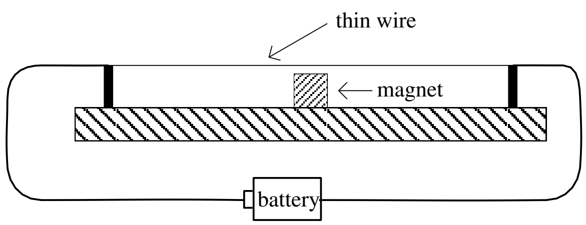
Rules: textbook YES; any other aid NO

Physical Constants:
proton charge $= e = 1.60 \times 10^{-19}$ C
permeability $= \mu_0 = 4\pi \times 10^{-7}$ T $\cdot$ m/A

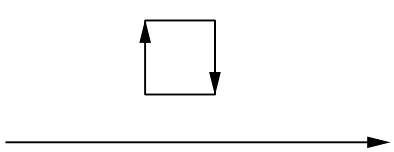
Unless otherwise stated, select the letter of the single best answer. Each question is worth 1 point.

1. The picture below shows a device very similar to one used in class. A battery drives a current through a thin wire which is suspended above a magnet. When the battery is connected the thin wire moves out of the page. What sort of pole is the top of the magnet?



   A. N
   B. S
   C. E
   D. W

2. There is a current flowing clockwise around a square loop and also a current flowing to the right through a long straight wire that sits below the square. (The square loop and the wire sit in the plane of this sheet of paper as shown in the below figure.) The net force on the square points

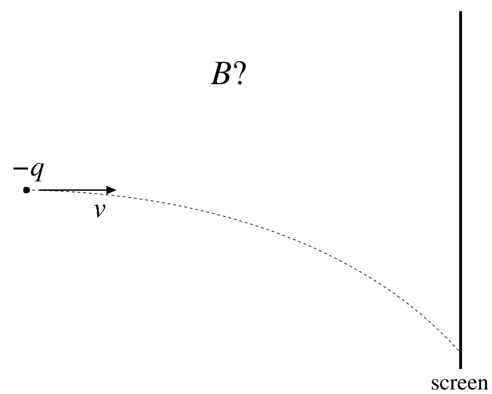


   A. down the page
   B. to the right
   C. out of the page
   D. up the page

3. With the situation as in the previous problem: Which way does the magnetic dipole of the square loop point and is it in a stable or unstable situation?

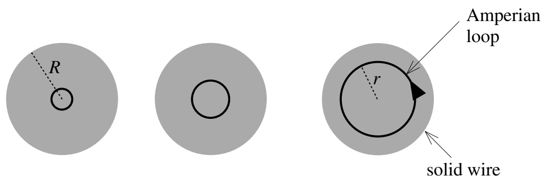
   A. out of this page, stable
   B. out of this page, unstable
   C. into this page, stable
   D. into this page, unstable

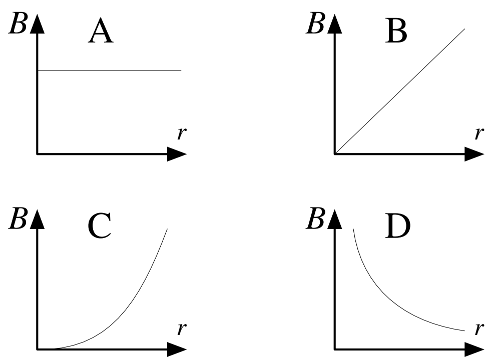
4. An electron moves horizontally toward a screen. The electron moves along the dotted path because of a magnetic force caused by a magnetic field. In what direction does that magnetic field point?



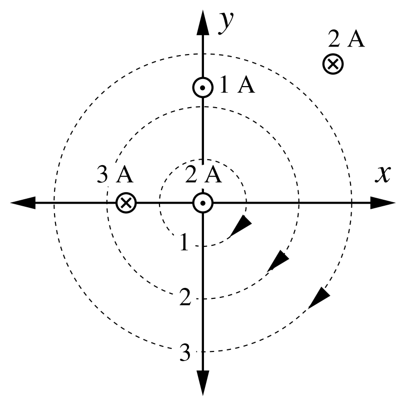
   A. Toward the top of this page
   B. Toward the bottom of this page
   C. Into this page
   D. Out of this page

5. The below figure shows, in cross section, three identical long solid cylindrical wires of radius R carrying a uniform current density J. Three Amperian loops are also shown; The three loops have differing radius r (but: $r < R$). 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?





6. The below figure shows where four infinitely long wires parallel to the z axis intersect the xy plane. The current in each wire is listed along with the flow direction: $\odot$ = out of page, $\otimes$ = into page. Consider various amperian loop integrals ($\mathcal{L} = \oint \vec{\mathbf{B}} \cdot d\vec{\boldsymbol{\ell}}$) along three circles centered on the origin with radii as shown in the figure. Which of the below options best describes the relationship between the integrals. ($\mathcal{L}_1$ denotes the loop integral for circle 1, etc. Negative numbers are smaller than any positive number.)



