End-of-Chapter Exercises

Exercises 1 – 12 are conceptual questions designed to see whether you understand the main concepts of the chapter.

1. You and your friend Leigh can both see Leigh's reflection in the same plane mirror. Leigh sees her image at a particular location. You are observing the situation from a different position than Leigh. Do you observe Leigh's image in the same position that Leigh does, or in a different position? Explain.

2. Figure 23.37 shows a red ball that is near a small plane mirror. Is it possible to see a reflection of the ball in this mirror? If so, sketch a diagram showing the location of the ball's image, and showing where your eye could be located so as to see the ball's image. If not, explain why not.

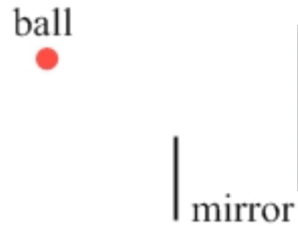


Figure 23.37: A ball near a small plane mirror, for Exercise 2.

3. As shown in Figure 23.38, a point source of light shines on a card that has a narrow vertical slit cut in it. The card is halfway between the source and a screen. Sketch the resulting pattern on the screen.

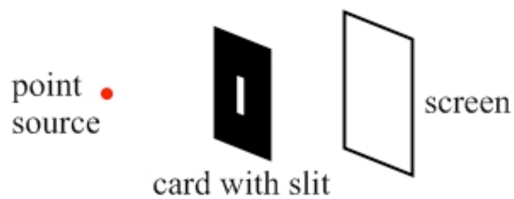


Figure 23.38: A point source of light illuminates a card with a narrow slit. For Exercise 3.

4. As shown in Figure 23.39, a light bulb with a long narrow vertical filament illuminates a card that has a small hole in it. The card is two-thirds of the way from the light bulb to a screen. Sketch the resulting pattern on the screen.

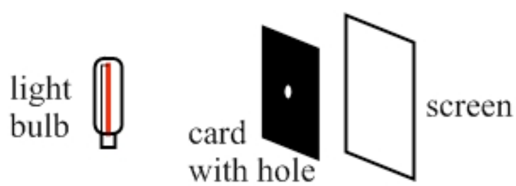


Figure 23.39: A light bulb with a vertical filament (in red) illuminates a card that has a small hole in it. For Exercise 4.

5. Two plane mirrors are placed so they are perpendicular to one another, and you stand in front of this pair of mirrors. You are represented by the red dot in Figure 23.40. (a) How many images of yourself do you observe? (b) Draw a diagram to show where the image(s) is/are located. (c) For the image farthest from you, sketch a ray diagram to show how the image is formed.

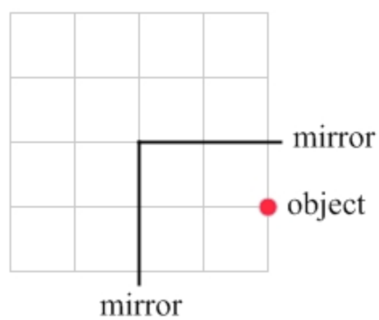


Figure 23.40: You, the object in this figure, stand in the position shown in front of a right-angled mirror. For Exercise 5.

6. Figure 23.41 shows a single ray on a ray diagram. Duplicate the diagram, and add a second ray to show the position of the image.

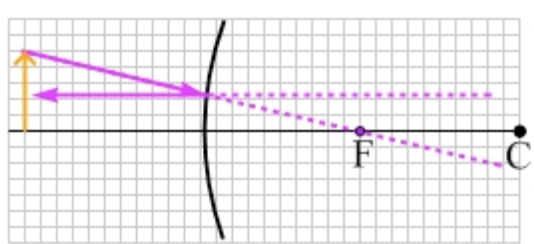


Figure 23.41: A single ray, directed toward the focal point of the mirror, is shown on the figure. For Exercise 6.

7. Two rays of light are shown on the ray diagram in Figure 23.42, along with two arrows representing the object and the image. Which arrow represents the object, and which represents the image?

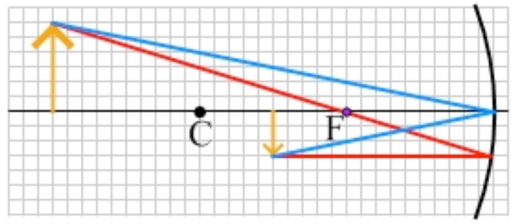


Figure 23.42: A ray diagram, for Exercise 7.

