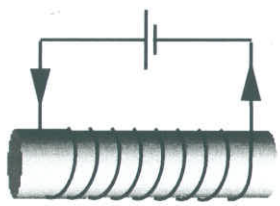
Physical Constants:
proton charge $= e = 1.60 \times 10^{-19}$ C
permittivity $= \epsilon_0 = 8.854 \times 10^{-12}\ \mathrm{C^2/(N \cdot m^2)}$
permeability $= \mu_0 = 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}$

Unless otherwise stated, select the letter of the single best answer. Each question is worth 1 point.

1. N turns of wire are wrapped around a cylinder of length ℓ and radius r forming a solenoid. The wire carries a current I in the direction shown. How many of the below statements are correct about this situation.



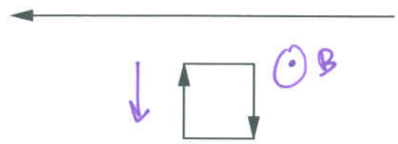
- The magnetic field inside the solenoid points to the left.
- If the solenoid is "long" (i.e., $\ell \gg r$) the magnetic field outside the solenoid is nearly zero.
- If the solenoid is "long" (i.e., $\ell \gg r$) the magnetic field in the center of the solenoid does not depend on r.
- If the solenoid is "short" (i.e., really a coil with $\ell \ll r$) the magnetic field in the center of the solenoid depends inversely on r.

A. one
B. two
C. three
D. four

2. Long straight wires 1 and 2 each carry identical currents flowing perpendicularly out of this page (⊙), as shown in the diagram. In what direction does the magnetic field point at position P?

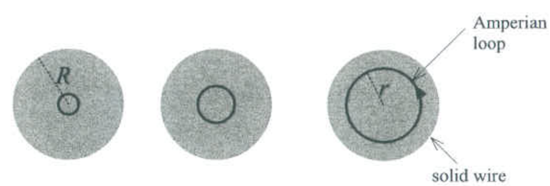
A. Toward the bottom of this page
B. Toward the top of this page
C. Left
D. Right

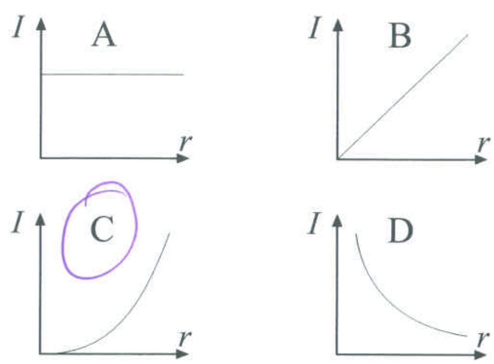
3. As shown below, there is a current flowing clockwise around a square loop and also a current flowing to the left through a long straight wire that sits above the square. (The square loop and the wire sit in the plane of this sheet of paper.) The net force on the square points



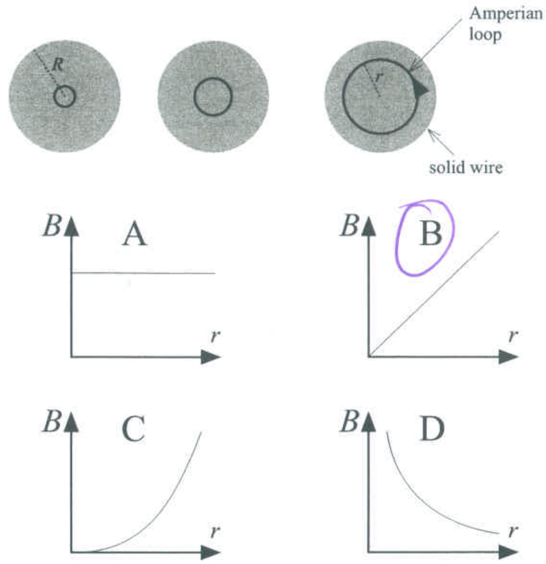
A. down the page
B. to the right
C. out of the page
D. up the page

4. The below figure shows, in cross section, three identical long solid cylindrical wires of radius R carrying a current distributed uniformly throughout the cross section. Three Amperian loops are also shown; The three loops have differing radius r (but: $r < R$). What is the magnitude of the current I enclosed by these loops as a function of r? Which of the below plots best displays the relationship between I and r?

