Seat Number ____________

PHYSICS 112 - SPRING 2004 - EXAM 3

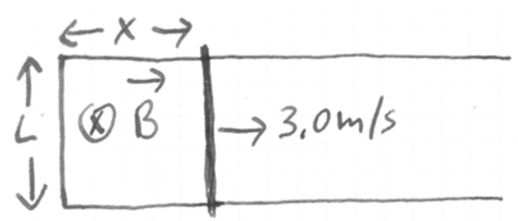
Name: ____ Recitation Section Number: ______

NO CALCULATORS ALLOWED - BUT, LUCKILY, NO CALCULATORS NEEDED.

SHOW YOUR WORK! Full credit will be given only if you explain how you arrived at your answer. Either show your work (especially in a calculation) or give a short explanation. Nothing elaborate is required, but the grader must be able to follow your reasoning clearly.

---

1. A metal bar rests on metal rails having a large U-shaped piece, as shown. The width between the parallel rails is $L = 0.50$ m. The bar is being pulled to the right with speed 3.0 m/s through a uniform magnetic field of magnitude 0.40 T directed down ($\otimes$). At the instant when the bar is at a distance $x = 2.0$ m from the endpiece of the rails, the circuit including the metal bar has resistance $R = 20\ \Omega$. Determine at that instant:



(a) [2 points] The magnitude of the magnetic flux through the circuit.

(b) [2 points] The rate of change of the magnitude of the magnetic flux

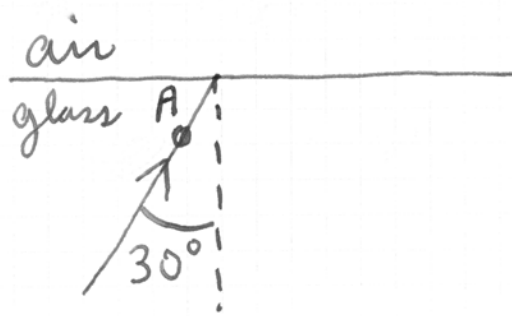
(c) [2 points] The magnitude of the induced electric current

(d) [2 points] The direction of the induced electric current *through the bar*

(e) [2 points] Suppose the magnetic field in this problem had been directed up ($\otimes$) instead of down. Which answer(s) (a)-(d), if any, would have been different, and how?

2. As shown in the diagram below, an electromagnetic wave of wavelength 1.0 μm traveling through glass with an index of refraction of 1.40 is incident at an angle $\theta = 30°$ at an interface with air ($n = 1.00$).

Possibly useful information: $\cos 0° = 1 = \sin 90°$; $\cos 30° = 0.9 = \sin 60°$; $\cos 45° = 0.7 = \sin 45°$; $\sin 30° = 0.5 = \cos 60°$; $\sin 0° = 0 = \cos 90°$.



(a) [2 points] What is the speed of the wave in the glass?

(b) [2 points] What is the frequency of this wave?

(c) [2 points] At an instant when the electric field of the incident wave is directed up out of the plane ($\odot$), what is the direction of the magnetic field of the wave at that point at that time (show it on the diagram at the point marked A)?

(d) [5 points] Sketch the reflected and refracted rays and determine the angles they make with the normal to the interface at the point where the wave strikes it.

(e) [2 points] What is the speed of the refracted wave?

(f) [1 point] What is the frequency of the refracted wave?

3. An object is located on the principal axis of a convergent lens at a a distance of 6.0 cm from the lens. The focal points of the lens are on either side of the lens at a distance of 12.0 cm.

(a) [5 points] Sketch a diagram of this system below, placing the object on the left side. (The principal axis is shown, together with the focal points and the vertex of the lens). Then draw three different rays that permit you to locate the image formed by the lens.

-------------------------------F------------------------v------------------------F-----------------------------

(b) [3 points] Characterize the image (real or virtual, orientation, size relative to object).

(c) [4 points] Use the lens equation to determine the image distance and magnification (including their correct signs!).

(d) Check that your results in (c) agree with your characterization of the image in (b). Do they? (If not, find your error!)

(e) [4 points] If the object is moved closer to the lens, will the image move to the left or right? Explain how you know this.

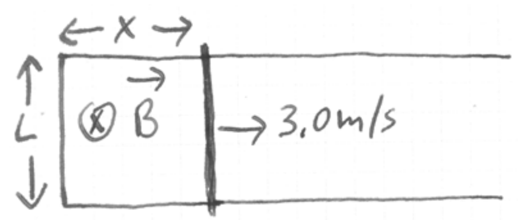
PHYSICS 112 - SPRING 2004 - EXAM 3 - PROBLEMS WITH SOLUTIONS

NO CALCULATORS ALLOWED - BUT, LUCKILY, NO CALCULATORS NEEDED.