8. Figure 23.43 shows an object in front of a concave mirror. First, re-draw the diagram, preferably on a piece of graph paper. For parts (a) – (d), start the ray from the tip of the object and show how the ray reflects from the mirror. (a) On your diagram, draw a ray that travels parallel to the principal axis toward the mirror. (b) Draw a ray that reflects from the mirror at the point the principal axis intersects the mirror. (c) Draw a ray that travels toward the mirror along the line connecting the tip of the object and the focal point. (d) Draw a ray that travels toward the mirror along the line connecting the tip of the object and the center of curvature. (e) Use the rays to locate the image on the diagram.

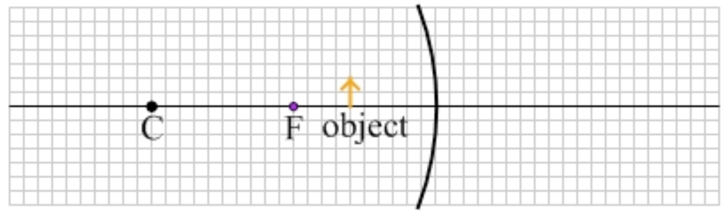


Figure 23.43: An object in front of a concave mirror, for Exercise 8.

9. Three rays of light are shown on the ray diagram in Figure 23.44. One of them is drawn incorrectly. (a) Identify the ray that is drawn incorrectly. (b) Draw a corrected diagram and show the location of the image.

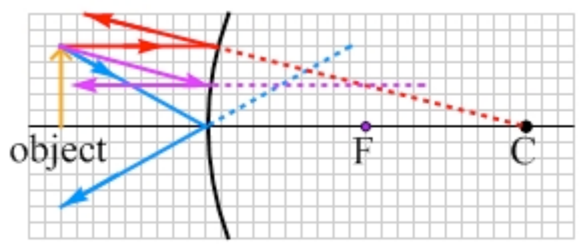


Figure 23.44: An incorrect ray diagram for an object in front of a convex mirror, for Exercise 9.

10. Figure 23.45 shows a concave mirror, and the virtual image formed by this mirror. Draw a ray diagram to show the location of the object in this situation.

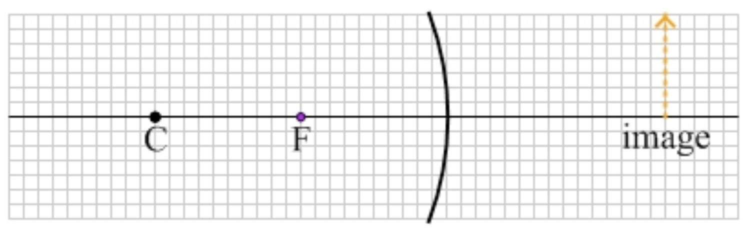


Figure 23.45: The virtual image created by a concave mirror. Draw the corresponding ray diagram to find the object. For Exercise 10.

11. Identify whether the mirror in this situation is a plane mirror, a convex mirror, or a concave mirror. For each part below, determine which of the possibilities you can rule out, if any. (a) First, when an object is placed 10 cm from a mirror, a virtual image is observed. (b) Then, when the object is moved a little closer to the mirror, the image is observed to move closer to the mirror. (c) As the object is moved closer to the mirror, the image is observed to decrease in size.

12. Identify whether the mirror in this situation is plane, convex, or concave. For each part below, determine which of the possibilities you can rule out, if any. (a) First, when an object is placed 10 cm from a mirror, a virtual image is observed. (b) Then, when the object is moved a little closer to the mirror, the image is observed to increase in size. (c) What, if anything, can you conclude about the mirror's focal length?

Exercises 13 – 14 involve plane mirrors.

13. A laser beam reflects from a plane mirror, as shown in Figure 23.46. The incident beam is at 40°, as measured from the horizontal. Initially, the reflected beam is horizontal. (a) What is the angle, initially, between the mirror and the horizontal? (b) When the mirror is tilted by 10°, what is the angle between the reflected beam and the horizontal?

Figure 23.46: In (a), a laser beam shining on a mirror reflects so the reflected beam is horizontal. In (b), the mirror is tilted by 10° from its orientation in (a). For Exercise 13.