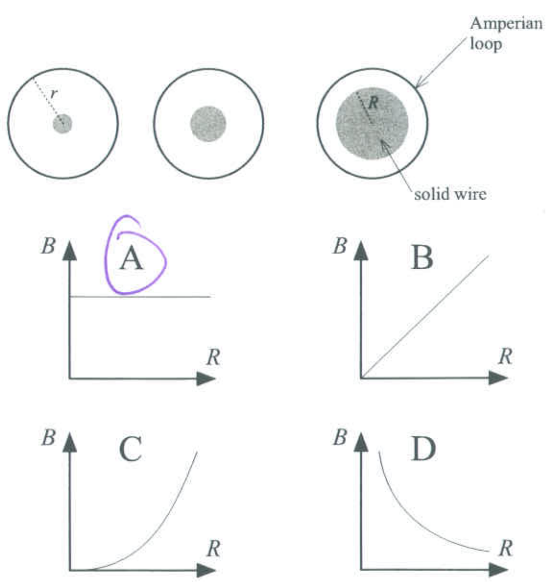




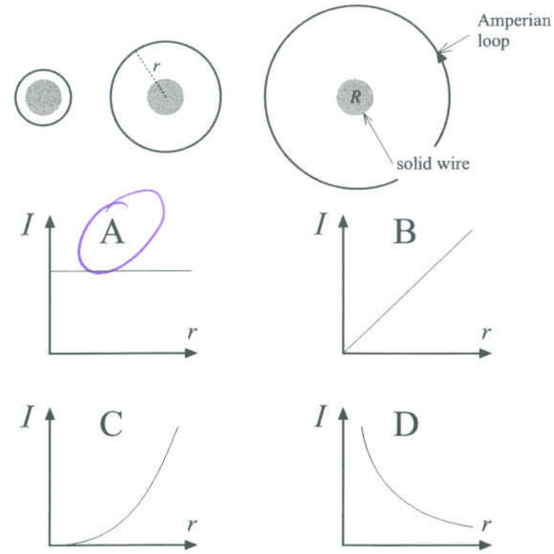
5. In the situation of the previous problem, which of the below plots best displays the relationship between the magnetic field B and r (for $r < R$)?



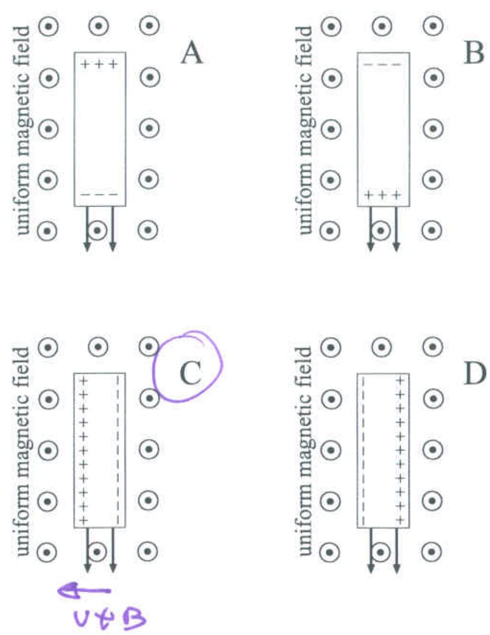
6. The below figure shows, in cross section, three long solid cylindrical wires with increasing radius R. Each wire carries the same total current distributed uniformly throughout the cross section. Three identical Amperian loops are also shown with $r > R$. What is the magnitude of the magnetic field B at these loops as a function of R? Which of the below plots best displays the relationship between B and R?



