

E Problems for Unit II

- E20: Electric Field of EM wave.** For an EM wave, $\vec{E} = (6.6 \times 10^4 \text{ N/C}) \cos(12\pi x - 3.6 \times 10^8 \pi t) \hat{j}$, with x in meters and t in seconds. Find the expression for the corresponding magnetic field.
- E21: Maxwell's Equations.** Describe in words each of Maxwell's equations. Make sure to discuss the physical phenomena associated with each.
- E22: Magnetic Monopole-y.** A team of scientists claims to have discovered a magnetic monopole. They base their claim on a unique signal that would be obtained when a magnetic monopole moves along the axis of a loop (see Figure 28-59b associated with problem 89 in chapter 28, for the signal that would be measured by a magnetic dipole moving along the axis of the loop).
- Make a qualitative graph of the magnetic flux ϕ_m through the loop as a function of time as the hypothetical monopole starts from the left of the loop, passes through the loop, and moves to the right of the loop.
 - Make a qualitative graph of the emf in the loop as a function of time (make sure to keep track of the negative sign in Faraday's Law here.)
- E23: Custom Car Antenna.** The antenna on your car is a long straight conducting metal rod that is vertically oriented.
- What might you deduce about the orientation of the transmitting antenna for your local radio station? Make sure you consider the case where the transmitter is a dipole antenna and the case where the transmitter is a loop antenna.
 - In a rage, the Incredible Hulk breaks off the antenna on your car. You choose to have the crew at West Coast Custom replace it with a loop antenna instead. What orientation should your new antenna have? What is a drawback to this kind of antenna for your car?
- E24: Magnetic Field of EM wave.** For an EM wave, $\vec{B} = (4.2 \times 10^{-5}) \sin(4\pi z + 1.2 \times 10^9 \pi t) \hat{j}$, where B is in T when z is in meters and t is in seconds. The wavelength of this wave is 50 cm.
- What is the direction of propagation of the EM wave?
 - Find the expression for the corresponding electric field.
 - Determine the frequency of this wave. In what part of the electromagnetic spectrum does this EM wave lie?
- E25: Magic Spring Reflections.** Observe reflections of waves made on the Magic Spring (generic Slinky knockoff). Hold your spring by one end and let it hang straight down. Lift the held end as high above your head as is comfortable and wait till the spring is motionless. Now look through the spring to an object behind it. You will use this object to determine if the spring deflects left or right. It will probably be useful to have a partner help you observe.
- Leave the lower end free and make a quick rightward jerk of the top of the spring. You should see a rightward pulse travel down the spring and reflect off the bottom. Which way does the spring first deflect as the wave travels back up (left or right)? You should try this many times to be sure.
 - Repeat, but hold the lower end in a fixed position with your other hand.

E26: Traveling Waves on Magic Spring. Make some traveling waves on a Magic Spring. Take your Magic Spring and attach one end to a door knob, bed post or a friend. Hold the other end and walk away so the spring is stretched to about 6 feet.

- Grab a few of the coils and pull them towards you and release so that a longitudinal compression wave pulse travels along the spring, bounces off the other end, and goes back and forth. See how far the pulse goes in five seconds (take the number of round trips multiplied by the round-trip distance). Get the wave speed of the longitudinal wave.
- Repeat by pulling the coils sideways to get a transverse wave pulse, and find the wave speed of the transverse wave.
- Compare your longitudinal wave speed and your transverse wave speed. Both waves are traveling through the same medium (the spring), so how should the longitudinal wave speed and the transverse wave speed compare? Does your predication match your experiment well or poorly?

E27: Pipe Organ Standing Waves. Consider a 10 m organ pipe, open at both ends.

- Sketch the standing wave pattern for the three longest wavelength modes.
- From each sketch, determine the wavelength λ and the wave number k .
- From the speed of sound in air (340 m/s), determine the frequencies of each mode.

E28: Beautiful (and Not so Beautiful) Music. Use your slide whistle for this one.

