Physics 123, Spring 2009
Homework #3
Due in P123 homework locker 4pm, Friday, February 13, 2009

Feel free to discuss the problems with me and/or each other. Each student must write up his/her own solutions separately.
Unless otherwise indicated, problems are from Giancoli, 4th edition.

1. Giancoli, chapter 31, question 9: Are the wavelengths of radio and television signals longer or shorter than those detectable by the human eye?

   Note: If you don't have a copy of volume II of Giancoli, you can find the following problems on the appended pages.

2. Giancoli, chapter 31, problem 16, page 833. *This problem is in the lower half of page 833.*
3. Giancoli, chapter 31, problem 18, page 833. *This problem is in the lower half of page 833.*
4. Giancoli, chapter 31, problem 63, page 836.
5. Giancoli, chapter 32, problem 3, page 860.
6. Giancoli, chapter 32, problem 4, page 860.
7. Giancoli, chapter 32, problem 5, page 860.

10. What does the wavelength calculated in Example 31–2 tell you about the phase of a 60-Hz ac current that starts at a power plant as compared to its phase at a house 200 km away?
11. When you connect two loudspeakers to the output of a stereo amplifier, should you be sure the lead wires are equal in length so that there will not be a time lag between speakers? Explain.
12. In the electromagnetic spectrum, what type of EM wave would have a wavelength of 10^3 km; 1 km; 1 m; 1 cm; 1 mm; 1 μm?
13. Can radio waves have the same frequencies as sound waves (20 Hz–20,000 Hz)?
14. Discuss how cordless telephones make use of EM waves. What about cellular telephones?
15. Can two radio or TV stations broadcast on the same carrier frequency? Explain.
16. If a radio transmitter has a vertical antenna, should a receiver's antenna (rod type) be vertical or horizontal to obtain best reception?
17. The carrier frequencies of FM broadcasts are much higher than for AM broadcasts. On the basis of what you learned about diffraction in Chapter 15, explain why AM signals can be detected more readily than FM signals behind low hills or buildings.
18. A lost person may signal by flashing a flashlight on and off using Morse code. This is actually a modulated EM wave. Is it AM or FM? What is the frequency of the carrier, approximately?

Problems

31–1 $\vec{\mathbf{B}}$ Produced by Changing $\vec{\mathbf{E}}$

1. (I) Determine the rate at which the electric field changes between the round plates of a capacitor, 6.0 cm in diameter, if the plates are spaced 1.1 mm apart and the voltage across them is changing at a rate of 120 V/s.
2. (I) Calculate the displacement current I_D between the square plates, 5.8 cm on a side, of a capacitor if the electric field is changing at a rate of 2.0×10^6 V/m·s.
3. (II) At a given instant, a 2.8-A current flows in the wires connected to a parallel-plate capacitor. What is the rate at which the electric field is changing between the plates if the square plates are 1.60 cm on a side?
4. (II) A 1500-nF capacitor with circular parallel plates 2.0 cm in diameter is accumulating charge at the rate of 38.0 mC/s at some instant in time. What will be the induced magnetic field strength 10.0 cm radially outward from the center of the plates? What will be the value of the field strength after the capacitor is fully charged?
5. (II) Show that the displacement current through a parallel-plate capacitor can be written $I_D = C\,dV/dt$, where V is the voltage across the capacitor at any instant.
6. (II) Suppose an air-gap capacitor has circular plates of radius $R = 2.5$ cm and separation $d = 1.6$ mm. A 76.0-Hz emf, $\mathscr{E} = \mathscr{E}_0 \cos \omega t$, is applied to the capacitor. The maximum displacement current is 35 μA. Determine (*a*) the maximum conduction current I, (*b*) the value of $\mathscr{E}_0$, (*c*) the maximum value of $d\Phi_E/dt$ between the plates. Neglect fringing.
7. (III) Suppose that a circular parallel-plate capacitor has radius $R_0 = 3.0$ cm and plate separation $d = 5.0$ mm. A sinusoidal potential difference $V = V_0 \sin(2\pi f t)$ is applied across the plates, where $V_0 = 150$ V and $f = 60$ Hz. (*a*) In the region between the plates, show that the magnitude of the induced magnetic field is given by $B = B_0(R)\cos(2\pi f t)$, where R is the radial distance from the capacitor's central axis. (*b*) Determine the expression for the amplitude $B_0(R)$ of this time-dependent (sinusoidal) field when $R \leq R_0$, and when $R > R_0$. (*c*) Plot $B_0(R)$ in tesla for the range $0 \leq R \leq 10$ cm.