SHOW YOUR WORK! Full credit will be given only if you explain how you arrived at your answer. Either show your work (especially in a calculation) or give a short explanation. Nothing elaborate is required, but the grader must be able to follow your reasoning clearly.

---

1. A metal bar rests on metal rails having a large U-shaped piece, as shown. The width between the parallel rails is $L = 0.50$ m. The bar is being pulled to the right with speed 3.0 m/s through a uniform magnetic field of magnitude 0.40 T directed down (⊗). At the instant when the bar is at a distance $x = 2.0$ m from the endpiece of the rails, the circuit including the metal bar has resistance $R = 20\ \Omega$. Determine at that instant:



(a) [2 points] The magnitude of the magnetic flux through the circuit.

$$\Phi = BA\cos\theta = BLx\cos\theta = (0.40\text{ T})(0.50\text{ m})(2.0\text{ m})(\cos 0°) = 0.40\text{ T}\cdot\text{m}^2.$$

(b) [2 points] The rate of change of the magnitude of the magnetic flux

The only factor in Φ that is changing is x, so

$$\Delta\Phi/\Delta t = BL(\Delta x/\Delta t)\theta = BLv\theta = (0.40\text{ T})(0.50\text{ m})(3.0\text{ m/s})(\cos 0°) = 0.60\text{ V}.$$

This can also be found by recognizing that $\Phi = 0$ at $t = 0$, the time when the bar is at the far left, and that $t = (2.0\text{ m})/(3.0\text{ m/s}) = (2/3)$ s at the time when $\Phi = 0.40\text{ T}\cdot\text{m}^2$, so that

$$\Delta\Phi/\Delta t = (\Phi_\text{f} - \Phi_\text{i})/\Delta t = (0.40\text{ T}\cdot\text{m}^2)/(2/3)\text{ s} = 0.60\text{ V}.$$

(c) [2 points] The magnitude of the induced electric current

$$I = (\Delta\Phi/\Delta t)/R = (0.60\text{ V})/(20\ \Omega) = 0.03\text{ A}.$$

(d) [2 points] The direction of the induced electric current *through the bar*

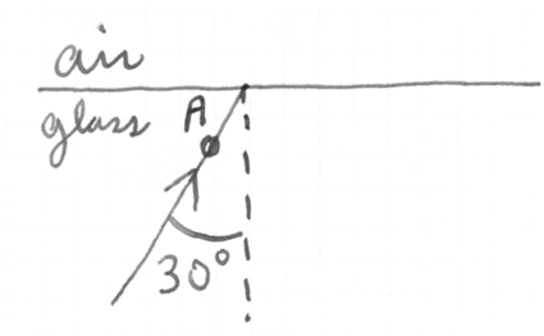
The magnetic field is down (⊗) and the flux is increasing, so the induced magnetic field of the circuit must be up (⊙) to counteract the decrease, so the current is counterclockwise, and the induced current in the bar is directed up the bar.

(e) [2 points] Suppose the magnetic field in this problem had been directed up (⊙) instead of down. Which answer(s) (a)-(d), if any, would have been different, and how?

Only (d) would have been different: the current would have been in the opposite direction.

2. As shown in the diagram below, an electromagnetic wave of wavelength 1.0 μm traveling through glass with an index of refraction of 1.40 is incident at an angle $\theta = 30°$ at an interface with air ($n = 1.00$).

Possibly useful information: cos 0° = 1 = sin 90°; cos 30° = 0.9 = sin 60° ; cos 45° = 0.7 = sin 45° ; sin 30° = 0.5 = cos 60°; sin 0° = 0 = cos 90°.



(a) [2 points] What is the speed of the wave in the glass?

$v = c/n = (3.0 \times 10^8 \text{ ms/})/(1.50) = 2.0 \times 10^8$ m/s.

(b) [2 points] What is the frequency of this wave?

$f = v/\lambda = (2.0 \times 10^8 \text{ m/s})/(1.0 \times 10^6 \text{ m}) = 2.0 \times 10^{14}$ Hz.

(c) [2 points] At an instant when the electric field of the incident wave is directed up out of the plane (⊙), what is the direction of the magnetic field of the wave at that point at that time (show it on the diagram at the point marked A)?

Using the right-hand-rule, with the electric field up (⊙) and the direction of propagation directed up and to the right on the diagram, the magnetic field would have been directed down and to the right.

