Hearing and Seeing; Tutorial 3 – Answers

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Example 34.6 A Half-Wave Antenna

A half-wave antenna works on the principle that the optimum length of the antenna is half the wavelength of the radiation being received. What is the optimum length of a car antenna when it receives a signal of frequency 94.7 MHz?

Solution Equation 34.13 tells us that the wavelength of the signal is

$$\lambda = \frac{3.00 \times 10^8 \text{ m/s}}{9.47 \times 10^7 \text{ Hz}} = \boxed{3.16 \text{ m}}$$

Thus, to operate most efficiently, the antenna should have a length of $(3.16 \text{ m})/2 = 1.58 \text{ m}$. For practical reasons, car antennas are usually one-quarter wavelength in size.

19. An empty plastic or glass dish being removed from a microwave oven is cool to the touch. How can this be possible? (Assume that your electric bill has been paid.)

20. Why should an infrared photograph of a person look different from a photograph taken with visible light?

21. Suppose that a creature from another planet had eyes that were sensitive to infrared radiation. Describe what the alien would see if it looked around the room you are now in. In particular, what would be bright and what would be dim?

22. A welder must wear protective glasses and clothing to prevent eye damage and sunburn. What does this imply about the nature of the light produced by the welding?

Q34.19 The frequency of EM waves in a microwave oven, typically 2.45 GHz, is chosen to be in a band of frequencies absorbed by water molecules. The plastic and the glass contain no water molecules. Plastic and glass have very different absorption frequencies from water, so they may not absorb any significant microwave energy and remain cool to the touch.

Q34.20 People of all the world's races have skin the same color in the infrared. When you blush or exercise or get excited, you stand out like a beacon in an infrared group picture. The brightest portions of your face show where you radiate the most. Your nostrils and the openings of your ear canals are bright; brighter still are just the pupils of your eyes.

Q34.21 Light bulbs and the toaster shine brightly in the infrared. Somewhat fainter are the back of the refrigerator and the back of the television set, while the TV screen is dark. The pipes under the sink show the same weak sheen as the walls until you turn on the faucets. Then the pipe on the right turns very black while that on the left develops a rich glow that quickly runs up along its length. The food on your plate shines; so does human skin, the same color for all races. Clothing is dark as a rule, but your bottom glows like a monkey's rump when you get up from a chair, and you leave behind a patch of the same blush on the chair seat. Your face shows you are lit from within, like a jack-o-lantern: your nostrils and the openings of your ear canals are bright; brighter still are just the pupils of your eyes.

Q34.22 Welding produces ultraviolet light, along with high intensity visible and infrared.

38. Classify waves with frequencies of 2 Hz, 2 kHz, 2 MHz, 2 GHz, 2 THz, 2 PHz, 2 EHz, 2 ZHz, and 2 YHz on the electromagnetic spectrum. Classify waves with wavelengths of 2 km, 2 m, 2 mm, 2 μm, 2 nm, 2 pm, 2 fm, and 2 am.

39. The human eye is most sensitive to light having a wavelength of 5.50×10^{-7} m, which is in the green-yellow region of the visible electromagnetic spectrum. What is the frequency of this light?

40. Compute an order-of-magnitude estimate for the frequency of an electromagnetic wave with wavelength equal to (a) your height; (b) the thickness of this sheet of paper. How is each wave classified on the electromagnetic spectrum?

P34.38 From the electromagnetic spectrum chart and accompanying text discussion, the following identifications are made:

Frequency, f	Wavelength, $\lambda = \frac{c}{f}$	Classification
$2\text{ Hz} = 2\times10^{0}\text{ Hz}$	150 Mm	Radio
$2\text{ kHz} = 2\times10^{3}\text{ Hz}$	150 km	Radio
$2\text{ MHz} = 2\times10^{6}\text{ Hz}$	150 m	Radio
$2\text{ GHz} = 2\times10^{9}\text{ Hz}$	15 cm	Microwave
$2\text{ THz} = 2\times10^{12}\text{ Hz}$	150 μm	Infrared
$2\text{ PHz} = 2\times10^{15}\text{ Hz}$	150 nm	Ultraviolet
$2\text{ EHz} = 2\times10^{18}\text{ Hz}$	150 pm	X-ray
$2\text{ ZHz} = 2\times10^{21}\text{ Hz}$	150 fm	Gamma ray
$2\text{ YHz} = 2\times10^{24}\text{ Hz}$	150 am	Gamma ray

