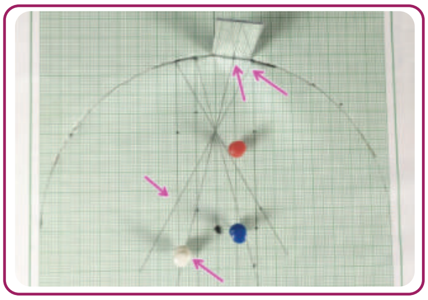


Fig. 5.12, Identify the point where all reflected rays merge as the focal point of the curved mirror. Measure the focal length and check if you see a relation with the radius of curvature of the curved mirror.

Imagine that you take this model to a different universe, where the laws of optics are a little different. There, the angle of reflection is more than the angle of incidence. Then you will notice that the focal length of the model of the curved mirror will be

a. More compared to this universe
b. Less compared to this universe
c. Same
d. Two times the focal length in this universe

Answer

Question 3

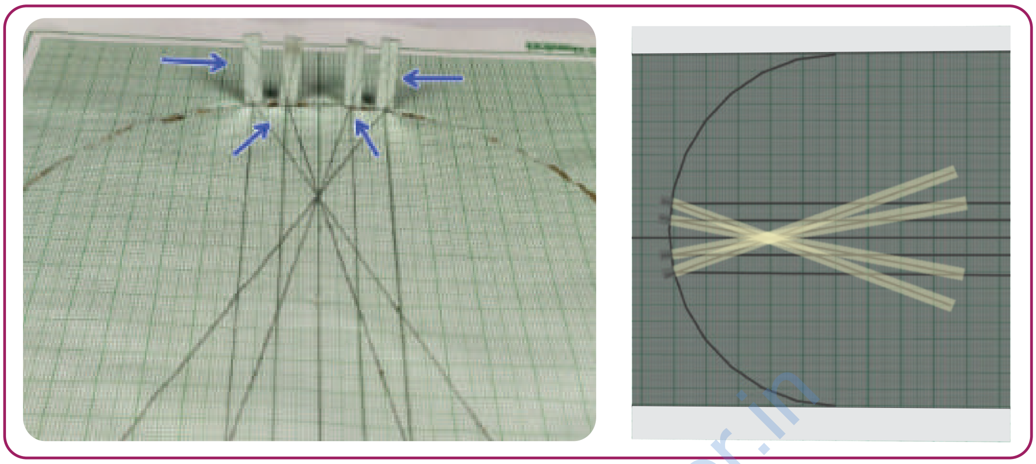


Fig. 5.14, Curved mirror model with light falling on the mirrors

If the above model is placed in direct sunlight, and we place an object at the focal point, it can heat up at a very fast rate. Many of you would have seen a similar behaviour with a magnifying glass. Aakash had a magnifying glass through which he could see the clear image of an object when he placed it 20 cm away from the object and 10 cm away from his eyes. How far should he place the glass from the paper to burn it using sunlight?

a. 10 cm	b. 15 cm
c. 20 cm	d. 30 cm

Answer

Case Study B - Snell's Law

The fact that the light rays coming out of a magnifying glass converge at one point implies that the rays bend as they pass through the magnifying glass. The extent to which a light ray bends when it passes through a medium is determined by Snell's law. Here is a simple experiment set-up to measure the refractive index of different mediums. It uses a transparent plastic box and a few board pins.

Fig. 5.14, Place a transparent rectangular container at the centre of an A4 sheet fixed on cardboard & trace its outline

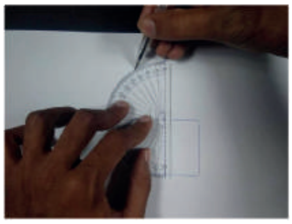


Fig. 5.15, Draw a normal at the middle of the rectangular outline. Place a protractor on the normal line and draw a line at an angle of your choice. This will be the incident line.

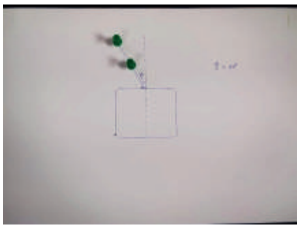


Fig. 5.16, Now, pierce two board pins on the incident line

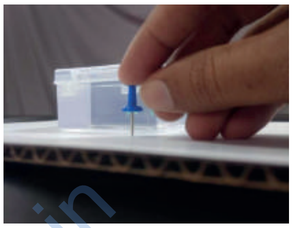


Fig. 5.17, Place the container filled with water on the outline and look through it such that the image of the two board pins merge into one. Pierce two more board pins such that while looking through the container, all 4 pins are in a straight line.

