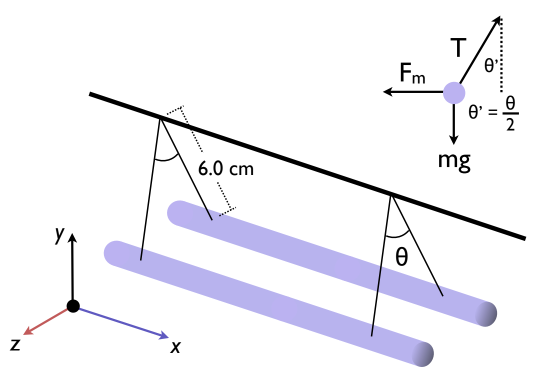
Name Date

PH 102 Exam II

20Mar07 LeClair

INSTRUCTIONS

1. **Solve 8 problems out of the 12 below.** All problems have equal weight.
2. Clearly mark the problems you choose by filling in the adjacent circle.
3. **Show as much work as possible for partial credit.**
4. Solve the problems on separate sheets. Staple your sheets to the exam when finished.



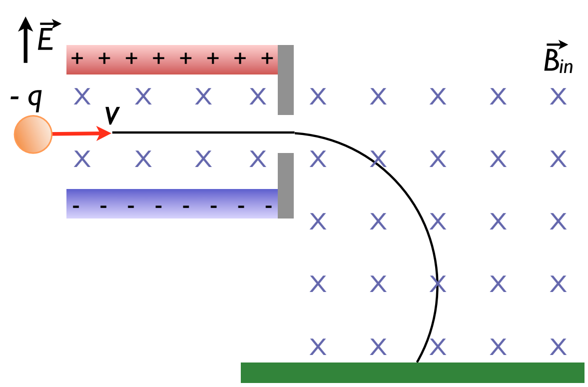
○ **1**. Two long parallel wires, each with a mass per unit length of $\lambda = m/l = 0.040\,\text{kg/m}$, are supported in a horizontal plane by 6.0 cm strings, as shown at left. Each wire carries the same current I, causing the wires to repel one another, which causes the supporting strings to make an angle $\theta = 16°$ with one another.

Are the currents in the same direction or opposing? Find the magnitude of each current.

Hint: consider the free-body diagram for one of the wires in the upper right. If a wire has mass m and length l, $\lambda = m/l$.

○ **2**. Sodium ions (Na^+) move at 0.85 m/s through a bloodstream in the arm of a person standing near a large magnet. The magnetic field has a strength of $|\vec{\mathbf{B}}| = 1.2\,\text{T}$ and makes an angle of 73° with the motion of the sodium ions. The arm contains $120\,\text{cm}^3$ of blood, with 3.0×10^{20} Na^+ ions per cubic centimeter.

If no other ions were present in the arm, what would be the magnetic force on the arm?



○ **3**. Consider the mass spectrometer shown at left. The electric field between the plates of the velocity selector is $|\vec{\mathbf{E}}| = 1000\,\text{V/m}$, and the magnetic fields in both the velocity selector and the deflection chamber have magnitudes of 1.0 T.

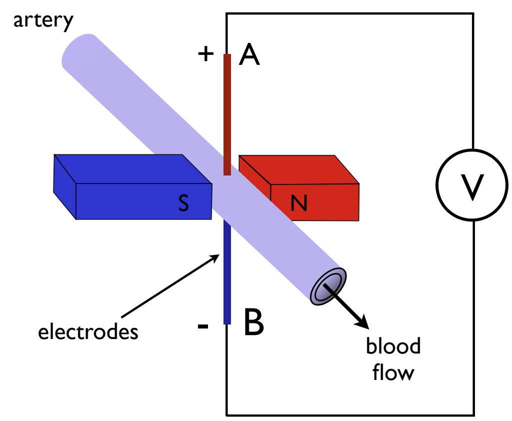
Calculate the *radius* of the circular path in the deflection chamber for a singly charged ion with mass $m = 7.3 \times 10^{-26}\,\text{kg}$ (corresponding to CO_2).

