26 Properties of Light

The opening photo for Part Six is Lillian's nephew, Christopher Lee, who has been helpful in our development of screencasts. Thank you Christopher!

For chapter photo openers, how lucky I was to come across this photo from space of a solar eclipse! An astronaut's view of a solar eclipse. With pride the second photo is my daughter and her husband Bob, with physics instructor friend Dave Wall. And how nice that a partial solar eclipse in 2012 was caught by lab manual author Dean Baird outside his classroom. The sunballs just before the eclipse beautifully transform to crescents as the Moon passes in front of the Sun. Exploratorium physicist and senior staff scientist Paul Doherty traveled to Nevada to catch the totality, and a rare annular eclipse, nicely caught in the fifth photo.

The personal profile is James Clerk Maxwell, who among so many other things showed how electricity and magnetism connect to become light.

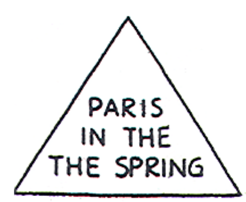
Some instructors begin their course in physics with light, a topic that has greater appeal to many students than mechanics. Your course could begin with this chapter and continue through the following chapters of Part 6, or you could first integrate chapters on vibrations, waves, and sound from Part 4 in your sequence. Since the chapters are nearly self-contained allows you flexibility. If you're doing Parts 4 and 6 together, the reason for jumping in at this chapter may be to avoid the more technical nature of Chapter 19. This sequence, Chapters 26, 27, 19-21, 28, and 30, is a gradual entrance to the study of physics. If this chapter is used as a launch point, you need only introduce the definitions of speed and frequency. In addition, give a demonstration of resonance with a pair of tuning forks—a foundation for explanations of the interaction of light and matter.

Note that the "depth of the plow" in the treatment of light is respectably deep. The aim is not to separate and name categories such as transmission, reflection, and absorption, but to promote good physics comprehension. Your students will experience some good physics in this chapter—and understand it. Understanding more than they may expect, and discovering more than they thought they could, is the real joy of learning. So this should be an enjoyable chapter—why some teachers opt to begin here.

Of particular interest to your students is the box on Fractal Antenna and mobile phones on page 490. The box is a jumping off place if you wish to further discuss fractals—fascinating information!

Figure 26.4 features Bruce Novak, whose many suggestions for this edition I am grateful for. For one thing, I've used his photo of the color spectrum in three of my screencast backgrounds.

In reference to the optical illusions of Figure 26.23: The slanted line is not broken, as can be seen looking at the book at a grazing angle. The dashes are all the same length, as a ruler will show. For a bit of humor, the vertical lines are *not* parallel. And a look at the page at a grazing angle will confirm that the tiles are not crooked. The width of the hat is the same as its height, the "fork" and "rectangular" piece could not be made in the shop, and there are two THEs in the PARIS IN THE THE SPRING.



How nice eyeglasses are light sensitive and become sunglasses when UV light hits them. My sister complains that they “don’t work” when driving. A nice physics anecdote! Of course they don’t work in an automobile because the glass windows shield the UV necessary to activate their darkness. Share that info with your class.

One page 2 of **Practicing Physics** is a fascinating exercise on the pinhole image of the Sun. One of my very favorites! Its early placement is to provide a first measuring activity to accompany Chapter 1. If you haven’t done it there, consider it here, although you should call attention to the box on page 535 of the next chapter that describes the pinhole camera. Interestingly, most people don’t notice the circles or ellipses of sunlight that are cast beneath trees due to the openings between leaves. Many artists who paint splotches of light in the shade of trees paint irregular shapes because they expect the shapes should be as irregular as the openings in the leaves above. Renoir, as Chapter 1 indicated, saw what was there and painted it accordingly (back on page 7). This exercise puts you in a beautiful role: being the person to point out the niceties in the world that ordinarily might be missed. That’s one of the niceties of being a physics instructor!