7. The below figure shows, in cross section, three identical solid cylindrical wires of radius R carrying the same current distributed uniformly throughout the cross section. Three Amperian loops are also shown; The three loops have differing radius r (but: $r > R$). What is the magnitude of the current I enclosed by these loops as a function of r? Which of the below plots best displays the relationship between I and r?



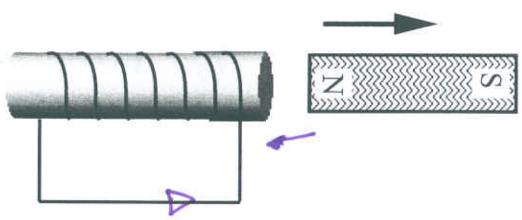
8. A copper bar moves to down this page in a region where the magnetic field points out of this page. Because of the bar's motion, the electrons in the copper will experience a magnetic force and will redistribute themselves producing parts of the bar with net charge. Which picture best displays how the charge becomes redistributed?



9. A long straight wire and a square loop of wire sit in the plane of this sheet of paper. For several minutes there has been no current flowing in any wire. A battery (not shown) is connected and a current starts to flow to the left through the long straight wire. In what direction will current induced in the square flow?

A. clockwise
B. counter-clockwise

10. The north pole of a bar magnet is moving to the right, away from a solenoid. What induced current will be found in the straight horizontal wire attached to the solenoid? The induced current in the straight horizontal wire flows:



C. to the right
D. to the left

11. One of Maxwell's Equations states:

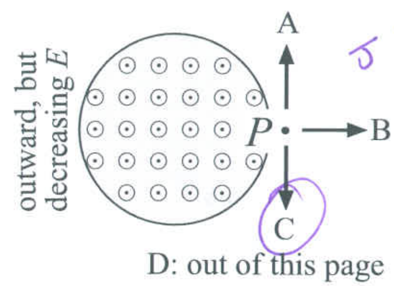
$$\oint \vec{\mathbf{B}} \cdot d\vec{\ell} = \mu_0 \left(I_{\text{encl}} + \epsilon_0 \frac{d\Phi_E}{dt} \right)$$

In terms of units this equation is:

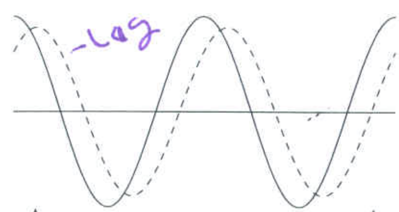
A. $\text{T} = (\text{T} \cdot \text{m/A})\left(\text{A} + (\text{C}^2/\text{N} \cdot \text{m}^2)\text{N} \cdot \text{m/C} \cdot \text{s}\right)$
B. $\text{N/A} = (\text{T} \cdot \text{m/A})\left(\text{A} + (\text{C}^2/\text{N} \cdot \text{m}^2)\text{V} \cdot \text{m/s}\right)$
C. $\text{T} \cdot \text{m} = (\text{T} \cdot \text{m/A})\left(\text{A} + (\text{C}^2/\text{N} \cdot \text{m}^2)\text{N/C} \cdot \text{s}\right)$
D. $\text{T} \cdot \text{m}^2 = (\text{T} \cdot \text{m/A})\left(\text{A} + (\text{C}^2/\text{N} \cdot \text{m}^2)\text{V} \cdot \text{m/s}\right)$

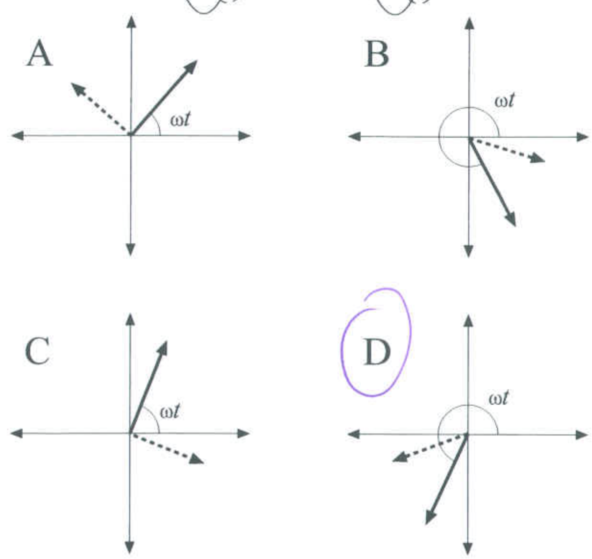
$T = \frac{N}{A \cdot m}$ $\Phi = \frac{V}{m} \cdot m^2$