○ **4**. Assume that the Sun delivers an average power ($\mathscr{P}$) per unit area (A) of about $\mathcal{I} \equiv \mathscr{P}/A = 1.00 \times 10^3\,\text{W/m}^2$ to Earth's surface.

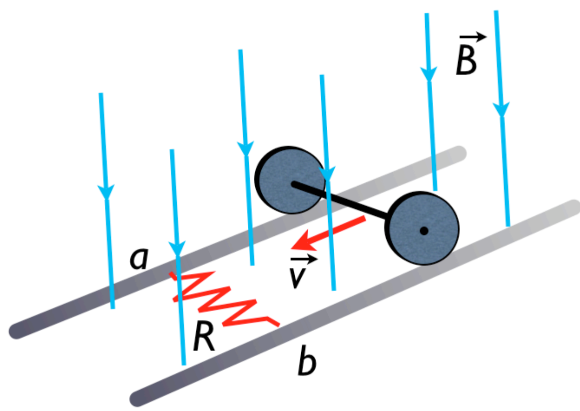
(a) Calculate the total power incident on a flat tin roof 7.17 m by 21.1 m. Assume that the radiation is incident normal (perpendicular) to the roof.

(b) Calculate the peak electric and magnetic fields of the light.

◯ **5**. Using an electromagnetic flowmeter (see figure), a heart surgeon monitors the flow rate of blood through an artery. Electrodes A and B make contact with the outer surface of the blood vessel, which has inside **diameter** 3.2 mm. Permanent magnets outside the blood vessel create a magnetic field perpendicular to the blood flow direction. For a magnetic field strength of $|\vec{\mathbf{B}}| = 0.037\,\mathrm{T}$, a potential difference of $\Delta V = 160\,\mu\mathrm{V}$ appears between the electrodes.



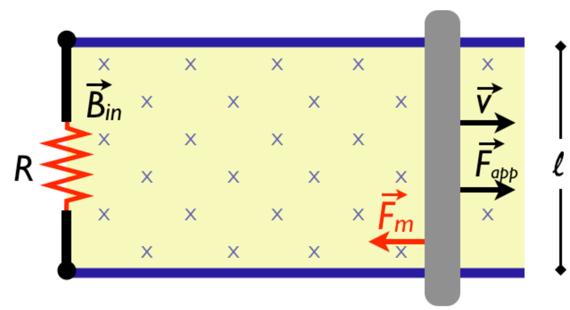
(a) Calculate the speed of the blood.
(b) Does the sign of the potential difference depend on whether the mobile ions in the blood are predominantly positively or negatively charged?



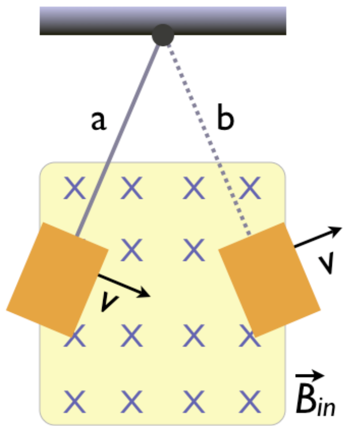
◯ **6**. In the figure, the rolling axle, 1.50 m long, is pushed along horizontal rails at a constant speed $|\vec{\mathbf{v}}| = 4.00\,\mathrm{m/s}$. A resistor $R = 0.4\,\Omega$ is connected to the rails at points a and b, directly opposite each other. (The wheels make good electrical contact with the rails, so the axle, rails, and R form a closed-loop circuit. The only significant resistance in the circuit is R.) A uniform magnetic field $|\vec{\mathbf{B}}| = 0.1500\,\mathrm{T}$ is directed vertically downwards.