Practicing Physics:
• Pinhole Image of the Sun

Next-Time Questions:
• Radio and Sound Waves
• Faster than *c*

Hewitt Drew It! Screencast: •*Speed of Light*

SUGGESTED LECTURE PRESENTATION

If this chapter follows E&M, and your students have just finished Chapter 25, then begin your lecture with **Begin 1** that follows. If you’re beginning your course with light without having covered E&M, then jump ahead to **Begin 2**.

Begin 1: **Electromagnetic Waves**: Usually I begin my lecture by asking the class to recall my recent demonstration of charging a rubber rod with cat’s fur and how when I brought it near a charged pith ball, I produced *action at a distance*. When I moved the charged rod, the charged ball moved also. If I gently oscillate the rod, the ball in turn oscillates. State that one can think of this behavior as either action-at-a-distance or the interaction of the ball with the space immediately around it—the electric field of the charged rod. For low frequencies, the ball will swing in rhythm with the shaking rod. But the inertia of the ball and its pendulum configuration makes response poor for any vigorous shaking of the rod (that’s why it’s best not to actually show this, but to only describe it and go through the motions as if the equipment were present—you avoid the “that’s the way it should behave” situation). You can easily establish in your students’ minds the reasonableness of the ball shaking to-and-fro in response to the shaking electric field about the shaking rod. Carry this further by considering the ball to be simply a point charge with negligible mass. Now it will respond in synchronous rhythm with the shaking rod. Increase the frequency of the shaking rod and state that not only is there a shaking electric field about the rod, but because of its changing, there is a different kind of field.

> CHECK QUESTIONS: What kind of field is induced by the charged shaking rod? What kind of field in turn, does this induced field induce? And further in turn, what kind of field does this further induced field induce? And so on.

Develop the idea of the optimum speed of the field emanation, that is consistent with energy conservation, discussed in the section *Electromagnetic Wave Velocity*. This is treated in the *Speed of Light* screencast.

Begin 2: **Electromagnetic waves**: Begin by stating that everybody knows that if you place the end of a stick in a pond and shake the stick back-and-forth, you’ll generate waves across the water surface. But what everybody doesn’t know is that if you shake a charged rod back-and-forth in free space, you’ll generate waves also. Not waves of water, or even waves of the medium in which the stick exists, but waves of electric and magnetic fields. You'll generate *electromagnetic waves*. Shaking the rod at low frequencies generates radio waves. Shaking at a million billion times per second generates waves one could see in the dark. For those waves would be seen as light.

Electromagnetic Wave Velocity

If you've just covered E&M, go into some detail on the mutual induction of electric and magnetic fields, and how the critical speed of light is determined by the conservation of energy (in the section *Electromagnetic Wave Velocity*). But if you're jumping into light without having done E&M, tell your students that this section should be treated lightly, and to move onward. A small price for jumping into the middle of a book!

CHECK QUESTION: So the speed of light is finite; does this mean your image in the mirror is always a bit younger or a bit older than you? [Younger, but of course not by very much!]

Electromagnetic Spectrum

Continue by stating that, strictly speaking, light is the only thing we see. And to understand what light is, we will first try to understand how it behaves. Call attention to the rainbow of colors that are dispersed by a prism or by raindrops in the sunlight, evidence that white light can be spread into a spectrum of colors. Ask your students to consider the world view of little creatures who could only see a tiny portion of the spectrum, who would be color blind to all the other parts. Their world view would be very limited. Then state that we are like those little creatures, in that the spectrum of colors we can see are a tiny portion of the *electromagnetic spectrum* (Figure 26.3)—less than a tenth of one percent! We are color blind to the other parts. The instruments of science have extended our view of the other parts. These instruments are not microscopes and telescopes, for they enable closer viewing of the part of the spectrum we are familiar with. It is the infrared detecting devices, microwave and radio receivers, that allow us to explore the lower-frequency end of the spectrum, and ultraviolet, x-ray, and gamma-ray detectors that let us "see" the higher-frequency end. What we see without unaided eyes is a tiny part of what's out there!

Buckminster Fuller put it well when he stated that ninety-nine percent of all that is going to affect our tomorrows is being developed by humans using instruments that work in ranges of reality that are nonhumanly sensible.

CHECK QUESTION: Where does sound fit in the electromagnetic spectrum? [It doesn't!]