- Extend the slide all the way out. Blow softly but steadily on the whistle and note the pitch. Now push the slide in as you continue to blow. What do you hear? Explain your observations.
- Bring the slide all the way out and again blow softly but steadily on the whistle. Continue to play the whistle as you push the slide inward, and stop when you reach a note that is an octave above what you started with; you may need to be patient as this might take several tries. What determines how far the slide should be pushed to increase the pitch by one octave? Make a simple measurement to verify your idea.
- More slide whistle mayhem! Extend the slide mostly or all the way out. When you blow softly but steadily on the slide whistle, you want to hear a pleasant note. Make a sketch of the standing wave in the air column associated with this note.
- Now, keep the slide in the same position and blow harder on the whistle until the pitch changes. This new note will almost certainly be much less pleasant than the previous sound. Did you hear any frequencies between the old pleasant note and the new less-than-pleasant note? Explain your observations.
- How is the frequency of the new note related to the frequency of the old note? Draw a sketch of the standing wave to support your answer.

E29: Testing Wave Functions. Determine by direct substitution whether the following proposed wave functions $y(x,t)$ are solutions to the classical wave equation:

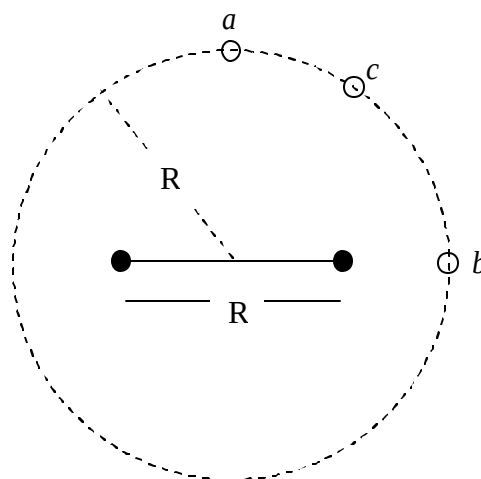
- $y(x,t) = A e^{kx - \omega t}$
- $y(x,t) = A \sin kx \sin \omega t$
- $y(x,t) = A t^2 \sin kx$

E30: Wave on a String. A harmonic wave moves down a string with speed 12.4 m/s. A particle on the string has a maximum displacement of 4.5 cm and a maximum speed of 9.4 m/s.

- Find the wavelength of this wave.
- Find the frequency of this wave.
- Write an equation for the wave function that describes this wave.

- E31: Wave on a Wire.** A very long wire can be vibrated up and down with a mechanical motor to produce waves traveling down the wire. At the far end of the wire, the traveling waves are absorbed by a clever device that allows no reflected waves to be returned to the motor. The wave speed is observed to be 240 m/s, the maximum transverse displacement of the wire is 1 cm, and the distance between maxima is 3.0 m.
- Write a wave function to represent the wave propagating down this wire.
 - What is the frequency of vibration of the motor?
 - What is the period of the transverse oscillations of the wire?
 - What is the maximum transverse velocity of a small insect clinging to the wire?
- E32: Magic Spring Standing Waves.** Find a friend to help you time and count Magic Spring standing wave oscillations.
- Hold the spring with one end in each hand and generate standing waves. Get at least the fundamental mode and the next two higher harmonics. For each mode, count ten full oscillations and have your friend measure the time for the ten oscillations. Determine the period and frequency for each mode. Calculate the ratio of each mode frequency to the fundamental frequency. What do you notice?
 - What is the highest frequency mode you personally can achieve?
 - Estimate the wavelength for each mode. Use these wavelengths and corresponding frequency for each mode to determine a wave speed. Compare these to the speed of transverse waves measured in **Traveling Waves on Magic Spring**.
 - Estimate the amplitude of the standing wave. Now, write down an equation for the wave function that describes this standing wave.
- E33: Bass Fiddle.** The lowest note that can be played on a bass fiddle is E1 (frequency 41.2 Hz) on a string of length 1.2 m (secured at both ends).
- Sketch the standing wave pattern for the three longest wavelength modes of the string.
 - From each sketch, determine the wave number k and the wavelength λ . Is the wavelength in the string the same as the wavelength of the note in the air?
 - Determine the wave speed for this string.
 - Find the frequencies of the modes you sketched in part a).
- E35: Filmed in Color.**
- Here's one to try in the shower! Get your hands very wet and soapy. Then slowly slide your forefinger along your thumb stretching a soap film bigger and bigger. You can catch it on your other hand to make a big thin film. (If you are not good at this, try using bubbles from the goo in your kit. Blow a big bubble, catch it on the wand, and hold it while it thins out.) Now with the light behind you, look at the reflections off the film. You should see some really cool patterns of colors! Try to sketch the patterns and show where each color is. Briefly explain your observations in terms of thin films and interference.
 - Go look in a parking lot for a spot where some motor oil has dripped. If it hasn't rained recently, pour some water on the spot. If the light is good, you will see some colors. Describe the pattern and placement of colors that you see. Try to explain what you see in terms of interference in thin films.
- E34: Groovy, Man.** Take a copy of your favorite music CD and look at the groovy side in strong light. Make sure that you are looking at a commercially mass produced CD, and not one that was burned on a personal computer. Tip the CD at different angles. Why do you see colors? Do they change for different tip angles? Explain briefly.