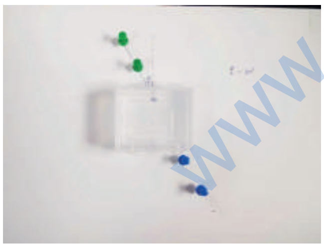


Fig. 5.18, Remove the container and board pins from the cardboard. Join the marks made by the pins and extend the straight line up to the outline and join it to the incident line on the other end.

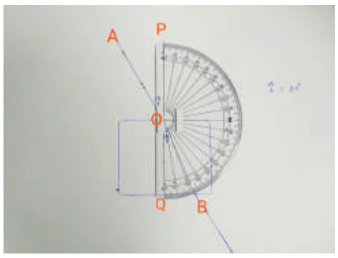


Fig. 5.19, Measure the angle of refraction with the help of a protractor.

Recall that ∠AOP in Fig. 5.19 is the angle of incidence and ∠QOB is the angle of refraction.

Question 4

The plastic container here was filled with a sample of water collected from a lake at 5 different times of the year. The angle of incidence and angle of refraction were plotted, as shown in the graph in Fig. 5.20.

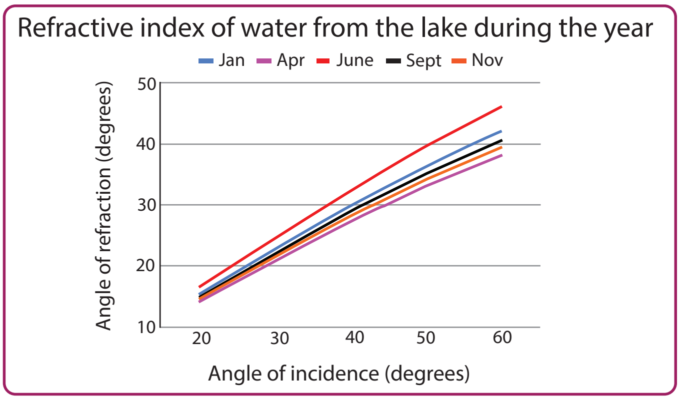


Fig. 5.20, Graph of angle of refraction vs angle of incidence for water collected from the lake at different times of the year.

Which of the following inferences can be drawn for sure based on the graph above?

a. The water of the lake continued to get polluted as the year progressed.

b. The density of water continued to increase as the year progressed.

c. The visibility of light through the lake water was highest during June and lowest during April.

d. The visibility of light through the lake water was lowest during June and highest during April.