CHECK QUESTION: A photographer wishes to photograph a lightning bolt, and comes up with the idea of having the camera triggered by the sound of thunder. A good idea or a poor idea? [Very poor, for light travels about a million times faster than sound. By the time the sound of thunder arrives, the lightning bolt is long gone!]

A sunburn is easier to get at the beach because the UV reflects from both water and to a lesser extent, sand. You're lit not just from above, but from beside and below. And for the record, you can get sunburned through a wet T-shirt.

Transparent Materials

Recall your earlier demonstration of sound resonance (or if you haven't done this, demonstrate now the resonance of a pair of tuning forks mounted on sounding boxes (Figure 26.6). The tuning fork demo provides important experience for your students in understanding the interaction of light and matter. In some cases light strikes a material and rebounds—reflection (Chapter 28). In cases where light continues through the material, we say the material is transparent.

DEMONSTRATION: Show the swinging balls apparatus (Newton's cradle) that is usually used to illustrate momentum and energy conservation. Here you are showing that the energy that cascades through the system of balls is analogous to light energy cascading through transparent matter. Just as the incident ball is not the same ball that emerges, the incident "photon" of light upon glass is not the same photon that emerges through the other side. Although too difficult to see, slight interaction times between balls produces a slight time delay between incidence and emergence of balls. Likewise for light.

Note that the text does not mention photons in the light-through-glass explanation. Photons aren't introduced until Chapter 30 (although this treatment of light passing through glass does invoke photon in my screencast *Speed of Light*).

> CHECK QUESTION: Compared to the speed of light in a vacuum, why is the speed of light less in transparent materials such as water or glass? [Answer: According to the model treated in the text, there is a time delay between the absorption of light and its re-emission. This time delay serves to decrease the average speed of light in a transparent material.]

Another analogy for light traveling through glass is the average speed of a basketball moving down a court. It may fly through the air from player to player at one constant speed, but its average speed down the court depends on the holding time of the players. Carrying the analogy further, different materials have different players, and although the instantaneous speed of light is always the same, the average speed depends on the number of players encountered, and the holding time of each player.

Why light travels in a straight line is not evident at this point. Later in Chapter 29, Huygens' principle provides an explanation (Figure 29.4).

On the subject of glass, it's interesting to note that we see through it for the same reasons we see through water. Despite the appearance of glass, it is really a highly viscous liquid rather than a solid. Its internal structure is not the regular crystalline latticework of most solids, but is essentially random like that of liquids. Whereas conventional liquids have a freezing point at which they become solid, liquid glass gets stiffer as it cools. At room temperature its rate of flow is so slow that it takes centuries for it to appreciably ooze out of shape. Because of the downward flow due to gravity, windowpanes only several decades old show a lens effect at their bottoms due to the increased thickness there (most cases of window glass being thicker at the bottom, however, is due to installers favoring the thicker part for the bottom).

Opaque Materials

State that light generally has three possible fates when incident upon a material: (1) reflects, (2) is transmitted through the material, or (3) is absorbed by the material. Usually a combination of all three fates occurs. When absorption occurs, the vibrations given to electrons by incident light are often great enough to last for a relatively long time, during which the vibratory energy is shared by collisions with neighboring atoms. The absorbed energy warms the material.

> CHECK QUESTION: Why is a black tar road hotter to the touch when in sunlight than a pane of window glass? [Sunlight is absorbed and transformed into internal energy in the road surface, but transmitted through the glass to somewhere else.]

For the record, we say that ultraviolet light cannot penetrate glass. Hence you cannot get a sunburn through glass. But *some* ultraviolet light does pass through glass—long wavelength ultraviolet light, which has insufficient energy to cause a sunburn. Most sunlamps *aren't* made of ordinary glass—they're made of quartz or special UV-transparent glass.

Shadows

Illustrate the different shadows cast by small and large sources of light. Ask why there appears no definite shadow of students' hands when held above their desks, and relate this to the multiple sources and diffused light in the room.

Eclipses

Explain and distinguish solar and lunar eclipses.