12. Consider a point P on the edge of a parallel plate capacitor made of two disks. Between the plates of the capacitor (as shown below, the actual plates of the capacitor would be a bit above and below this sheet of paper) the electric field points out of this page, but the strength of the electric field is decreasing (because the capacitor is discharging). What is the direction of the magnetic field (caused by the displacement current, due to the changing $\vec{\mathbf{E}}$) at the point P?

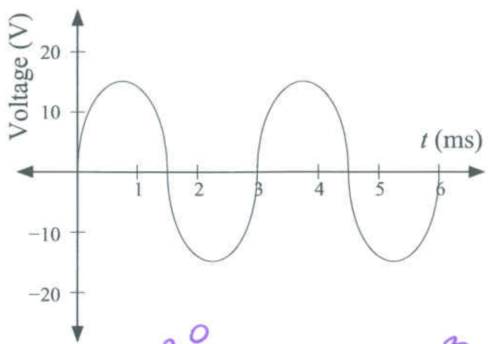


13. Much like an oscilloscope, the below plot displays two voltages (solid and dotted) as a function of time. Which of the below phasor pairs is consistent with this plot?





14. The below plot—similar to that of an oscilloscope—displays voltage vs. time. Such signals may be characterized by the rms voltage ($V_{\rm rms}$), the peak-to-peak voltage ($V_{\rm pp}$), the period (T), and the angular frequency (ω). Which of the below is a good estimate of one of these quantities?

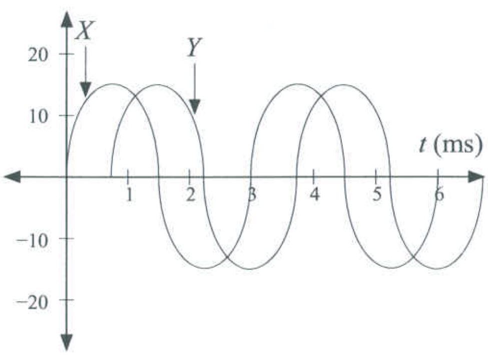


~30 ~.003

A. $V_{\rm pp} = 3$ V C. $T = .0015$ s

B. $V_{\rm rms} = 7$ V ~10 D. $\omega = 2000$ rad/s $\frac{2\pi}{.003} = 2100$

15. The below figure shows two sinusoidally varying plots: X and Y. Which combination of the below statements is correct.



✓ I. X leads Y

II. X lags Y ELI

✓ III. If this figure displays the signals of an inductor, X is the voltage across the inductor and Y is the current through the inductor.

IV. If this figure displays the signals of a capacitor, X is the voltage across the capacitor and Y is the current through the capacitor.

A. II, III C. I, III

B. II, IV D. I, IV

Complete four (4) of the following five (5) problems (10 points each)

16. Define the following words:

A. Diamagnetism

atomic $\vec{\mu}$ anti alligned with applied $\vec{B}$

B. Paramagnetism

existing atomic $\vec{\mu}$ alligns with $\vec{B}$; perturbations by thermal motions disrupt that allignment

C. Ferromagnetism

atomic $\vec{\mu}$s fully alligned in microscopic regions called domains. Large resulting M with applied $\vec{B}$