Wavelength, λ	Frequency, $f = \frac{c}{\lambda}$	Classification
$2\text{ km} = 2\times10^{3}\text{ m}$	$1.5\times10^{5}\text{ Hz}$	Radio
$2\text{ m} = 2\times10^{0}\text{ m}$	$1.5\times10^{8}\text{ Hz}$	Radio
$2\text{ mm} = 2\times10^{-3}\text{ m}$	$1.5\times10^{11}\text{ Hz}$	Microwave
$2\ \mu\text{m} = 2\times10^{-6}\text{ m}$	$1.5\times10^{14}\text{ Hz}$	Infrared
$2\text{ nm} = 2\times10^{-9}\text{ m}$	$1.5\times10^{17}\text{ Hz}$	Ultraviolet/X-ray
$2\text{ pm} = 2\times10^{-12}\text{ m}$	$1.5\times10^{20}\text{ Hz}$	X-ray/Gamma ray
$2\text{ fm} = 2\times10^{-15}\text{ m}$	$1.5\times10^{23}\text{ Hz}$	Gamma ray
$2\text{ am} = 2\times10^{-18}\text{ m}$	$1.5\times10^{26}\text{ Hz}$	Gamma ray

P34.39 $f = \frac{c}{\lambda} = \frac{3.00\times10^{8}\text{ m/s}}{5.50\times10^{-7}\text{ m}} = \boxed{5.45\times10^{14}\text{ Hz}}$

P34.40 (a) $f = \frac{c}{\lambda} = \frac{3\times10^{8}\text{ m/s}}{1.7\text{ m}}\ \boxed{\sim10^{8}\text{ Hz}}\ \boxed{\text{radio wave}}$

(b) 1 000 pages, 500 sheets, is about 3 cm thick so one sheet is about 6×10^{-5} m thick.

$f = \frac{3.00\times10^{8}\text{ m/s}}{6\times10^{-5}\text{ m}}\ \boxed{\sim10^{13}\text{ Hz}}\ \boxed{\text{infrared}}$

Example 35.3 An Index of Refraction Measurement

A beam of light of wavelength 550 nm traveling in air is incident on a slab of transparent material. The incident beam makes an angle of 40.0° with the normal, and the refracted beam makes an angle of 26.0° with the normal. Find the index of refraction of the material.

Solution Using Snell's law of refraction (Eq. 35.8) with these data, and taking $n_1 = 1.00$ for air, we have

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2} = (1.00) \frac{\sin 40.0°}{\sin 26.0°}$$

$$= \frac{0.643}{0.438} = \boxed{1.47}$$

From Table 35.1, we see that the material could be fused quartz.

Example 35.4 Angle of Refraction for Glass

A light ray of wavelength 589 nm traveling through air is incident on a smooth, flat slab of crown glass at an angle of 30.0° to the normal, as sketched in Figure 35.15. Find the angle of refraction.

Solution We rearrange Snell's law of refraction to obtain

$$\sin \theta_2 = \frac{n_1}{n_2} \sin \theta_1$$

From Table 35.1, we find that $n_1 = 1.00$ for air and $n_2 = 1.52$ for crown glass. Therefore,

$$\sin \theta_2 = \left(\frac{1.00}{1.52}\right) \sin 30.0° = 0.329$$

$$\theta_2 = \sin^{-1}(0.329) = \boxed{19.2°}$$

Because this is less than the incident angle of 30°, the refracted ray is bent toward the normal, as expected. Its change in direction is called the *angle of deviation* and is given by $\delta = |\theta_1 - \theta_2| = 30.0° - 19.2° = 10.8°$.

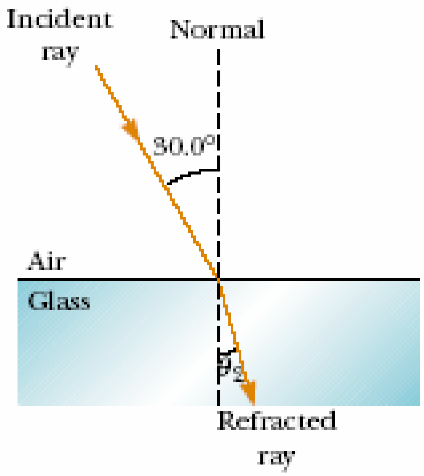

Figure 35.15 (Example 35.4) Refraction of light by glass.

$\boxed{15.}$ Explain why a diamond sparkles more than a glass crystal of the same shape and size.

Q35.15 Diamond has higher index of refraction than glass and consequently a smaller critical angle for total internal reflection. A brilliant-cut diamond is shaped to admit light from above, reflect it totally at the converging facets on the underside of the jewel, and let the light escape only at the top. Glass will have less light internally reflected.

21. Why does the arc of a rainbow appear with red on top and violet on the bottom?

35.21 Suppose the Sun is low in the sky and an observer faces away from the Sun toward a large uniform rain shower. A ray of light passing overhead strikes a drop of water. The light is refracted first at the front surface of the drop, with the violet light deviating the most and the red light the least. At the back of the drop the light is reflected and it returns to the front surface where it again undergoes refraction with additional dispersion as it moves from water into air. The rays leave the drop so that the angle between the incident white light and the most intense returning violet light is 40°, and the angle between the white light and the most intense returning red light is 42°. The observer can see a ring of raindrops shining violet, a ring with angular radius 40° around her shadow. From the locus of directions at 42° away from the antisolar direction, the observer receives red light. The other spectral colors make up the rainbow in between. An observer of a rainbow sees violet light at 40° angular separation from the direction opposite the Sun, then the other spectral colors, and then red light on the outside the rainbow, with angular radius 42°.