CHECK QUESTION: Does the Earth cast a shadow in space whenever a lunar or solar eclipse occurs? [Yes, but not only when these events occur—the Earth, like all objects illuminated by light from a small source, casts a shadow. Evidence of this perpetual shadow is seen at these special times.]

CHECK QUESTION: Why do you not cast a shadow on the ground on an overcast day? [A relatively small light source such as the Sun casts a relatively sharp shadow. On an overcast day the primary Sun is blocked and the whole sky, the secondary light source, illuminates you. The source is now so big that no shadow is seen.]

Point out that light from a point source follows the inverse-square law (first treated in Chapter 9, and again for Coloumb's law in Chapter 22). A camera flash is a point source, obeys the inverse-square law, something that is not understood by people who attempt to take pictures of far-away nighttime scenes with flash cameras—like snapping long-distance shots at a nighttime concert, or a night view of a distant city. Cite how light from the flash spreads out on both the outgoing and return trip to the camera, consequently delivering very little light to the camera.

Seeing Light—The Eye

An interesting tidbit not in the chapter is the explanation for the seemingly luminous eyes of nocturnal animals such as cats and owls at night. It turns out there are reflective membranes located in back of the rods in the animals' eyes, which provide a "second chance" for the animal to perceive light that initially misses the rods. This arrangement, common in night predators, gives excellent night vision. Hence also the reflection from their eyes when light is shone on them.

Discuss the function of the rods and three types of cones in the retina of the eye, and how color cannot be perceived in dim light, and how the colored stars appear white to us whereas they show up clearly colored with camera time exposures. (I show a colored slide that I took of the stars, and discuss the curved lines encircling the North Star, and get into a discussion of how long the camera shutter was held open.)

In discussing color vision, point out that in a bullfight, the bull is angry not at the redness of the cape that is flaunted before him, but because of the darts that have been stuck into him! Whereas a frog is "wired" to see only motion, so it is also on the periphery of our vision. Discuss the fact that we see only motion and no color at the periphery of our vision.

DEMONSTRATION: Figure 26.19; stand at a corner of the room and shake brightly colored cards, first turned backward so the color is hidden and students can adjust the position of their heads (somewhat facing the opposite corner of the room). When they barely see the moving cards, turn them over so the color shows. They'll see the cards, but not their colors! Try with different colors. This goes over well, and is surprising to most students.

Pupilometrics (Figure 26.20) is prone to misunderstanding. If you lecture on this topic, it is important to dispel misconceptions your students may associate with pupil size. It would not be well for people who normally have small pupils to feel self-conscious about this and mistakenly believe that small pupils display a slight negativity. Also, pupil size decreases with age. It would not be well for young people to mistakenly feel that their older peers were "emotionally down" in general. It is the *change* in pupil size, not the pupil size itself, that pupilometrics is about. For more on this, Google *pupilometrics* on the Internet.

Figure 26.21 on lateral inhibition is just one more reminder to your students that they should be careful about believing firmly in what appears to be true. By obstructing the edge between the rectangles, a whole different picture is presented. Our eyes do indeed deceive us from time to time. We should always be open to new ways to look at what we consider is real.

The tiles illusion in Figure 26.23 is nicely employed in the public restrooms in the San Francisco Exploratorium. The shape of grey caulking between tiles makes a big difference. Quite impressive!