D. Hysteresis

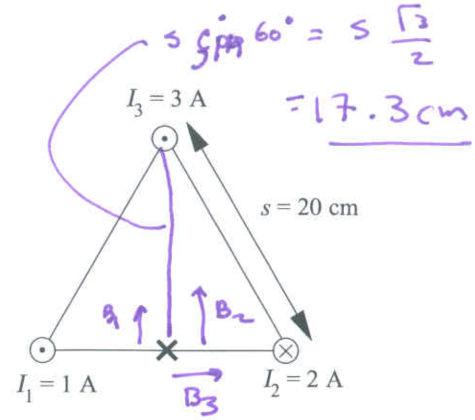
$\vec{M}$ "sticks" so history of $\vec{B}$ required to know $\vec{M}$ not just current value of $\vec{B}$

E. Magnetization

$M = \frac{\Sigma \vec{\mu}}{\text{volume}}$ ← sum of atomic magnetic dipoles

$= \frac{\text{net } \vec{\mu}}{\text{volume}}$

16. As shown in the diagram, three long parallel wires run perpendicular to this sheet of paper and pierce this sheet at the vertices an equilateral triangle with side 20 cm. The currents I_1 and I_3 come directly out of this page; I_2 goes into the page. Find the magnitude of the magnetic field vector at the spot marked with an X (i.e., the midpoint of the horizontal segment).



single line: $B = \frac{\mu_0 I}{2\pi r}$

$B_1 = \frac{\mu_0 \cdot 1}{2\pi(.1)} = 2 \times 10^{-6}\ T$ ~~$= B_2$~~ $\quad B_2 = \frac{\mu_0 \cdot 2}{2\pi(.1)} = 4 \times 10^{-6}\ T$

$B_3 = \frac{\mu_0\, 3}{2\pi(.173)} = \frac{2\times10^{-7} \cdot 3}{(.173)} = 3.47 \times 10^{-6}\ T$

$\vec{B} = B_3\,\hat{i} + (B_1 + B_2)\,\hat{j} = (3.47\,\hat{i} + 6\,\hat{j}) \times 10^{-6}\ T$

$|\vec{B}| = \sqrt{(3.47)^2 + 6^2} \times 10^{-6} = 6.93 \times 10^{-6}\ T$

17. An electron moves in a uniform magnetic field $\vec{\mathbf{B}}$. (No other forces are present.)

A. If the velocity of the electron is $\vec{\mathbf{v}} = (2\hat{\mathbf{i}} + 3\hat{\mathbf{j}} + 4\hat{\mathbf{k}})$ m/s and the magnetic field is $\vec{\mathbf{B}} = (5\hat{\mathbf{i}} + 7\hat{\mathbf{j}} + 13\hat{\mathbf{k}})$ T, find the magnetic force vector on the electron.

B. Describe in words the future trajectory of the electron.

$\vec{F} = q\vec{v} \times \vec{B}$

$q \rightarrow -e = -1.6 \times 10^{-19}$

$$\vec{v} \times \vec{B} = \begin{vmatrix} i & j & k \\ 2 & 3 & 4 \\ 5 & 7 & 13 \end{vmatrix}$$

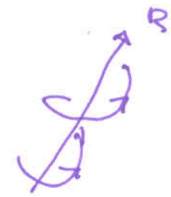
$$= \hat{i}(3 \cdot 13 - 4 \cdot 7) + \hat{j}(4 \cdot 5 - 2 \cdot 13) + \hat{k}(2 \cdot 7 - 3 \cdot 5)$$

$$= 11\hat{i} - 6\hat{j} - 1\hat{k}$$

$$\vec{F} = -1.6 \times 10^{-19}(11\hat{i} - 6\hat{j} - 1\hat{k})$$

$$= (-1.76\hat{i} + .96\hat{j} + .16\hat{k}) \times 10^{-18}\ \text{N}$$

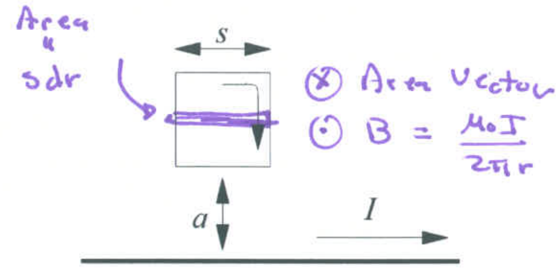
B) spiral around direction of $\vec{B}$



18. Consider an infinite straight wire placed a distance a away from a square wire loop (with side s).

A. If the straight wire carries a current I, what is the magnetic flux through the square (please include the *sign* of the flux).