21. When the light illustrated in Figure P35.21 passes through the glass block, it is shifted laterally by the distance *d*. Taking $n = 1.50$, find the value of *d*.

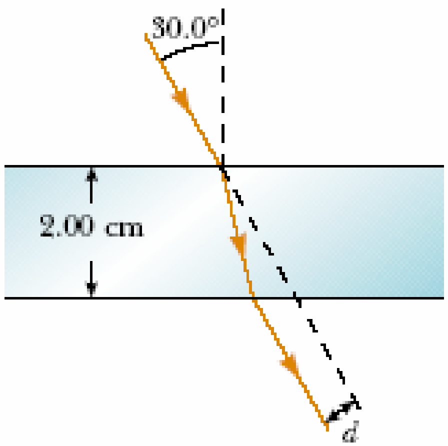

Figure P35.21 Problems 21 and 22.

22. Find the time interval required for the light to pass through the glass block described in the previous problem.

P35.21 At entry, $n_1 \sin\theta_1 = n_2 \sin\theta_2$

or $1.00 \sin 30.0° = 1.50 \sin\theta_2$

$\theta_2 = 19.5°$.

The distance h the light travels in the medium is given by

$$\cos\theta_2 = \frac{2.00 \text{ cm}}{h}$$

or $h = \dfrac{2.00 \text{ cm}}{\cos 19.5°} = 2.12 \text{ cm}$.

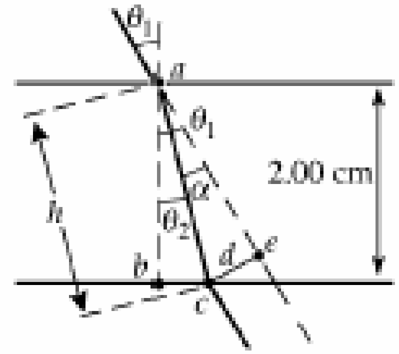

FIG. P35.21

The angle of deviation upon entry is $\alpha = \theta_1 - \theta_2 = 30.0° - 19.5° = 10.5°$.

The offset distance comes from $\sin\alpha = \dfrac{d}{h}$: $d = (2.21 \text{ cm}) \sin 10.5° = \boxed{0.388 \text{ cm}}$.

P35.22 The distance, h, traveled by the light is $h = \dfrac{2.00 \text{ cm}}{\cos 19.5°} = 2.12 \text{ cm}$

The speed of light in the material is $v = \dfrac{c}{h} = \dfrac{3.00 \times 10^8 \text{ m/s}}{1.50} = 2.00 \times 10^8 \text{ m/s}$

Therefore, $t = \dfrac{h}{v} = \dfrac{2.12 \times 10^{-2} \text{ m}}{2.00 \times 10^8 \text{ m/s}} = 1.06 \times 10^{-10} \text{ s} = \boxed{106 \text{ ps}}$.

40. Unpolarized light passes through two polaroid sheets. The axis of the first is vertical, and that of the second is at 30.0° to the vertical. What fraction of the incident light is transmitted?

$\boxed{41.}$ Plane-polarized light is incident on a single polarizing disk with the direction of $\mathbf{E}_0$ parallel to the direction of the transmission axis. Through what angle should the disk be rotated so that the intensity in the transmitted beam is reduced by a factor of (a) 3.00, (b) 5.00, (c) 10.0?

P38.40 The average value of the cosine-squared function is one-half, so the first polarizer transmits $\frac{1}{2}$ the light. The second transmits $\cos^2 30.0° = \frac{3}{4}$.

$$I_f = \frac{1}{2} \times \frac{3}{4} I_i = \boxed{\frac{3}{8} I_i}$$

P38.41 $I = I_{max} \cos^2 \theta \quad \Rightarrow \quad \theta = \cos^{-1} \sqrt{\frac{I}{I_{max}}}$

(a) $\frac{I}{I_{max}} = \frac{1}{3.00} \quad \Rightarrow \quad \theta = \cos^{-1} \sqrt{\frac{1}{3.00}} = \boxed{54.7°}$

(b) $\frac{I}{I_{max}} = \frac{1}{5.00} \quad \Rightarrow \quad \theta = \cos^{-1} \sqrt{\frac{1}{5.00}} = \boxed{63.4°}$

(c) $\frac{I}{I_{max}} = \frac{1}{10.0} \quad \Rightarrow \quad \theta = \cos^{-1} \sqrt{\frac{1}{10.0}} = \boxed{71.6°}$