14. Maria stands 50 cm away from a small plane mirror that is mounted on the wall in front of her. Maria's face is about 20 cm tall. (a) If Maria is to be able to see the image of her entire face without moving, what is the minimum height the mirror can be? (b) Describe how this minimum-height mirror should be mounted on the wall. (c) If Maria is 1.0 m from the mirror, what is the minimum height the mirror can be? (d) Sketch one or more ray diagrams to support your answers to parts (a) – (c).

Exercises 15 – 19 are designed to give you practice applying the mirror equation.

15. As you are analyzing a spherical mirror situation, you write an equation that states: $\frac{1}{f} = \frac{1}{+20 \text{ cm}} + \frac{1}{+30 \text{ cm}}$. (a) What is the value of $1/f$ in this situation? (b) What is the mirror's focal length? (c) What kind of mirror is this?

16. Return to Exercise 15. What is the object distance in this situation, and what is the image distance?

17. As you are analyzing a spherical mirror situation, you write an equation that states: $\frac{1}{f} = \frac{1}{+20 \text{ cm}} + \frac{1}{-60 \text{ cm}}$. (a) What is the value of $1/f$ in this situation? (b) What is the mirror's focal length? (c) What kind of mirror is this?

18. As you are analyzing a spherical mirror situation, you write an equation that states: $\frac{1}{f} = \frac{1}{+20 \text{ cm}} + \frac{1}{-10 \text{ cm}}$. (a) What is the value of $1/f$ in this situation? (b) What is the mirror's focal length? (c) What kind of mirror is this?

19. As you are analyzing a spherical mirror situation, you write an equation that states: $\frac{1}{+20 \text{ cm}} = \frac{1}{+20 \text{ cm}} + \frac{1}{d_i}$. (a) What is the value of $1/d_i$ in this situation? (b) What is the image distance?

Exercises 20 – 24 are designed to give you practice applying the general method for analyzing a problem involving mirrors.

20. An object is placed 25 cm away from a mirror that has a focal length of 10 cm. (a) Sketch a ray diagram, to show the position of the image and the image characteristics. (b) Determine the image distance. (c) Determine the magnification.

21. An object is placed 25 cm away from a mirror that has a focal length of –10 cm. (a) Sketch a ray diagram, to show the position of the image and the image characteristics. (b) Determine the image distance. (c) Determine the magnification.

22. Some people like to place large reflective balls in their gardens. Let's say that such a ball has a radius of curvature of 20 cm, and a bird perched on a branch is 1.0 m from the ball. (a) Determine the image distance for the bird's image. (b) Sketch a ray diagram to verify your calculation in part (a).

23. A shiny spoon can be approximated as a spherical mirror with a radius of curvature of 8.0 cm. You hold your finger 12.0 cm from the spoon's concave side. (a) Sketch a ray diagram to determine the image location and the image characteristics. (b) Apply the mirror equation and the magnification equation to determine the location of the image of your finger, and the size of the image compared to the size of your finger.

24. Repeat Exercise 23 but, this time, flip the spoon over so your finger is 12.0 cm from the spoon's convex side.

Exercises 25 – 29 involve applications of reflection and mirrors.

25. The Federal Motor Carrier Safety Administration, in the United States, mandates that all cars have a convex passenger-side rear-view mirror. A particular rear-view mirror on a car has a radius of curvature of 1.2 m. If a large truck is 8.0 m away from this mirror, determine (a) the image distance, and (b) the magnification. (c) Which of these results explains why "Objects in mirror are closer than they appear," which is the warning stamped on the mirror.

26. Figure 23.47 shows a picture of a periscope, such as that used by submarine captains to see what is at the surface of the water, or by spectators at golf tournaments to see over the heads of people standing in front. Two parallel plane mirrors are used to make the periscope. (a) Re-draw the diagram, and show the location of the image, created by mirror 1, of the object. (b) The image created by mirror 1 is the object for mirror 2. Show where the image created by mirror 2 is located. This is the image you see when you look in the periscope.

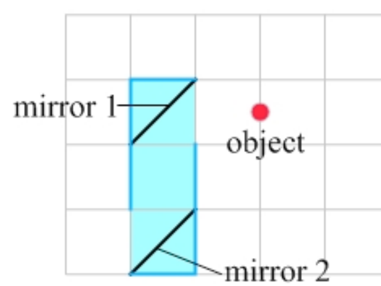


Figure 23.47: A periscope, which has two parallel plane mirrors, is an example of a practical device that involves reflection, for Exercise 26.