B. If the straight-wire current is uniformly increasing in time ($I = kt$), what emf is induced in the square? In which direction would the square's current flow (please draw a picture showing current direction)?



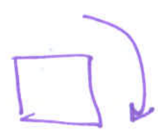
Since $\vec{B}$ & $\overrightarrow{Area}$ are antiparallel $\Phi < 0$

$$d\Phi = -\frac{\mu_0 I}{2\pi} s \frac{dr}{r}$$

$$\Phi = \frac{-\mu_0 I s}{2\pi} \int_a^{a+s} \frac{dr}{r} = \frac{-\mu_0 I s}{2\pi} \left[\ln(a+s) - \ln(a) \right]$$

$$= \frac{-\mu_0 I s}{2\pi} \ln\left(\frac{a+s}{a}\right)$$

$$\mathcal{E} = \frac{-d\Phi}{dt} = \frac{\mu_0 \frac{dI}{dt} s}{2\pi} \ln\left(\frac{a+s}{a}\right) = \frac{\mu_0 k s}{2\pi} \ln\left(\frac{a+s}{a}\right)$$

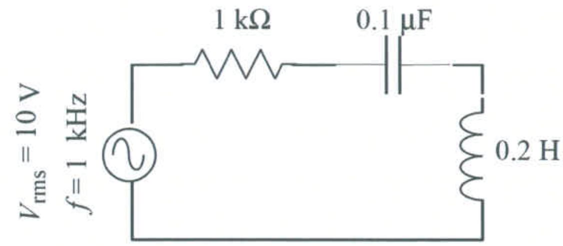


19. Currents and voltages (rms) are to be measured in the circuit shown with digital multimeters (DMM).

   A. Redraw this circuit and show how the DMM ammeter should be placed to measure current. What current value will the ammeter read?

   B. Redraw this circuit and show how the DMM voltmeter should be placed to measure the voltage across the inductor. What voltage value will the voltmeter read?

   C. What voltage would the voltmeter find across the capacitor?



$\omega = 2\pi \times 10^3$

$X_C = \frac{1}{\omega C} = 1.592\ k\Omega$

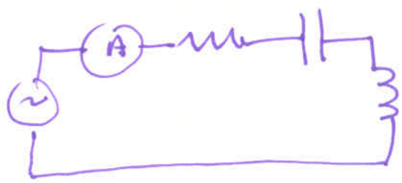
$X_L = \omega L = 1.257\ k\Omega$

$X_C - X_L = 335\ \Omega$

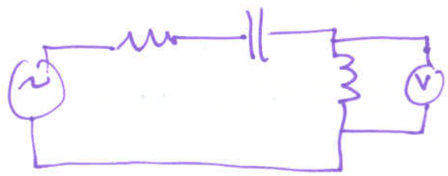
$Z = \sqrt{R^2 + (X_C - X_L)^2}$

$= \sqrt{1000^2 + 335^2} = 1.055\ k\Omega$

A) $I = \frac{V}{Z} = \frac{10}{1055} = 9.48\ mA$



B) $V_L = I X_L = (9.48 \times 10^{-3})(1.257 \times 10^3) = 11.9\ V$



C) $V_C = I X_C = (9.48 \times 10^{-3})(1.592 \times 10^3) = 15.1\ V$

When finished: insert your formula sheet inside this booklet, make sure your name is on the front cover, and place the resulting packet in the pile at the front of the classroom. Failure to include your formula sheet will result in lost points!