31–5 EM Waves

8. (I) If the electric field in an EM wave has a peak magnitude of 0.57×10^{-4} V/m, what is the peak magnitude of the magnetic field strength?
9. (I) If the magnetic field in a traveling EM wave has a peak magnitude of 12.5 nT, what is the peak magnitude of the electric field?
10. (I) In an EM wave traveling west, the B field oscillates vertically and has a frequency of 80.0 kHz and an rms strength of 7.75×10^{-9} T. Determine the frequency and rms strength of the electric field. What is its direction?
11. (II) The electric field of a plane EM wave is given by $E_x = E_0 \cos(kz + \omega t)$, $E_y = E_z = 0$. Determine (*a*) the direction of propagation and (*b*) the magnitude and direction of $\vec{\mathbf{B}}$.
12. (III) Consider two possible candidates $E(x, t)$ as solutions of the wave equation for an EM wave's electric field. Let A and α be constants. Show that (*a*) $E(x, t) = Ae^{-\alpha(x-vt)^2}$ satisfies the wave equation, and that (*b*) $E(x, t) = Ae^{-(\alpha x^2 - vt)}$ does not satisfy the wave equation.

31–6 Electromagnetic Spectrum

13. (I) What is the frequency of a microwave whose wavelength is 1.50 cm?
14. (I) (*a*) What is the wavelength of a 25.75×10^9 Hz radar signal? (*b*) What is the frequency of an X-ray with wavelength 0.12 nm?
15. (I) How long does it take light to reach us from the Sun, 1.50×10^8 km away?
16. (I) An EM wave has frequency 8.56×10^{14} Hz. What is its wavelength, and how would we classify it?
17. (I) Electromagnetic waves and sound waves can have the same frequency. (*a*) What is the wavelength of a 1.00-kHz electromagnetic wave? (*b*) What is the wavelength of a 1.00-kHz sound wave? (The speed of sound in air is 341 m/s.) (*c*) Can you hear a 1.00-kHz electromagnetic wave?
18. (II) Pulsed lasers used for science and medicine produce very brief bursts of electromagnetic energy. If the laser light wavelength is 1062 nm (Neodymium–YAG laser), and the pulse lasts for 38 picoseconds, how many wavelengths are found within the laser pulse? How brief would the pulse need to be to fit only one wavelength?
19. (II) How long would it take a message sent as radio waves from Earth to reach Mars (*a*) when nearest Earth, (*b*) when farthest from Earth?
20. (II) An electromagnetic wave has an electric field given by
$$\vec{\mathbf{E}} = \hat{\mathbf{i}}(225\ \text{V/m})\sin[(0.077\ \text{m}^{-1})z - (2.3 \times 10^7\ \text{rad/s})t].$$
(*a*) What are the wavelength and frequency of the wave? (*b*) Write down an expression for the magnetic field.

57. What is the maximum power level of a radio station so as to avoid electrical breakdown of air at a distance of 0.50 m from the transmitting antenna? Assume the antenna is a point source. Air breaks down in an electric field of about 3×10^6 V/m.

58. In free space ("vacuum"), where the net charge and current flow is zero, the speed of an EM wave is given by $v = 1/\sqrt{\epsilon_0 \mu_0}$. If, instead, an EM wave travels in a nonconducting ("dielectric") material with dielectric constant K, then $v = 1/\sqrt{K\epsilon_0 \mu_0}$. For frequencies corresponding to the visible spectrum (near 5×10^{14} Hz), the dielectric constant of water is 1.77. Predict the speed of light in water and compare this value (as a percentage) with the speed of light in a vacuum.

59. The metal walls of a microwave oven form a cavity of dimensions 37 cm × 37 cm × 20 cm. When 2.45-GHz microwaves are continuously introduced into this cavity, reflection of incident waves from the walls set up standing waves with nodes at the walls. Along the 37-cm dimension of the oven, how many nodes exist (excluding the nodes at the wall) and what is the distance between adjacent nodes? [Because no heating occurs at these nodes, most microwaves rotate food while operating.]