27. As part of a show about optical illusions, the illusionist sets up a large concave mirror, with a focal length of 2.0 m, at the back of the stage. This arrangement is shown in Figure 23.48. Hidden underneath the stage is a model of a lion, only ¼ as tall as a real lion. (a) How far should the model be placed from the mirror so that the audience sees a life-size lion hovering over the stage? (b) If the audience is to see an upright lion, should the model be upright or inverted?

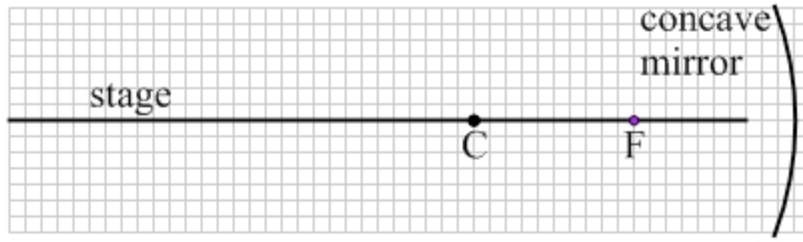


Figure 23.48: A large concave mirror, used by an illusionist to create an optical illusion, for Exercise 27.

28. A concave mirror used by a person who is shaving or applying makeup creates a virtual image of the face that is 1.5 times larger than the person's actual face when the face is 25 cm from the mirror. Determine (a) the image distance, and (b) the mirror's focal length.

29. A particular convex mirror has a radius of curvature of 1.5 m. The mirror is mounted in the corner of a store, near the ceiling, to help prevent shoplifting. (a) Let's say that you are 1.8 m tall, and that you are standing 2.0 m away from the mirror. How tall is your image in this mirror? (b) If, when you look in that mirror, you can see the face of the clerk at the checkout counter, does that mean that the clerk can see you in the mirror? Briefly justify your answer.

General problems and conceptual questions

30. If you hold your hand up in the beam of a film projector or slide projector, you can cast a shadow (in the shape of a rabbit's head, for instance) on a screen. Is this shadow consistent with the ray model of light? Explain.

31. When you are on a train, you can often see clear reflections of some of the other passengers when you look at the train windows. Explain why it is generally easier to see these reflected images when the train is passing through a dark tunnel than when the train is traveling outside on a bright sunny day.

32. A well-known philosophical question about sound is "If a tree falls in a forest and there is no-one there to hear it, does it make a sound?" A similar question regarding light could be "If a mirror is placed near a tree and there is no-one there to look into the mirror, is there an image?" Based on the principles of physics covered in this chapter, what do you think?

33. When you are looking in a plane mirror at the image of an object that remains at rest, does the image of the object move when you shift position? Draw one or two ray diagrams to help explain your answer. Also, in your explanation, make a comparison between a window and a mirror. When you look through a window at an object that remains at rest, the object's position stays fixed as you change your vantage point. Does the same thing happen with the image of a stationary object when viewed in a mirror, or not?

34. You are walking toward a plane mirror with a speed of 2.5 m/s. What is the velocity of your image, relative to you?

35. You are standing between two plane mirrors that are parallel to one another, and separated by 4.0 m. This situation, as you have probably observed, creates multiple images. You are 1.5 m from one of the mirrors, and 2.5 m from the other (neglecting your own width). (a) How far away is your image that is closest to you? (b) How far away are the three next-closest images?

36. You are 2.0 m from a plane mirror, holding a camera, and you want to take a photograph of your image in the mirror. To what distance should the camera be focused so you get the sharpest image of yourself?

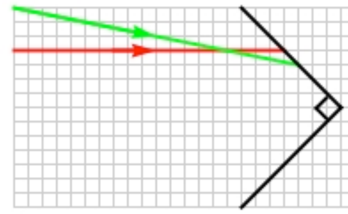


Figure 23.49: Two rays of light are incident on a pair of plane mirrors that are mounted at right angles to one another. For Exercise 37.

37. Two rays of light are incident on a pair of plane mirrors that are mounted at 90° to one another, as shown in Figure 23.49. (a) After experiencing two reflections, one from each mirror, through what angle has the red ray been deflected? Sketch the path of the red ray. (b) Repeat for the green ray. Note that the grid can help you to sketch the path for the green ray.