Answers and Solutions for Chapter 26

Reading Check Questions

1. A changing magnetic field induces a changing electric field.
2. A changing electric field induces a changing magnetic field.
3. An electromagnetic wave is produced by vibrating electric and magnetic fields.
4. If the wave slowed, regeneration of waves would decrease, and lose energy. Therefore this doesn't occur.
5. If the wave sped up, there would be greater regeneration of waves and energy would increase. Therefore this doesn't occur.
6. Electric and magnetic fields contain and transport energy.
7. The principle difference between radio, light, and X-rays is frequency.
8. Light occupies about one millionth of 1% of the measured spectrum.
9. Red for lowest frequencies, violet for highest visible frequencies.
10. The frequencies of vibrating electrons are transferred to the waves, so the frequencies of both are the same.
11. Higher frequencies of light have shorter wavelengths.
12. The wavelength is 300,000 km long.
13. Outer space is filled with electromagnetic waves, for one thing.
14. Light encountering a transparent material causes atoms in the material to vibrate.
15. The resonant frequency of glass is in the ultraviolet region.
16. The energy of ultraviolet light becomes thermal energy.
17. The energy of visible light transmits through the glass and passes out the other side.
18. The energy of infrared light becomes thermal energy.
19. The frequencies match.
20. The average speed of light in glass is less than its speed in a vacuum.
21. The incident and emerging speed of light are the same.
22. Infrared waves cause whole atoms and molecules to vibrate.
23. Light is absorbed and turns to thermal energy.
24. Metals are shiny because their free electrons easily vibrate to incoming light.
25. Multiple reflections absorb light and the light emerging is weaker.
26. Umbra is the totally dark part of a shadow; a partial shadow is a penumbra.
27. All object in sunshine cast shadows, so yes, Earth and Moon always cast shadows. When the Sun or Moon passes within the other's shadow, we have an eclipse.
28. Rods in the eye see brightness but not color; cones are sensitive to color.
29. Object on the periphery is best seen when moving.
30. The pupil widens with emotional interest.

Think and Do

31. You may be surprised to find that the size of the Moon in the sky is that same whether low or high in the sky, even though a casual look finds it larger nearer the horizon. The explanation is physiological.
32. Open ended and interesting!

Think and Solve

33. Speed $= \dfrac{300,000,000 \text{ km}}{1300 \text{ s}}$ = 231,000 km/s. This value is 77% the modern value.

34. Round trip is 30 km, so from *d* = *ct, t* = *d/c* = 30 km/300,000 km/s = 0.0001 second.

35. From $v = \dfrac{d}{t}$, $t = \dfrac{d}{v} = \dfrac{d}{c} = \dfrac{1.5 \times 10^{11} \text{m}}{3 \times 10^{8} \text{m/s}} = 500 \text{ s}$ (which equals 8.3 min).
The time to cross the diameter of the Earth's orbit is twice this, or **1000 s**, as estimated fairly closely by Roemer (question 33).

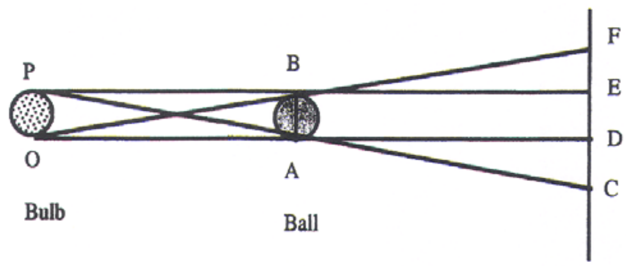
36. Earth-Moon distance is 3.8×10^8 m, so the round-trip distance is 7.6×10^8 m. As in the previous problem, $t = \dfrac{d}{v} = \dfrac{d}{c} = \dfrac{7.6 \times 10^{8} \text{m}}{3 \times 10^{8} \text{m/s}} = 2.5 \text{ s}$.

37. As in the previous problem, $t = \frac{d}{v} = \frac{d}{c} = \frac{4.2 \times 10^{16}\ \text{m}}{3 \times 10^{8}\ \text{m/s}} = 1.4 \times 10^{8}\ \text{s}$.

Converting to years by dimensional analysis,

$1.4 \times 10^8\ \text{s} \times \frac{1\ \text{h}}{3600\ \text{s}} \times \frac{1\ \text{day}}{24\ \text{h}} \times \frac{1\ \text{yr}}{365\ \text{day}} = 4.4\ \text{yr}.$

38.



The lines OAD and PBE are parallel, so the umbra, between D and E, has the same diameter as the ball. The triangles OAB and ODF are similar, with sides in the ratio of 2 to 1, so the distance DF is twice the distance AB. This means that the distances CD, DE, and EF are the same, so the penumbra, between C and F, has three times the diameter of the ball.