60. Imagine that a steady current I flows in a straight cylindrical wire of radius R_0 and resistivity ρ. (*a*) If the current is then changed at a rate dI/dt, show that a displacement current I_D exists in the wire of magnitude $\epsilon_0 \rho(dI/dt)$. (*b*) If the current in a copper wire is changed at the rate of 1.0 A/ms, determine the magnitude of I_D. (*c*) Determine the magnitude of the magnetic field B_D (T) created by I_D at the surface of a copper wire with $R_0 = 1.0$ mm. Compare (as a ratio) B_D with the field created at the surface of the wire by a steady current of 1.0 A.

61. The electric field of an EM wave pulse traveling along the x axis in free space is given by $E_y = E_0 \exp[-\alpha^2 x^2 - \beta^2 t^2 + 2\alpha\beta x t]$, where E_0, α, and β are positive constants. (*a*) Is the pulse moving in the $+x$ or $-x$ direction? (*b*) Express β in terms of α and c (speed of light in free space). (*c*) Determine the expression for the magnetic field of this EM wave.

62. Suppose that a right-moving EM wave overlaps with a left-moving EM wave so that, in a certain region of space, the total electric field in the y direction and magnetic field in the z direction are given by $E_y = E_0 \sin(kx - \omega t) + E_0 \sin(kx + \omega t)$ and $B_z = B_0 \sin(kx - \omega t) - B_0 \sin(kx + \omega t)$. (*a*) Find the mathematical expression that represents the standing electric and magnetic waves in the y and z directions, respectively. (*b*) Determine the Poynting vector and find the x locations at which it is zero at all times.

63. The electric and magnetic fields of a certain EM wave in free space are given by $\vec{\mathbf{E}} = E_0 \sin(kx - \omega t)\hat{\mathbf{j}} + E_0 \cos(kx - \omega t)\hat{\mathbf{k}}$ and $\vec{\mathbf{B}} = B_0 \cos(kx - \omega t)\hat{\mathbf{j}} - B_0 \sin(kx - \omega t)\hat{\mathbf{k}}$. (*a*) Show that $\vec{\mathbf{E}}$ and $\vec{\mathbf{B}}$ are perpendicular to each other at all times. (*b*) For this wave, $\vec{\mathbf{E}}$ and $\vec{\mathbf{B}}$ are in a plane parallel to the yz plane. Show that the wave moves in a direction perpendicular to both $\vec{\mathbf{E}}$ and $\vec{\mathbf{B}}$. (*c*) At any arbitrary choice of position x and time t, show that the magnitudes of $\vec{\mathbf{E}}$ and $\vec{\mathbf{B}}$ always equal E_0 and B_0, respectively. (*d*) At $x = 0$, draw the orientation of $\vec{\mathbf{E}}$ and $\vec{\mathbf{B}}$ in the yz plane at $t = 0$. Then qualitatively describe the motion of these vectors in the yz plane as time increases. [Note: The EM wave in this Problem is "circularly polarized."]

Answers to Exercises

A: (*c*).

B: (*b*).

C: (*a*) 3.8×10^6 Hz; (*b*) 5.5×10^{18} Hz.

D: 45 cm.

E: Yes; the signal still travels 72,000 km.

F: Over 4 hours.

Problems

32–2 Reflection; Plane Mirrors

1. (I) When you look at yourself in a 60-cm-tall plane mirror, you see the same amount of your body whether you are close to the mirror or far away. (Try it and see.) Use ray diagrams to show why this should be true.

2. (I) Suppose that you want to take a photograph of yourself as you look at your image in a mirror 2.8 m away. For what distance should the camera lens be focused?

3. (II) Two plane mirrors meet at a 135° angle, Fig. 32–45. If light rays strike one mirror at 38° as shown, at what angle ϕ do they leave the second mirror?

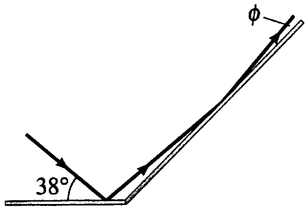

FIGURE 32–45
Problem 3.

4. (II) A person whose eyes are 1.64 m above the floor stands 2.30 m in front of a vertical plane mirror whose bottom edge is 38 cm above the floor, Fig. 32–46. What is the horizontal distance x to the base of the wall supporting the mirror of the nearest point on the floor that can be seen reflected in the mirror?

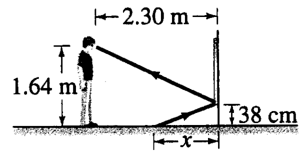

FIGURE 32–46
Problem 4.