38. A small plane mirror is mounted on a wall. A laser beam is incident on the mirror at a 45° angle, as shown in Figure 23.50. The reflected beam makes a spot on a wall 5.0 m from, and parallel to, the wall with the mirror. When you push on the wall with the mirror, you deform the wall a little, shifting the angle of the mirror slightly and moving the spot on the other wall. If the spot moves by 12.0 cm (down, in the figure), through what angle has the mirror been rotated?

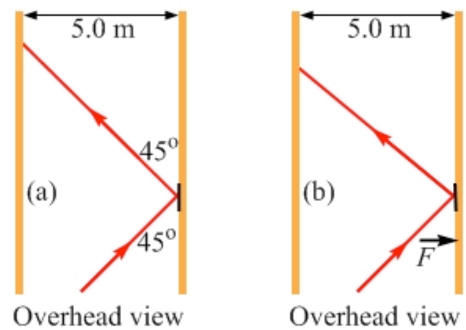


Figure 23.50: Mounting a mirror on a wall and reflecting a laser beam off it can help show how the wall is deformed when you push on it. (a) The initial situation. (b) The situation when you are pushing on the wall with a force *F*, as shown. For Exercise 38.

39. A common application of mirrors is in astronomical telescopes. Choose one of the following, do some research about how it works, and write a couple of paragraphs describing it: 1. The Keck 1 and Keck 2 telescopes. 2. The Large Zenith Telescope. 3. The Hubble Space Telescope.

40. Exercise 39 involves research-grade optical telescopes. Mirrors are also used in many telescopes used by amateur astronomers. Choose one of the following, do some research about how it works, and write a couple of paragraphs describing it: 1. A Newtonian telescope. 2. A Cassegrain telescope. 3. A Dobsonian telescope.

41. In a particular case of an object in front of a spherical mirror, the object distance is 12 cm and the magnification is +4.0. Find (a) the image distance, (b) the mirror's focal length.

42. In a particular case of an object in front of a spherical mirror with a focal length of 12 cm, the magnification is +4.0. Find (a) the object distance, (b) the image distance.

43. An object is placed 60 cm from a spherical mirror. When you look in the mirror, you see an image of the object that is 3.0 times larger than the object. (a) What kind of mirror is it? (b) How far from the mirror is the object? (c) Sketch a ray diagram to check your calculations. Make sure you find all possible solutions.

44. Figure 23.51 shows an object and a real image created by a spherical mirror. Assume the boxes on the grid measure 10 cm × 10 cm. Find the position of the mirror, and the mirror's focal length.

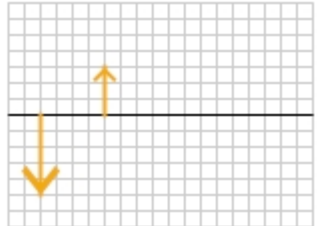


Figure 23.51: This figure shows an object and a real image created by a spherical mirror. For Exercise 44.

45. Figure 23.52 shows an object (the larger arrow) and the virtual image of that object, created by a spherical mirror. Assume the boxes on the grid measure 10 cm × 10 cm. Find the position of the mirror, and the mirror's focal length.

Figure 23.52: The larger arrow represents an object, while the smaller arrow represents the virtual image of that object, created by a spherical mirror. For Exercise 45.

46. Sketch a ray diagram for the situation shown in (a) Figure 23.51, (b) Figure 23.52.

47. In the situation shown in Figure 23.53, a small red LED (light-emitting diode) is placed on the principal axis 7.0 cm from a concave mirror that has a radius of curvature of 14 cm. The LED can be considered to be a point source. Draw a ray diagram to show what happens to rays of light that are emitted by the LED and reflect from the mirror.

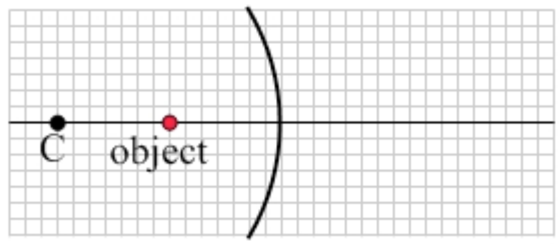


Figure 23.53: A small red LED (light-emitting diode) is placed in front of a concave mirror, for Exercise 47.