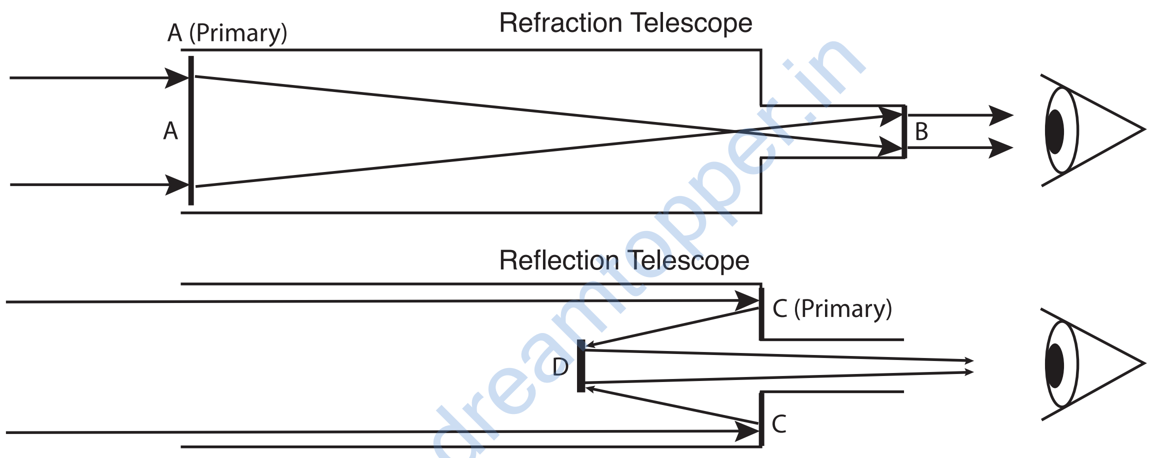
Answer

Case Study C - Telescope

Galileo and Newton are not quite contemporaries, the former predating the latter by a few decades in the 17th century, but both giants of science that will endure for all time. Another great scientist, Copernicus, postulated that the Earth was NOT the centre of the universe, let alone the so-called "Solar System". He studied the motion of planets and stars in the night sky and determined that the explanation for the Earth being at the centre required all kinds of complicated geometry that didn't make sense in nature. However, it was Galileo (who of course liked Copernicus' idea but had to prove it too!) using his wonderful refracting telescope that saw evidence first-hand that all things don't revolve around the Earth (we now know that only the Moon and some artificial satellites do, but back then people - and the Church - thought EVERY heavenly body revolved around the Earth). He observed Jupiter and noticed it had 4 bright spots, in a line, on either side of it. Over hours of observations over many nights, he noticed that these dots move and seem to be moving around Jupiter. That was the only way to explain their changing position. So he was convinced of Copernicus' theory and had the proof for it too. However, the Church didn't like it and jailed him for his views. Meanwhile, scientists like Kepler, and then Newton started talking about planetary motion, how we perhaps revolve around the Sun, and how gravity can explain all these motions so simply. Using Kepler's Laws, Newton was able to form his Universal Law of Gravitation, and the rest - as we say - is history! Like Galileo, Newton too was a compulsive experimentalist and conducted experiments in virtually every field of physics, often creating altogether new fields. So he too, of course, built a telescope! In his case, he built a reflecting telescope.

Question 5

Below is a schematic of a refracting and a reflecting telescope. The shapes of the labelled parts - A, B, C, D - are not accurate. They are only placeholders.



The shapes of the labelled parts - A, B, C, D - are not accurate.

Fig. 5.21, Schematics of refracting and reflecting telescopes

For the refracting telescope, parts A and B do the job of focusing the light from a faraway object, such that light from the object can be captured by an optical device, be it the human eye or a camera or a spectrometer. In the spaces below, write down what kind of optical element you think A and B are. Your options are: convex lens / concave lens / convex mirror / concave mirror.

A ______________________________

B ______________________________

Question 6

In the reflecting telescope, the purpose of C and D is the same as that of A and B in a refracting telescope. What do you think C and D are? Your answer options are the same: convex lens / concave lens / convex mirror / concave mirror.

C ______________________________

D ______________________________

Question 7

Referring to the schematic diagram in Fig 5.21, what kind of image do you think you get from the two telescopes shown there?

a. Both show an inverted image

b. Inverted for reflecting and upright for refracting

c. Inverted for refracting and upright for reflecting

d. Both show an upright image

Answer

Question 8

As you can see from the schematic of the reflecting telescope, the primary element C has a hole in the middle! This means that some of the area of C is lost and the telescope can capture less light than if it didn't have the hole.

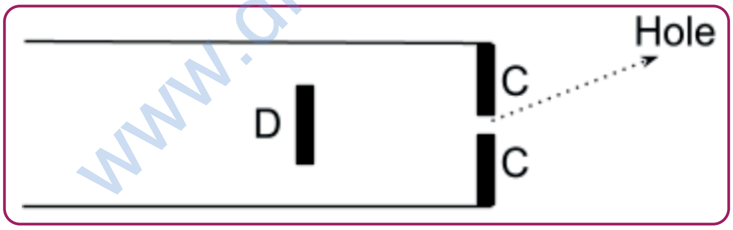


Fig. 5.22, Hole in the primary element of a reflecting telescope

Does this imply that reflecting telescopes are less preferred than refracting telescopes? Let us quantify the area lost due to the hole. Typically, the size of the hole is about one-tenth of the diameter of C. E.g., if the primary has a diameter of 1 m, then the hole has a diameter of 10 cm. Given this, what per cent of the light would a telescope with a hole capture compared to if it didn't have a hole?

a. 50%	b. 90%
c. 75%	d. 99%

Answer

Case Study D - Prism Spectrometer

A prism will disperse white light into different colours. Using a prism, we can build a spectrometer with which we can measure the wavelength of light from different sources. The collimator (see Fig. 5.22) helps in allowing only a narrow beam of light to be incident on the prism and the telescope is where you see the dispersed light.