39. (a) Frequency = speed/wavelength = $(3 \times 10^8\ \text{m/s})/(0.03\ \text{m}) = 1.0 \times 10^{10}\ \text{Hz} = 10\ \text{GHz}$.
(b) Distance = speed × time, so time = distance/speed = $(10{,}000\ \text{m})/(3 \times 10^8\ \text{m/s}) = 3.3 \times 10^{-5}$ s. (Note the importance of consistent SI units to get the right numerical answers.)

40. Light in water travels at 0.75*c*. $\lambda = \frac{c}{f}$ for light in a vacuum (or air), and $\lambda = \frac{0.75c}{f}$ for light in water.
The ratio of λ_{water} to λ_{air} is therefore 0.75, the same for all frequencies.
So the wavelength of light in water is $^3/4$ its value in air. Wavelength changes while frequency remains the same. In water, the wavelength of this orange light is (0.75)(600) = 450 nm.
In Plexiglas, its wavelength is (0.67)(600) = 400 nm.

Think and Explain

41. Your friend is correct. Also in a profound tone, your friend could say that sound is the only thing we hear!

42. Your friend is again correct. Light is the oscillation of electric and magnetic fields that continually regenerate each other.

43. The fundamental source of electromagnetic radiation is oscillating electric charges, which emit oscillating electric and magnetic fields.

44. The wavelengths of radio waves are longer than those of light waves, which are longer than the wavelengths of X-rays.

45. Ultraviolet has shorter wavelengths than infrared. Correspondingly, ultraviolet also has the higher frequencies.

46. Use film or a photosensitive element that is sensitive to the infra-red part of the spectrum, for things in the environment emit infrared waves, whether they are in darkness or in light.

47. What waves in a light wave are the electric and magnetic fields. Their oscillation frequency is the frequency of the wave.

48. Frequency; a gamma ray has a higher frequency (and therefore more energy per photon) than an infrared ray.

49. Speed is *c*, the speed of light.

50. Both travel at the same speed *c*.

51. Agree. They are both electromagnetic waves.

52. Agree, for a radio wave is an E&M wave while sound is a mechanical wave.

53. Agree. Electromagnetic wave are everywhere.

54. Both are much longer because their frequencies are much lower than the frequencies of visible light.

55. The faster wave has the longer wavelength—light, in accord with the rule $\lambda = v/f$.

56. Sound requires a physical medium in which to travel. Light does not.

57. Radio waves are electromagnetic waves and travel at the speed of light. (Don't confuse sound waves with radio waves!)

58. Radio waves and light are both electromagnetic, transverse, move at the speed of light, and are created and absorbed by oscillating charge. They differ in their frequency and wavelength and in the type of oscillating charge that creates and absorbs them.

59. The shorter wavelength corresponds to a higher frequency, so the frequency of the blue-green light from the argon laser has higher frequency than the red light from the helium-neon laser.

60. The average speed of light will be less where it interacts with absorbing and re-emitting particles of matter, such as in the atmosphere. The greater the number of interactions along the light's path, the less the average speed.

61. Glass is opaque to frequencies of light that match its own natural frequencies. This is because the electrons in the absorbing medium are driven to oscillations of much larger amplitudes than occurs for non-resonant frequencies. These large amplitudes result in energy transfer to neighboring atoms and an increase in internal energy rather than a re-emission of light.

62. The greater number of interactions per distance tends to slow the light and result is a smaller average speed.

63. Transparency or opaqueness is determined by the match between incident light frequencies and the resonant frequency of the material. A substance that is transparent to a range of light frequencies will be opaque to those frequencies that match its own resonant frequency.

64. Clouds are transparent to ultraviolet light, which is why clouds offer very little protection from sunburn. Glass, however, is opaque to ultraviolet light, and will therefore shield you from sunburn.

65. The sunglasses will be warmer in sunlight than regular reading glasses because the reading glasses transmit most of the light energy that is incident upon them, whereas the sunglasses absorb more light energy, increasing their internal energy.

66. Any shadow cast by a faraway object such as a high-flying plane is filled in mainly by light tapering in from the Sun, which is not a point source. This tapering is responsible for the umbra and penumbra of solar eclipses (Figure 26.14). If the plane is low to the ground, however, the tapering of light around the airplane may be insufficient to fill in the shadow, part of which can be seen. This idea is shown in Figure 26.12.