48. In the situation shown in Figure 23.54, a small red LED (light-emitting diode) is placed on the principal axis 4.0 cm from a concave mirror that has a radius of curvature of 14 cm. The LED can be considered to be a point source. Find the location of the image of the LED.

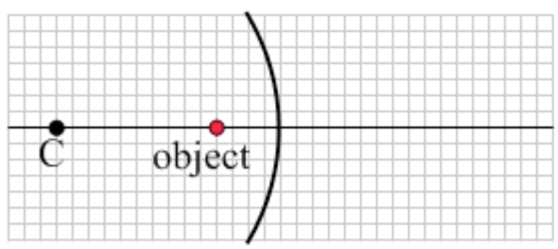
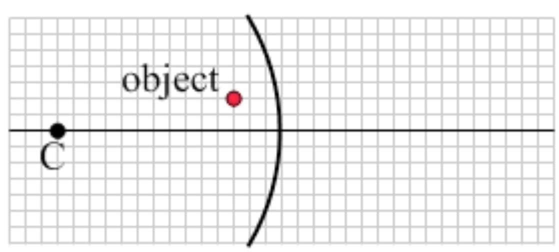


Figure 23.54: A small red LED (light-emitting diode) is placed in front of a concave mirror, for Exercises 48 and 50.



49. The LED from the previous exercise is moved to a location 2.0 cm above the principal axis, and 3.0 cm horizontally from the center of the mirror, as shown in Figure 23.55. Find the location of the image of the LED.

50. Draw several rays showing how the image of the LED is formed in (a) Figure 23.54, and (b) Figure 23.55.

Figure 23.55: A small red LED (light-emitting diode) is placed in front of a concave mirror, for Exercises 49 and 50. The LED is 2.0 cm above the principal axis.

51. A model of a horse is placed 32 cm away from a mirror that has a focal length of 20 cm. The model is 5.0 cm tall. Determine (a) the location of the image, (b) the height of the image, (c) whether the image is real or virtual, and (d) whether the image is upright or inverted.

52. Repeat Exercise 51, with the model of the horse 12 cm from the mirror instead.

53. A model of a horse is placed 32 cm away from a mirror that has a focal length of –20 cm. The model is 5.0 cm tall. Determine (a) the location of the image, (b) the height of the image, (c) whether the image is real or virtual, and (d) whether the image is upright or inverted.

54. Return to the situation described in Exercise 53. Describe what happens to the position and size of the image if the model is moved a little bit closer to the mirror.

55. Return to the situation described in Exercise 51. Describe what happens to the position and size of the image if the model is moved a little bit closer to the mirror.

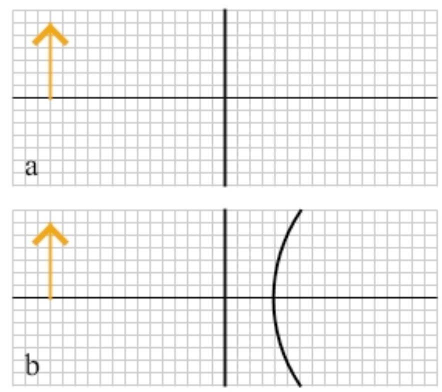


Figure 23.56: (a) An object in front of a plane mirror. (b) A convex mirror is placed behind the plane mirror, at the location shown. For Exercise 56.

56. Figure 23.56(a) shows an object placed in front of a vertical plane mirror. A convex mirror is then placed behind the plane mirror, in the location shown in Figure 23.56(b). Does adding the convex mirror cause the object's image to shift to the left, the right, or does it have no effect? Explain.

57. A particular mirror has a focal length of +20 cm. (a) For this mirror, plot a graph of $1/d_i$ as a function of $1/d_o$ for object distances between +10 cm and +40 cm. (b) How can you read the focal length directly from the graph?