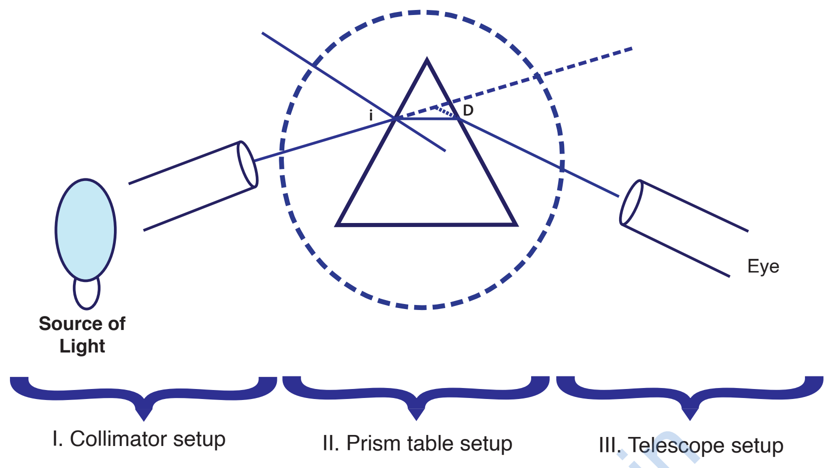


Fig. 5.23, Prism spectrometer

While doing the experiment with a spectrometer, one would need to vary the angle of incidence (i) and also, measure the angle of deviation (D).

Question 9

Among the three setups mentioned in Fig. 5.23, how many of them should be movable (not fixed) at the least, in order to conduct experiments with a spectrometer?

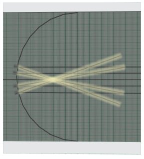
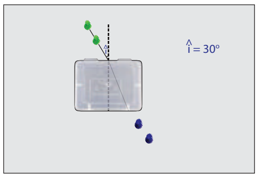
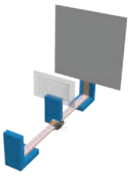
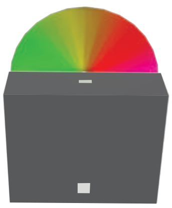
a. 0	b. 1	Answer
c. 2	d. All the three	

Question 10

If you use white light as the source of light for the prism spectrometer, which colour will have the maximum value for D?

a. Red	b. Yellow	Answer
c. Green	d. Violet	

Exploration Pathway

 Explore Curved Mirror	Curved mirrors come under a broad category of mirrors that have a reflecting surface, which is curved. When the surface is curved inwards it's called a concave mirror, and those with an outward bulge are called convex mirrors. In this TACtivity, we determine the focal length of a concave mirror by obtaining an image of the object placed at different points.
 Snell's Law	The speed of light through a medium depends on a property of the material, called its refractive index. This is closely related to the density of the material. This feature of light changing its speed in different materials is known as refraction. This is manifest in the form of a light ray changing its direction towards the normal of a surface, when it enters a denser medium, because its speed has reduced. Snell's Law states that the ratio of the refractive indices of two materials is the same as the ratio of the sine of the angle of the incident and refracted rays. In this classic experiment, we use square glass containers at home and test their refractive index, using pins and observing the "bend" between the incident and refracted rays.
 DIY Optic Bench (Fresnel Lens)	An optical bench is a versatile tool useful in conducting a series of optics experiments, involving lenses and mirrors. It is particularly useful when two or more optical elements need to be placed in a straight line and at a fixed level so that their optical axes align. Here, we make our own Optical Bench, using foam, skewers, straws and graph paper, and conduct various focal length experiments, using lenses and/or mirrors.
 Spectroscope Model	The visible light we see, from the Sun or from a bulb, is often made up of many colours of light. How can we separate these colours? Such an instrument that does so is called a "Spectroscope", which uses a phenomenon called "diffraction", to split light into its constituent colours. The CD by itself is an excellent spectroscope, as the closely placed optical lines act as a perfect diffraction grating. Here, we create a cardboard encasing for the CD and point it towards any light source to then see emission spectral lines, i.e. the light split into its constituent colours.