

Show equations, substitutions, units, and vector directions. Explain your reasoning. Use sensible rounding.

Answers appear below each question beside a vertical bar. Equivalent correct reasoning is acceptable.

Constants	$c = 3.00 \times 10^8 \text{ m/s}$ $h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$ $1 \text{ nm} = 10^{-9} \text{ m}$
Equations	$f = 1/T$ $v = f\lambda$ $\lambda_n = 2L/n$ (string fixed at both ends) $c = f\lambda$ $\theta_i = \theta_r$ $n_{\text{index}} = c/v$ $n_1 \sin \theta_1 = n_2 \sin \theta_2$ $E_{\text{photon}} = hf = hc/\lambda$

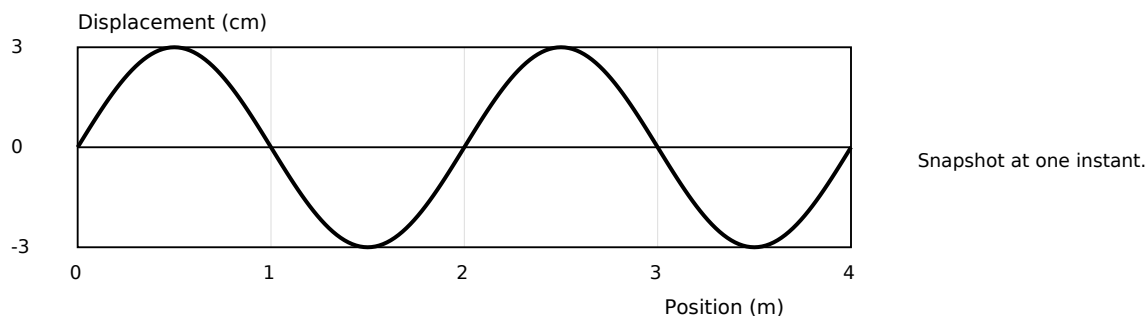
Measure optical angles from the normal. n means harmonic number or refractive index as labeled.

9.1 Wave Basics

1. Classify each wave as mechanical or electromagnetic and transverse or longitudinal: sound in air, a wave on a stretched rope shaken sideways, and visible light. What do waves transfer?

Sound: mechanical, longitudinal. Rope: mechanical, transverse. Visible light: electromagnetic, transverse. Waves transfer energy. Medium particles oscillate rather than traveling along with the wave as a group.

2. Read the wave snapshot. Find amplitude and wavelength. Mark one crest, one trough, and the equilibrium line. Explain why the crest-to-trough vertical distance is not the amplitude.



Amplitude = 3.0 cm. Wavelength = 2.0 m. Crests occur at $x = 0.5$ and 2.5 m. Troughs occur at 1.5 and 3.5 m. Equilibrium is $y = 0$. Crest-to-trough vertical distance is $6.0 \text{ cm} = 2A$.

9.2 Frequency, Period, and Wave Speed

3. A buoy completes 15 full oscillations in 30 s. Find frequency and period. If neighboring crests are 8.0 m apart, find wave speed.

$f = 15/30 = 0.50 \text{ Hz}$. $T = 1/f = 2.0 \text{ s}$. $v = f\lambda = (0.50)(8.0) = 4.0 \text{ m/s}$.

4. Sound travels at 343 m/s and has frequency 490 Hz. Find wavelength. For a nondispersive medium under unchanged conditions, what happens to wavelength when frequency doubles?

$\lambda = v/f = 343/490 = 0.700 \text{ m}$. If speed stays fixed while frequency doubles, wavelength halves to 0.350 m.

ANSWER KEY

9.3 Interference

5. Find the displacement during overlap for (a) +4.0 cm and +2.0 cm pulses, (b) +4.0 cm and -2.0 cm pulses, and (c) +4.0 cm and -4.0 cm pulses. Name each interference type.