E36: Two Speakers. Consider two speakers that produce sound waves (no phase difference is introduced at the source) with amplitude A and wavelength $\lambda = R$. The speakers are a distance R apart, as shown in the figure below, where the speakers are represented by the two filled dots. The points a , b , and c are on a circle of radius R that is centered on the line segment connecting the two speakers.



- The point a is a distance R from the center point, at an angle of 90° from the horizontal, as shown. Calculate the amplitude of the combined wave at point a , in terms of A .
- The point b is a distance R from the center point, at an angle of 0° from the horizontal, as shown. Calculate the amplitude of the combined wave at point b , in terms of A .
- The point c is a distance R from the center point, at an angle of 60° from the horizontal. Calculate the amplitude of the combined wave at point c , in terms of A .

E37: Somewhere Over the Rainbow. On your way to the Bucknell Observatory, you look at a distant light in the football stadium with your Laser Vision Glasses™. At the center, you can clearly observe the distant light. You notice very clear continuous spectra, basically radiating out from the center. You observe that blue is closest to the center and red is furthest away in each rainbow pattern (try it yourself and see!) Let's estimate that the closest violet blue edge of the first rainbow pattern is 1.2 cm away from the center, that the distance to the light is 100 m, and that your Glasses are about 4 cm from the front of your eyes.

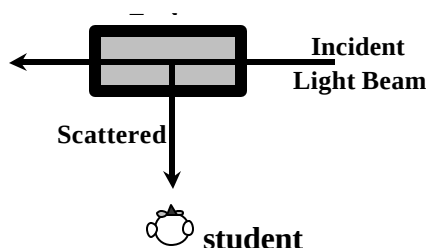
- Determine the slit spacing associated with your glasses.
- At what distance from the center do you predict the first red spot to be?

E38: Clock Work. Go out to the academic quad and stand at the end opposite the library, as far from the library as you can safely get while still being able to observe the clock.

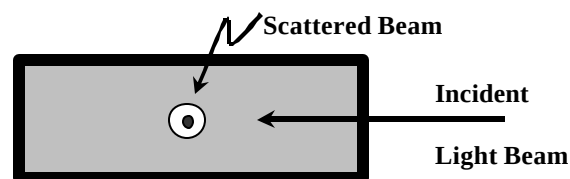
- Look at the clock on the library tower. Specifically, look at the Roman numeral 8 (VIII), which is actually made up of 5 separate lines. From your far away position, can you distinguish between the 5 lines? Why not?
- Now, walk toward the library until you can just distinguish the five separate lines that make up the VIII. Now pace off your distance to the library doors. Add 30 ft. to get the total distance between your former position and the clock face (think about the triangle formed by your former position, the library doors, and the clock face if you're not sure why you're adding thirty feet). If you don't know your pace length, use $2\frac{1}{2}$ ft.
- Now using Rayleigh's criterion, calculate the minimum separation of objects on the clock face that you could distinguish with the naked eye. Assume that the visible light you use has a wavelength of 500 nm. How does your calculated separation compare with Prof. Bowen's estimate of the actual separation between lines (5 cm)?

E39: Bendy Light. Load up your fiber optics flashlight toy (Galaxy Wand) with the two little AA batteries (this may already be done). Turn it on and notice how the cool colors of light come out the ends of the fibers but not out the sides. Take one of the fibers and bend it until it kinks. Some of the light in that kinked fiber will then escape. Why does it escape? Why doesn't it escape if you make smooth curves in the fiber rather than a kink? Justify your answer with the Law of Refraction and with sketches of the geometry of the fiber.