67. Rods, not cones, will respond to weak light, so you want to focus low-intensity light on a part of the retina that is composed of rods. That would be off to the side of the fovea. If you're looking at a dim star, look a bit off to the side of where you expect to see it. Then its image will fall on a part of your eye where rods may pick it up.

68. The light reflected by objects in the moonlight is most often too dim to stimulate the color-perceiving cones in the eye. So we see these objects primarily with our rods, which explains their lack of color.

69. We see no color at the periphery of our vision simply because there are no cones located on the outermost regions of the retina.

70. Unless light reaching her eyes has increased in intensity, her contracting pupils imply that she is displeased with what she sees, hears, tastes, smells, or how she feels. In short, she may be displeased with you!

71. The blind spot is located on the side of the fovea away from your nose.

72. We cannot infer that people with large pupils are generally happier than people with small pupils. The size of a person's pupils has to do with the sensitivity of the retina to light intensity. Your pupils tend to become smaller with age as well. It is the *change* in pupil size that suggests one's psychological disposition.

73. In accord with the inverse-square law, brightness is less than 1/25 that seen from Earth.

74. No, for the brightest star may simply be the closest star.

75. You're seeing the galaxy as it "was" when light left it, long, long ago.

76. You see your hand in the past! How much? To find out, simply divide the distance between your hands and your eyes by the speed of light. (At 30 cm, this is about a billionth of a second.)

77. From the Conversion Factors table on the inside back cover, note that 1 ft = 0.3048 m. So 20 feet is 20 $\times$ 0.3048 m = 6.096 m. So rounded off, in the metric system you could hope for 6/6 vision.

Think and Discuss

78. The terms are misleading in that they imply that ultraviolet and infrared are forms of visible light. More correctly, they are forms of electromagnetic radiation. So in the sense used, "light" is used to mean "electromagnetic radiation." This usage stems from the fact that the ultraviolet and infrared regions of the spectrum are adjacent to visible light. The terms "radio light" and "x-ray light" are uncommon, for one likely reason, that radio x-ray parts of the spectrum are far removed from the visible part.

79. We can see the Sun and stars.

80. Radio waves are electromagnetic waves, not to be confused with sound, which is a mechanical wave entirely different than any electromagnetic wave. Neither is visible.

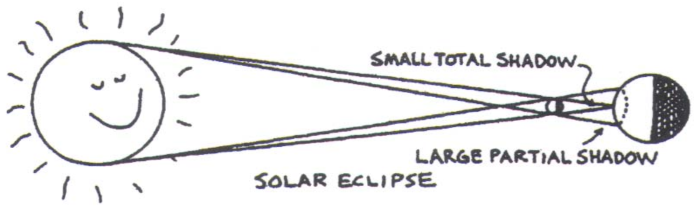
81. The fact that the different parts of the electromagnetic spectrum emitted in the explosion are received simultaneously is evidence for the frequency independence of the speed of light. If wave speed depended on frequency, different frequencies would be received at different times.

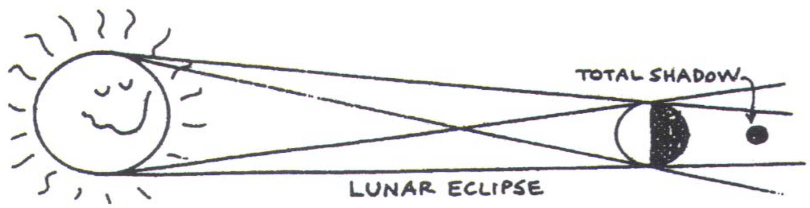
82. The instantaneous speed of the bullet after penetrating the board is less than its incident speed, but not so with light. The instantaneous speed of light before meeting the glass, while passing through it, and when emerging is a constant, *c*. The fundamental difference between a bullet fired through a board and light passing through glass is that the *same* bullet strikes and later emerges. Not so for light. The "bullet of light" (photon) that is incident upon glass is absorbed by its interaction with an atom or molecule. The atom or molecule in turn then emits, with some time delay, a new "bullet of light" in the same direction. This process cascades through the glass with the result being that the "bullet of light" emerging is not the same "bullet" that was first incident. In the space between the atoms in matter the instantaneous speed of light is *c*. Because of the time delay of the interactions, only its average speed is less than *c*. The light that emerges has speed *c*.