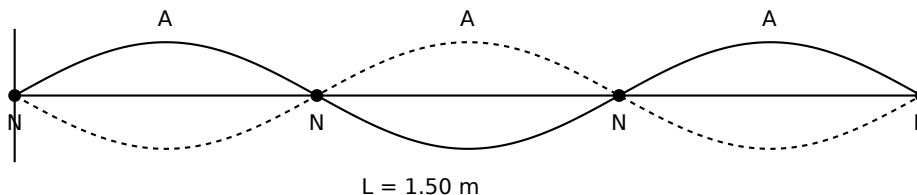
(a) +6.0 cm, constructive. (b) +2.0 cm, partially destructive. (c) 0 cm, completely destructive at that overlap. Displacements add algebraically.

6. Two equal and opposite pulses cancel at one instant on an ideal rope. Have they disappeared permanently? Describe what happens after they pass and how this relates to noise-cancelling headphones.

The pulses continue through each other and reappear with their original shapes and directions in an ideal linear medium. Cancellation is temporary superposition. Headphones generate a sound wave that opposes unwanted sound at the listener's ear.

9.4 Standing Waves

7. A 1.50 m string is fixed at both ends and vibrates in its third harmonic. Sketch the pattern, label nodes and antinodes, and find wavelength. Count endpoint nodes.



There are three loops, four nodes including both ends, and three antinodes. $\lambda = 2L/n = 2(1.50)/3 = 1.00 \text{ m}$.

8. For the string in Question 7, wave speed is 60 m/s. Find the third-harmonic frequency and fundamental frequency. Explain resonance.

Third harmonic: $f_3 = v/\lambda_3 = 60/1.00 = 60 \text{ Hz}$. Fundamental wavelength $= 2L = 3.00 \text{ m}$, so $f_1 = 60/3.00 = 20 \text{ Hz}$. Resonance occurs when driving frequency matches a natural frequency and produces a large response.

ANSWER KEY

9.5 The Electromagnetic Spectrum

9. List radio, microwave, infrared, visible, ultraviolet, X-ray, and gamma radiation in order of increasing frequency. Which has the longest wavelength? Compare their speeds in a vacuum.

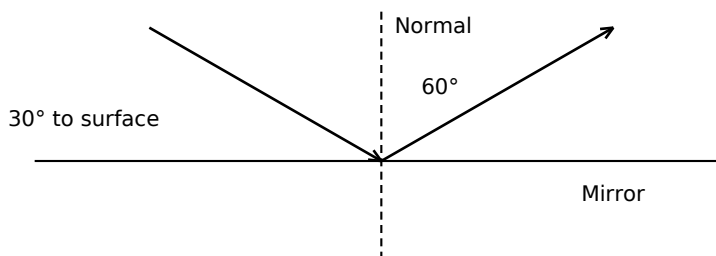
Increasing frequency: radio, microwave, infrared, visible, ultraviolet, X-ray, gamma. Radio has the longest wavelength. All travel at $c = 3.00 \times 10^8$ m/s in vacuum.

10. Light has wavelength 600 nm in vacuum. Find its frequency. Compare its photon energy with 400 nm light and explain your reasoning without calculating either photon energy.

$600 \text{ nm} = 6.00 \times 10^{-7} \text{ m}$. $f = c/\lambda = (3.00 \times 10^8)/(6.00 \times 10^{-7}) = 5.00 \times 10^{14} \text{ Hz}$. The 400 nm photons have higher frequency and 1.5 times the energy because $E = hc/\lambda$.

9.6 Reflection and Mirrors

11. A ray meets a plane mirror at 30° to its surface. Draw the normal and reflected ray. Find incidence and reflection angles measured from the normal.



$\theta_i = 90^\circ - 30^\circ = 60^\circ$. $\theta_r = 60^\circ$. The reflected ray lies on the opposite side of the normal with the same angle.

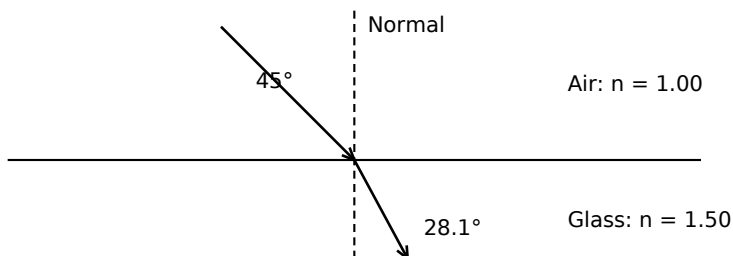
12. A student stands 2.0 m in front of a plane mirror. Locate the image and find the student-image distance. State image size and whether it is real or virtual. Compare smooth and rough-surface reflection.