E40: Something Fishy. A beam of un-polarized light is allowed to pass through a fish tank filled with cloudy water while students in the audience view the beam scattered from the water (see figure). The incident beam caused charges in the water to oscillate, thereby emitting scattered electromagnetic radiation traveling towards the student. Describe, from the student's point of view, the direction of polarization of the light scattered into the student's eye from the tank. Explain your reasoning.



Overhead view



Student's View

E41: Volcano Sunset. After the eruption of Mt. St. Helen's in Washington state, thousands of tons (if not more!) of tiny dust and ash particles were thrown into the sky. For months afterwards, people in the Pacific Northwest noticed that the sunsets were particularly red. Explain why this happened.

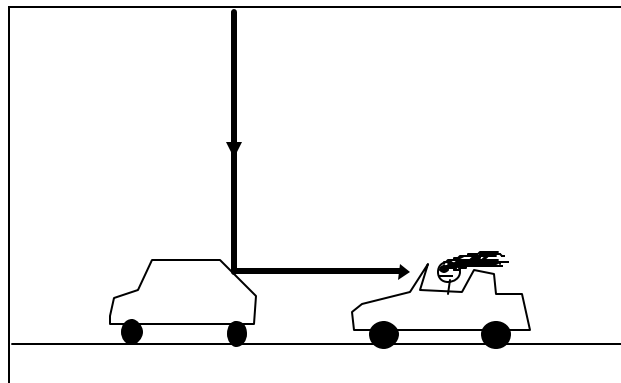
E42: Danger, Will Robinson? There is a lot of attention these days to the possible hazards of "electromagnetic fields", sometimes called "EMF" for short. The idea here is that the radiation emitted from common alternating current (AC) power transmission lines could be causing increased cases of cancer.

- Considering the fact that common AC current oscillates with a frequency of 60 Hz, what is the energy (in eV) of the photons associated with EMF from AC power?
- Considering the fact that the weakest molecular bonds have an energy of approximately 0.1 eV, why do you think there is substantial skepticism in the scientific community about claims of cancer dangers from EMF?

Note: some people have proposed other theories of how electromagnetic fields could cause cancer without breaking molecular bonds (i.e., without relying on the accepted theories of how electromagnetic radiation causes cancer), but none of those theories have yet been verified by laboratory experiments.

E43: Particle Properties of a Wave. Here's how to experience some particle properties of a wave. Hook your magic spring to something moveable but not breakable - like the leg of a light chair, a shoe, or a friend's hand. Now stretch the spring to about six feet. Fold a piece of paper and balance it on top of the spring. Send a single pulse from your end to the other. Do you see any delivery of momentum and energy from the wave pulse to the object at the far end? Explain briefly what aspect(s) of this demonstration is(are) indicative of the spring wave's particle properties (if any).

E44: Polarizing Sunglasses. You are driving on a highway, and the sun is reflecting into your eyes from the car in front of you (a representative ray of sunlight is shown in the diagram). This doesn't bother you, however, because you are wearing specially-made-for-this-situation-polarizing sunglasses, which cut down significantly on the reflected light. Use the re-radiation model to determine the optimal polarization direction of your sunglasses (i.e., the direction of the electric field oscillations that are allowed to pass through), and explain your reasoning.



E45: Color Table. Fill in the following table. Colors actually extend over a range of wavelength, frequencies, energy and momentum; for example violet light extends from approximately 400 nm to 440 nm. However, for this problem, a single frequency for each color has been selected.

Color	Wavelength (m)	Frequency (Hz)	Energy (J)	Momentum (kg m/s)
Red	7×10^{-7}			
Orange		5×10^{14}		
Green			3.96×10^{-19}	
Violet				1.65×10^{-27}

E46: Two-Slit Interference with Light "Particles". Consider the interference pattern made on a distant screen by monochromatic light passing through two adjacent slits. How can you interpret the "maxima" and "minima" of the interference pattern when you consider light to be a collection of photons? (In other words, what can you say about photons hitting the screen at maxima? At minima?)

E47: Microscope Limit. Could a light microscope be used to examine a 10 nm long virus? Why not? If you use an electron microscope to examine this virus, what would be the minimum speed for the electrons? (Assume that to examine the virus, you need to see structures as small as 1 nm, and consider the wavelength of a moving electron.)