(a) Find the induced current I in the resistor.
(b) What horizontal force (magnitude **and** direction) is required to keep the axle rolling at constant speed? *Hint: ignore everything but the axle.*

◯ **7**. A conducting rod of length l moves on two (frictionless) horizontal rails, as shown to the right. A constant force of magnitude $|\vec{\mathbf{F}}_{\mathrm{app}}| = 1.0\,\mathrm{N}$ moves the bar at a uniform speed of $|\vec{\mathbf{v}}| = 2.0\,\mathrm{m/s}$ through a magnetic field $\vec{\mathbf{B}}$ directed into the page. The resistor has a value $R = 8.0\,\Omega$.



(a) What is the current through the resistor R?
(b) What is the mechanical power delivered by the constant force?

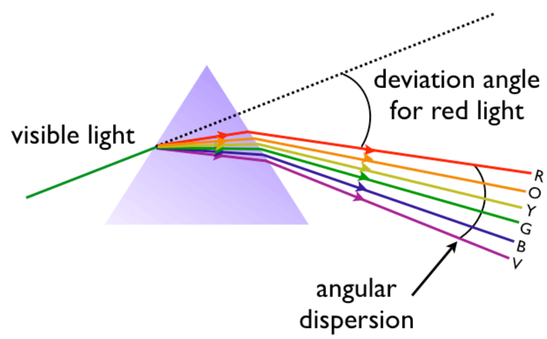


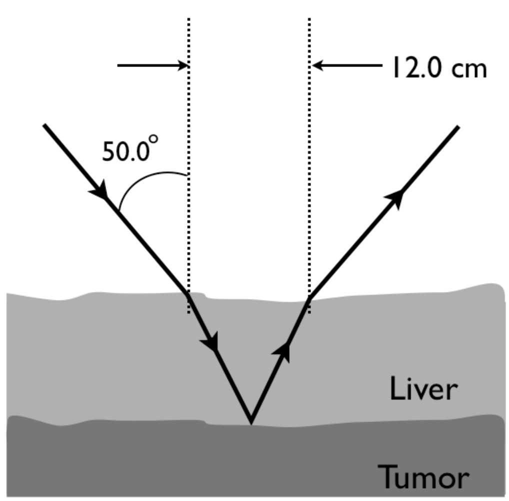
◯ **8**. Consider the flat metal plate swinging at the end of a bar as a pendulum, as shown at left. At position **a**, the pendulum is moving from a region where there is no magnetic field into a region where the field in is directed into the paper.

Find the direction of circulation of the eddy current and the direction of the force (relative to $\vec{\mathbf{v}}$) at **both** positions **a** and **b**.

◯ **9**. The index of refraction for **violet** light in silica flint glass is $n_{\text{violet}} = 1.66$, and for **red** light it is $n_{\text{red}} = 1.62$. In air, $n = 1$ for both colors of light.

What is the **angular dispersion** of visible light (the angle between red and violet) passing through an equilateral triangle prism of silica flint glass, if the angle of incidence is 50°? Recall that all angles in an equilateral triangle are 60°.





◯ **10**. A narrow beam of ultrasonic waves reflects off the liver tumor in the figure at left.

If the speed of the wave is 15.0% less in the liver than in the surrounding medium, determine the depth of the tumor.

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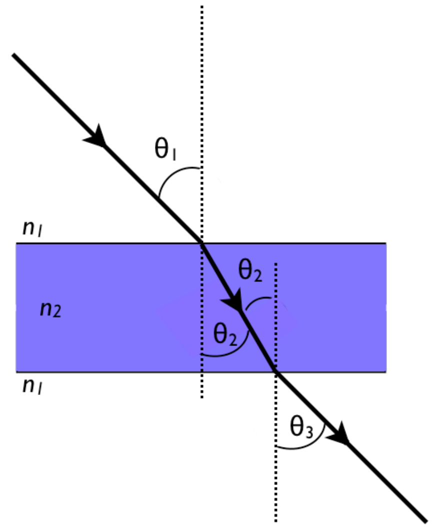
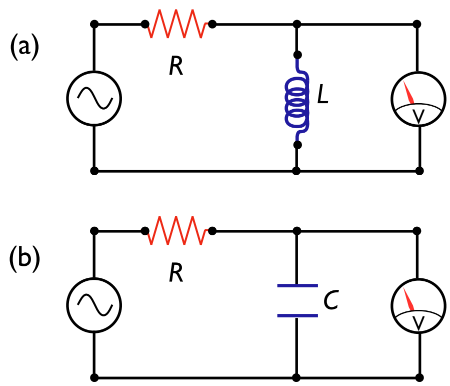
◯ **11**. A light beam traveling through a transparent medium of index of refraction n_1 passes through a thick transparent slab with parallel faces and an index of refraction n_2.