83. Walking across a room and pausing to greet others is analogous to the transmission-of-light model in that there is a pause with each interaction. However, the same person that begins the walk ends the walk, whereas in light transmission there is a "death-birth" sequence of events as light is absorbed and "new light" is emitted in its place. The light to first strike the glass is not the same light that finally emerges. (Another analogy is a relay race, where the runner to begin the race is not the runner to cross the finish line.)

84. A solar eclipse is a shadow of the Moon that reaches a relatively small part of the Earth, and only those people in the shadow or partial shadow experience it. But a lunar eclipse is the Earth's shadow

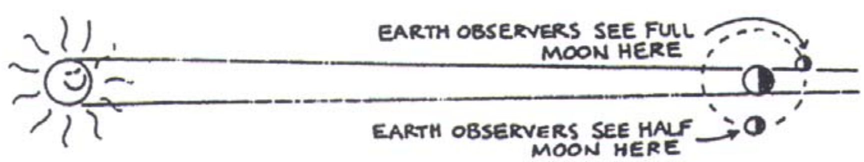
upon the Moon, which is visible to all who can see the Moon. So everyone who can see the Sun won't see its eclipse unless they're in its shadow, but everyone who can see the Moon will see its eclipse where there is one.





85. Yes. Evidence is a lunar eclipse, when the Moon passes in the Earth's shadow.

86. A lunar eclipse occurs when the Earth, Sun, and Moon all fall on a straight line, with the Earth between the Sun and the Moon. During perfect alignment the Earth's shadow falls on the Moon. Not-quite-perfect alignment gives Earth observers a full view of the Moon. Moonlight is brightest and the Moon is always fullest when the alignment is closest to perfect—on the night of a lunar eclipse. At the time of a half moon, however, lines from Earth to Moon and from Earth to Sun are at right angles to each other. This is as non-aligned as the Earth, Moon, and Sun can be, with the Moon nowhere near the Earth's shadow—no eclipse is possible. Similarly for the non-aligned times of a crescent moon.



87. During a partial eclipse where crescents of the Sun are cast, the Moon is partly in front of the Sun.

88. The solid angle from each opening in the leaves to the circles cast on Dean is the same solid angle between the leaves and the Sun. So just as 100 circles, each the size of the solar image, fit between Dean and the tree opening, 100 Suns would fit between the tree and its position from Earth, a distance of 150,000,000 km.

89. The Moon is farther away from its average distance from Earth, so is smaller in the sky. If it were closer, the Moon would appear bigger and the Sun would be entirely blocked when the Moon, Sun, and Earth align.

90. No eclipse occurred because no shadow was cast on any other body.

91. (a) Moon observers would see the Earth in the path of the sunlight and see a solar eclipse. (b) Moon observers would see a small shadow of the Moon slowly move across the full Earth. The shadow would consist of a dark spot (the umbra) surrounded by a not-as-dark circle (the penumbra).

92. Energy is spread out and diluted, but not "lost." We distinguish between something being diluted and something being annihilated. In accord with the inverse-square law, light intensity gets weaker with distance, but the total amount of light over a spherical surface is the same at all distances from the source.

93. Light from the flash spreads via the inverse-square law to the ground below, and what little returns to the airplane spreads further. The passenger will find that the flash makes no difference at all. Taking pictures at great distances, whether from an airplane or the football stands, with the flash intentionally turned on is rather foolish.

94. Some airplanes bounce radar waves to and from the ground below, measuring the round trip time for determining distance to the ground, much as a ship bounces sonic waves from the ocean floor to measure water depth. Far above the ground an altimeter is fine for determining the airplane's height above sea level, but close to the ground the pilot wants to know the airplane's distance from local ground.