58. Repeat the previous exercise, but now plot a graph of d_i as a function of d_o.

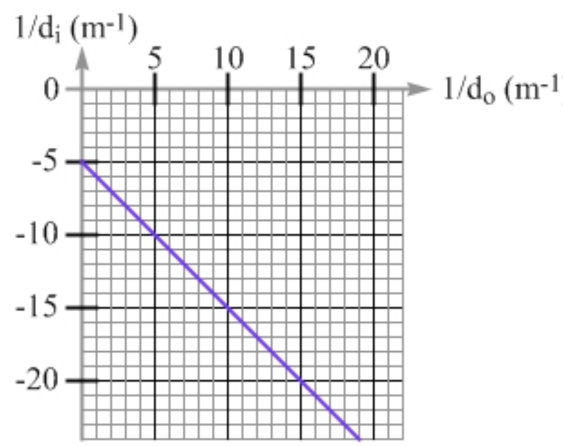


Figure 23.57: A graph of $1/d_i$ as a function of $1/d_o$ for a particular mirror. For Exercise 59.

59. Figure 23.57 shows a graph of $1/d_i$ as a function of $1/d_o$ for a particular mirror. What kind of mirror is it, and what is the mirror's focal length?

60. Refer to Figure 23.21, just above the start of section 23-4. (a) What, if anything, happens to the image if you cover up the bottom half of the mirror, preventing any light from reaching that part of the mirror? (b) Does your answer change if you cover up the top half of the mirror instead? Explain, and refer to Figure 23.21 in your explanations.

61. Figure 23.58 shows a small rectangular box, placed so its front surface is 10 cm from a convex mirror, while its back surface is 16 cm from the mirror. The mirror has a radius of curvature of 40 cm, while the box has a height of 8.0 cm. (a) Sketch a ray diagram to show the location of the image of the front surface of the box. (b) On the same diagram, show the location of the rear of the box. (c) How tall is the image of the front of the box? (d) How tall is the image of the rear of the box, when you look at the box in the mirror?

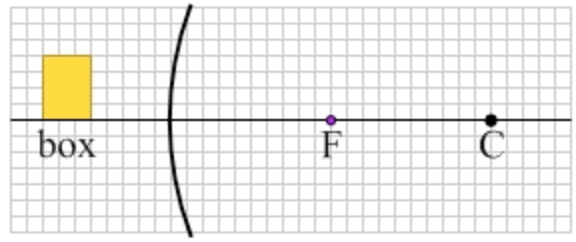


Figure 23.58: A box in front of a convex mirror. The boxes on the grid measure 2 cm × 2 cm. For Exercise 61.

62. As shown in Figure 23.59, an object is placed halfway between two identical concave mirrors, at a point that corresponds to the center of curvature of both mirrors. (a) How many images of the object could you see if you looked in either one of the mirrors? (b) How many of these images would be larger than the object, and how many would be smaller than the object? (c) Where would these images be located, relative to the object?

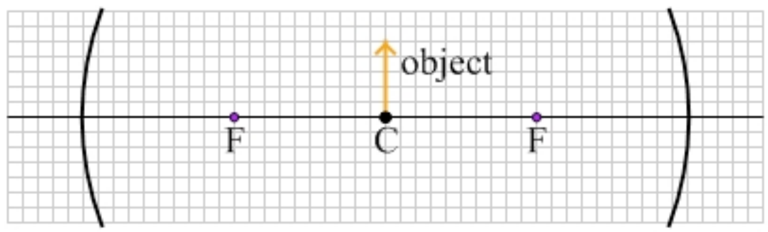


Figure 23.59: An object located at the common center of curvature of two identical concave mirrors. For Exercise 62.

63. Two students are having a conversation about a problem involving mirrors. Comment on each of their statements below. The problem is the following. We have an object in front of a spherical mirror. The image created by the mirror is smaller than the object, and real. We're asked what happens to the image when the object is moved a little closer to the mirror – does the image get larger or smaller, and does it move toward the mirror or away from the mirror?

Heather: Doesn't this depend on what kind of mirror we have? The problem just says it's a spherical mirror. It must matter whether the mirror is concave or convex, don't you think?

Mike: We could try both and see, I guess. How about we draw a ray diagram? Here, look at this. The ray that goes from the tip of the object, parallel to the principal axis, and then through the focal point, that ray stays the same even if we slide the object toward the mirror or away from the mirror. I think this tells us that, if the image gets closer to the mirror, it gets smaller, and if it gets farther away, it gets taller.

Heather: You drew that for a concave mirror. Does the same thing work for a convex mirror? I still think we need to know what kind of mirror we have.

Mike: Maybe there's something in the problem that gives that away? What does it say about the image? It's smaller, and real. Does that tell us what kind of mirror we have?