(d) [5 points] Sketch the reflected and refracted rays and determine the angles they make with the normal to the interface at the point where the wave strikes it.

The angle of reflection equals the angle of incidence (30°), and the angle of refraction θ_2 is found by Snell's law:

$n_2 \sin \theta_2 = n_1 \sin \theta_1$ so $(1.00)(\sin \theta_2) = (1.40)\ (\sin 30°)$ and

$\sin \theta_2 = (1.40)(0.50) = 0.7$, corresponding to $\theta_2 = 45°$

(e) [2 points] What is the speed of the refracted wave?

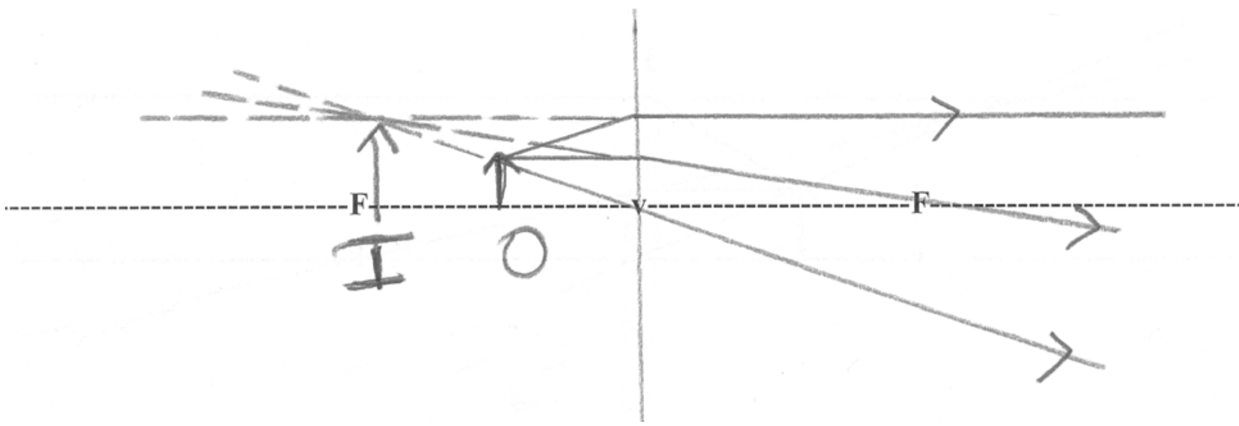
The refracted ray is in air, so its speed is $v = c/n = c/1.00 = c = 3.00 \times 10^8$ m/s

(f) [1 point] What is the frequency of the refracted wave?

It will be the same as the frequency of the incident wave, 2.0×10^{14} Hz.

3. An object is located on the principal axis of a convergent lens at a a distance of 6.0 cm from the lens. The focal points of the lens are on either side of the lens at a distance of 12.0 cm.

(a) [5 points] Sketch a diagram of this system below, placing the object on the left side. (The principal axis is shown, together with the focal points and the vertex of the lens). Then draw three different rays that permit you to locate the image formed by the lens.



(b) [3 points] Characterize the image (real or virtual, orientation, size relative to object).

The image is virtual, erect, and about twice as large as the object.

(c) [4 points] Use the lens equation to determine the image distance and magnification (including their correct signs!).

Using the lens equation $1/i + 1/o = 1/f$, recognizing that for a convergent lens $f > 0$,

$1/i = 1/f - 1/o = 1/(12\,\text{cm}) - 1/(6\text{ cm}) = (1-2)/(12\text{ cm}) = -1/(12\text{ cm})$

so $i = -12$ cm

and $m = -i/o = -(-12\text{ cm})/(6\text{ cm}) = +2.$

(d) Check that your results in (c) agree with your characterization of the image in (b). Do they? (If not, find your error!)

Yes, they agree.

(e) [4 points] If the object is moved closer to the lens, will the image move to the left or right? Explain how you know this.

From $1/i = 1/f - 1/o$ we can see that moving the object closer makes o smaller and $1/o$ larger, so $1/i$ will become a larger negative number and i will become a smaller in magnitude (a smaller but still negative number). This can also be determined by changing the ray traces.

What would happen to the magnification? This is harder to determine, since $m = -i/o$ and both i and o have become smaller. But if we solve the lens equation for i to get

$i = fo/(o-f)$ then $m = -i/o = -f/(o-f) = f/(f-o)$ and we can see that as o (which is less than f) becomes smaller, the denominator becomes larger so m becomes smaller.