5. (II) Show that if two plane mirrors meet at an angle ϕ, a single ray reflected successively from both mirrors is deflected through an angle of 2ϕ independent of the incident angle. Assume $\phi < 90°$ and that only two reflections, one from each mirror, take place.

6. (II) Suppose you are 88 cm from a plane mirror. What area of the mirror is used to reflect the rays entering one eye from a point on the tip of your nose if your pupil diameter is 4.5 mm?

7. (II) Stand up two plane mirrors so they form a 90.0° angle as in Fig. 32–47. When you look into this double mirror, you see yourself as others see you, instead of reversed as in a single mirror. Make a ray diagram to show how this occurs.

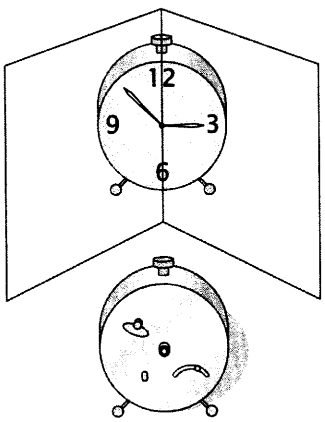

FIGURE 32–47
Problems 7 and 8.

8. (III) Suppose a third mirror is placed beneath the two shown in Fig. 32–47, so that all three are perpendicular to each other. (*a*) Show that for such a "corner reflector," any incident ray will return in its original direction after three reflections. (*b*) What happens if it makes only two reflections?

32–3 Spherical Mirrors

9. (I) A solar cooker, really a concave mirror pointed at the Sun, focuses the Sun's rays 18.8 cm in front of the mirror. What is the radius of the spherical surface from which the mirror was made?

10. (I) How far from a concave mirror (radius 24.0 cm) must an object be placed if its image is to be at infinity?

11. (I) When walking toward a concave mirror you notice that the image flips at a distance of 0.50 m. What is the radius of curvature of the mirror?

12. (II) A small candle is 35 cm from a concave mirror having a radius of curvature of 24 cm. (*a*) What is the focal length of the mirror? (*b*) Where will the image of the candle be located? (*c*) Will the image be upright or inverted?

13. (II) You look at yourself in a shiny 9.2-cm-diameter Christmas tree ball. If your face is 25.0 cm away from the ball's front surface, where is your image? Is it real or virtual? Is it upright or inverted?

14. (II) A mirror at an amusement park shows an upright image of any person who stands 1.7 m in front of it. If the image is three times the person's height, what is the radius of curvature of the mirror? (See Fig. 32–44.)

15. (II) A dentist wants a small mirror that, when 2.00 cm from a tooth, will produce a 4.0× upright image. What kind of mirror must be used and what must its radius of curvature be?

16. (II) Some rearview mirrors produce images of cars to your rear that are smaller than they would be if the mirror were flat. Are the mirrors concave or convex? What is a mirror's radius of curvature if cars 18.0 m away appear 0.33 their normal size?

17. (II) You are standing 3.0 m from a convex security mirror in a store. You estimate the height of your image to be half of your actual height. Estimate the radius of curvature of the mirror.

18. (II) An object 3.0 mm high is placed 18 cm from a convex mirror of radius of curvature 18 cm. (*a*) Show by ray tracing that the image is virtual, and estimate the image distance. (*b*) Show that the (negative) image distance can be computed from Eq. 32–2 using a focal length of −9.0 cm. (*c*) Compute the image size, using Eq. 32–3.

19. (II) The image of a distant tree is virtual and very small when viewed in a curved mirror. The image appears to be 16.0 cm behind the mirror. What kind of mirror is it, and what is its radius of curvature?

20. (II) Use two techniques, (*a*) a ray diagram, and (*b*) the mirror equation, to show that the magnitude of the magnification of a concave mirror is less than 1 if the object is beyond the center of curvature C $(d_o > r)$, and is greater than 1 if the object is within C $(d_o < r)$.

21. (II) Show, using a ray diagram, that the magnification m of a convex mirror is $m = -d_i/d_o$, just as for a concave mirror. [*Hint*: Consider a ray from the top of the object that reflects at the center of the mirror.]

22. (II) Use ray diagrams to show that the mirror equation, Eq. 32–2, is valid for a convex mirror as long as f is considered negative.

23. (II) The magnification of a convex mirror is +0.55× for objects 3.2 m from the mirror. What is the focal length of this mirror?