The image is 2.0 m behind the mirror, so student-image distance is 4.0 m. It is virtual, upright, and the same size. Smooth surfaces give specular reflection. Rough surfaces give diffuse reflection because their local normals vary. Both obey the law of reflection.

ANSWER KEY

9.7 Refraction

13. Light passes from air ($n = 1.00$) into glass ($n = 1.50$) at 45.0° from the normal. Find the refracted angle and light speed in glass. Sketch the refracted ray.



$\sin \theta_2 = (1.00/1.50)\sin 45.0^\circ = 0.4714$, so $\theta_2 = 28.1^\circ$. $v = c/n = (3.00 \times 10^8)/1.50 = 2.00 \times 10^8$ m/s. The ray bends toward the normal.

14. Light moves from water into air at an angle that permits transmission. Does it bend toward or away from the normal? What happens to speed, frequency, and wavelength? What if it enters along the normal?

It bends away from the normal as speed increases. Frequency stays unchanged across the stationary boundary, so wavelength increases. At normal incidence, the speed and wavelength change but there is no direction change.

9.8 The Photoelectric Effect

15. Calculate the energy of a photon with frequency 8.0×10^{14} Hz. A metal needs at least 4.0×10^{-19} J to release an electron. Can this photon release one?

$E = hf = (6.63 \times 10^{-34})(8.0 \times 10^{14}) = 5.3 \times 10^{-19}$ J. Yes, the photon's energy exceeds the stated minimum.

16. For the same metal, determine whether 700 nm light can release electrons. Would making that light much brighter change your conclusion in the single-photon model? Explain.

$E = hc/\lambda = [(6.63 \times 10^{-34})(3.00 \times 10^8)]/(700 \times 10^{-9}) = 2.84 \times 10^{-19}$ J. This is below 4.0×10^{-19} J, so no emission occurs. Greater brightness supplies more photons, but each still lacks enough energy.

ANSWER KEY**Unit 9 Review**

17. A 2.0 m string fixed at both ends has wave speed 24 m/s. Find wavelength and frequency for the first and fourth harmonics. Compare the number of nodes in each.

First: $\lambda_1 = 2L = 4.0$ m, $f_1 = 24/4.0 = 6.0$ Hz, two nodes. Fourth: $\lambda_4 = 2L/4 = 1.0$ m, $f_4 = 24/1.0 = 24$ Hz, five nodes. Nodes include both ends.

18. Light travels through a transparent material at 2.4×10^8 m/s. Find its refractive index. If its frequency is 6.0×10^{14} Hz, find its wavelength in the material and in vacuum.

$n = c/v = (3.00 \times 10^8)/(2.4 \times 10^8) = 1.25 \approx 1.3$. In material: $\lambda = v/f = 4.0 \times 10^{-7}$ m = 400 nm. In vacuum: $\lambda_0 = c/f = 5.0 \times 10^{-7}$ m = 500 nm.

19. A metal already emits electrons under monochromatic light. Predict the effects of (a) greater intensity at the same frequency and (b) greater frequency at the same photon arrival rate. Assume all photons still exceed the threshold.

(a) More incident photons per second can eject more electrons per second, but do not raise their maximum kinetic energy. (b) Each photon has more energy, increasing the maximum kinetic energy of emitted electrons. With equal photon arrival and emission efficiency, the emission rate need not increase.

20. Give one observation supporting the wave model of light and one supporting the photon model. Explain why a single classical wave model cannot explain the photoelectric threshold frequency.

Interference or diffraction supports wave behavior. The photoelectric effect supports photon energy packets. Below the threshold, increasing intensity does not cause single-photon emission. The photon model explains this with $E = hf$: each photon must supply the required minimum energy.