Find the angle θ_3 in terms of (at most) θ_1, n_1, and n_2. Detailed calculation is not necessary if you have a solid physical argument.





◯ **12**. A variable-frequency ac voltage source(circles with sine waves inside) is hooked up to **(a)** a resistor R and an inductor L, and **(b)** a resistor R and a capacitor C. The resistor is the same in both cases. A voltmeter monitors the voltage on the inductor in circuit **(a)**, and on the capacitor in circuit **(b)**.

Make a *rough* sketch of the relative voltage read by the meter as a function of the source frequency in each case (V versus f). Identify which one of these circuits the voltmeter preferentially reads low frequencies ("low-pass filter"), and which one the voltmeter preferentially reads high frequencies ("high-pass filter").

Hint: how does each component respond to high and low frequencies? Which one(s) dislike fast changes in voltage, which one(s) like it, and which one(s) don't care?

BONUS (worth $\frac{1}{2}$ a normal question): During an in-class demonstration, we dropped a magnet and a non-magnet of equal weight and size through a copper tube. The non-magnet fell through the tube at the expected rate, but the non-magnet took many times longer to fall out, due to eddy current braking.

Is it possible to have a magnet strong enough (or a tube conductive enough, *etc*) that it would actually *stop* inside the tube? Explain.

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Useful Things

Constants:

$$
\begin{aligned}
\mu_0 &\equiv 4\pi \times 10^{-7}\,\mathrm{T \cdot m/A} \\
e &= 1.602 \times 10^{-19}\,\mathrm{C} \\
\epsilon_0 &= 8.85 \times 10^{12}\,\mathrm{C^2/N \cdot m^2} \\
c &= \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 2.99792 \times 10^8\,\mathrm{m/s} \\
h &= 6.63 \times 10^{-34}\,\mathrm{J \cdot s} \\
m_{e^-} &= 9.11 \times 10^{-31}\,\mathrm{kg} \\
m_{p^+} &= 1.67 \times 10^{-27}\,\mathrm{kg}
\end{aligned}
$$

Magnetism

$$
\begin{aligned}
|\vec{\mathbf{F}}_B| &= q|\vec{\mathbf{v}}||\vec{\mathbf{B}}|\sin\theta_{vB} \ \text{ charge } q \\
|\vec{\mathbf{F}}_B| &= BIl\sin\theta \ \text{ wire} \\
|\vec{\tau}| &= BIAN\sin\theta \ \text{ torque current loop} \\
\vec{\mathbf{B}} &= \frac{\mu_0 I}{2\pi r}\,\hat{\theta} \ \text{ wire} \\
\vec{\mathbf{B}} &= \mu_0 \frac{N}{L} I\,\hat{\mathbf{z}} \equiv \mu_0 n I\,\hat{\mathbf{z}} \ \text{ solenoid} \\
\frac{|\vec{\mathbf{F}}_{12}|}{l} &= \frac{\mu_0 I_1 I_2}{2\pi d} \ \text{ 2 wires, force per length}
\end{aligned}
$$

Electricity

$$
\begin{aligned}
\vec{\mathbf{F}}_E &= q\vec{\mathbf{E}} \\
\tau &= RC \ \text{ time const} \\
\Delta V &= IR \\
\mathscr{P} &= I^2 R = IV \ \text{ power}
\end{aligned}
$$

Induction:

$$
\begin{aligned}
\Phi_B &= B_\perp A = BA\cos\theta_{BA} \\
\boldsymbol{\mathcal{E}} &= -N\frac{\Delta\Phi_B}{\Delta t} \\
L &= N\frac{\Delta\Phi_B}{\Delta I} = \frac{N\Phi_B}{I} \\
\Delta V &= |\vec{\mathbf{v}}||\vec{\mathbf{B}}|l = |\vec{\mathbf{E}}|l \ \text{ motional } \boldsymbol{\mathcal{E}}
\end{aligned}
$$

Quadratic formula:

$$
\begin{aligned}
ax^2 &+ bx^2 + c = 0 \\
x &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}
\end{aligned}
$$

Basic Equations:

$$
\begin{aligned}
\vec{\mathbf{F}}_{\text{net}} &= m\vec{\mathbf{a}} \ \text{ Newton's Second Law} \\
\vec{\mathbf{F}}_{\text{centr}} &= \frac{mv^2}{r} \\
\text{KE} &= \frac{1}{2}mv^2 \ \text{ Kinetic energy} \\
\text{KE}_{\text{initial}} + \text{PE}_{\text{initial}} &= \text{KE}_{\text{final}} + \text{PE}_{\text{final}}
\end{aligned}
$$

Optics:

$$
\begin{aligned}
\mathscr{E} &= hf = \frac{hc}{\lambda} \\
n &= \frac{\text{speed of light in vacuum}}{\text{speed of light in a medium}} = \frac{c}{v} \\
\frac{\lambda_1}{\lambda_2} &= \frac{v_1}{v_2} = \frac{c/n_1}{c/n_2} = \frac{n_2}{n_1} \ \text{ refraction} \\
\lambda_1 n_1 &= \lambda_2 n_2 \ \text{ refraction} \\
n_1 \sin\theta_1 &= n_2 \sin\theta_2 \ \text{ Snell's refraction} \\
n_1 \sin\theta_c &= n_2 \sin 90^\circ = n_2 \ \text{ total internal refl.}
\end{aligned}
$$

ac Circuits

$$
\begin{aligned}
\tau &= L/R \ \text{ RL circuit} \\
X_C &= \frac{1}{2\pi f C} \ \text{ "resistance" of a capacitor for ac} \\
X_L &= 2\pi f L \ \text{ "resistance" of an inductor for a} \\
X_R &= R \ \text{ "resistance" of a resistor for ac}
\end{aligned}
$$

EM Waves:

$$
\begin{aligned}
c &= \lambda f \\
c &= \frac{|\vec{\mathbf{E}}|}{|\vec{\mathbf{B}}|} \\
\mathcal{I} &= \frac{\text{energy}}{\text{time} \cdot \text{area}} = \frac{E_{\max} B_{\max}}{2\mu_0} = \frac{\text{power } (\mathscr{P})}{\text{area}} = \frac{E_{\max}^2}{2\mu_0 c}
\end{aligned}
$$

$\uparrow$ radiation intensity

Right-hand rule # 1 (2 equivalent versions): $\vec{\mathbf{F}}$, $\vec{\mathbf{B}}$, and $\vec{\mathbf{v}}$

1. point your right fingers along velocity.
2. point your right thumb along $\vec{\mathbf{B}}$.
3. magnetic force for $+q$ points out from the back of your hand.

1. Point your fingers in the direction of $\vec{\mathbf{v}}$.
2. Curl your fingers in the direction of $\vec{\mathbf{B}}$, moving through the smallest angle.
3. Your thumb now points in the direction of the magnetic force for a positive charge.

Right-hand rule #2: $\vec{\mathbf{B}}$ and I for wires

1. Right thumb along wire, in direction of I.
2. Your fingers naturally curl around $\vec{\mathbf{B}}$
3. $\vec{\mathbf{B}}$ circulates around the wire.

Right-hand rule #3 for plane EM waves:

1. Point your right-hand fingers along $\vec{\mathbf{E}}$.
2. Curl them along the direction of $\vec{\mathbf{B}}$.
3. Thumb gives the wave traveling direction.