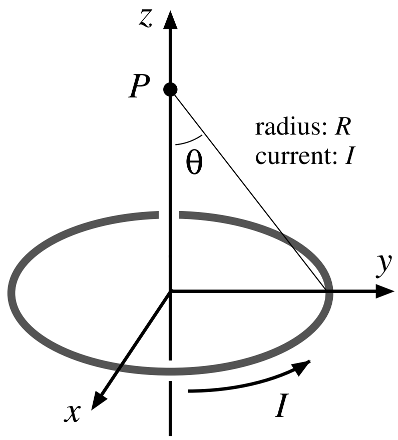
A. $\mathcal{L}_1 > \mathcal{L}_3 > \mathcal{L}_2$

B. $\mathcal{L}_1 > \mathcal{L}_2 > \mathcal{L}_3$

C. $\mathcal{L}_2 > \mathcal{L}_3 > \mathcal{L}_1$

D. $\mathcal{L}_3 > \mathcal{L}_2 > \mathcal{L}_1$

7. A current I flows around a circle (radius R) that sits in the xy plane with its center at the origin. Consider the problem of finding the magnitude of the magnetic field, B, directly above the center, i.e., on the z axis at a point $P = (0, 0, z)$.



A. Since all of the current elements are the same distance from P:

$$B = \frac{\mu_0 I 2\pi R}{4\pi(R^2 + z^2)}$$

B. Since $d\vec{\boldsymbol{\ell}} \times \hat{\mathbf{r}} = d\ell \sin\theta$

$$B = \frac{\mu_0 I 2\pi R \sin\theta}{4\pi(R^2 + z^2)}$$

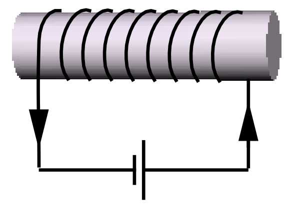
C. Since the net B field is in the z direction we need to include the angle:

$$B = \frac{\mu_0 I 2\pi R}{4\pi(R^2 + z^2)} \sin\theta$$

D. Since the net B field is in the z direction we need to include the angle:

$$B = \frac{\mu_0 I 2\pi R}{4\pi(R^2 + z^2)} \cos\theta$$

8. 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. Select the most complete combination of correct statements about this situation.



I. The magnetic field inside the solenoid points to the left.

II. Starting at the center of the solenoid and moving to the right along the axis of the solenoid, the magnetic field gradually diminishes, but always points in the same direction.

III. The magnetic field in the center of the solenoid is proportional to I.

IV. If the solenoid is "long" (i.e., $L \gg r$) the magnetic field in the center of the solenoid is proportional to N/L.

V. If the solenoid is "long" (i.e., $L \gg r$) the magnetic field in the center of the solenoid is inversely proportional to r^2.

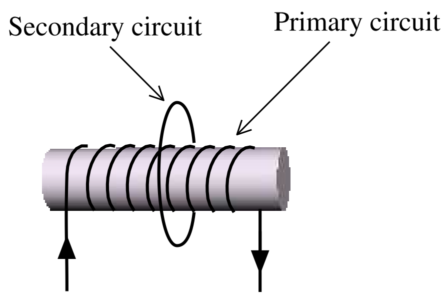
A. I, III

B. II, III, IV

C. III, IV, V

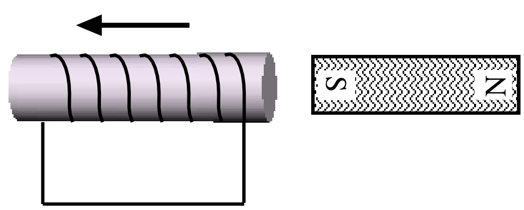
D. I, II, III, IV, V

9. The first circuit consists of a "primary" wrapped around a cylinder and a single-loop "secondary". The current in the primary started at zero but now an ever increasing current is flowing in the direction indicated. What current will be induced in the secondary? At the top of the secondary loop the induced current is flowing:



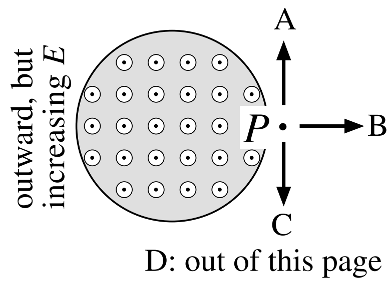
A. out of the page
B. into the page

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



A. to the right
B. to the left

11. 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, and the strength of the electric field is increasing. What is the direction of the magnetic field (caused by the displacement current, due to the changing $\vec{E}$) at the point P?



12. One of Maxwell's Equations states:

$$\oint \vec{\mathbf{E}} \cdot d\vec{\boldsymbol{\ell}} = -\frac{d\Phi_B}{dt}$$

In terms of units this equation is:

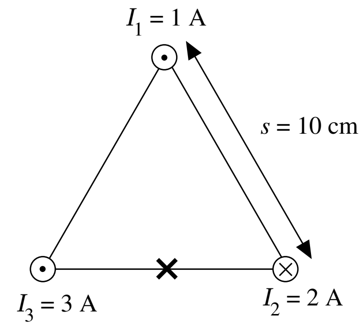
A. $\mathrm{N/C} = \mathrm{T} \cdot \mathrm{m}^2/\mathrm{s}$
B. $\mathrm{J/C} = \mathrm{Wb}$
C. $\mathrm{N} \cdot \mathrm{m/C} = \mathrm{T} \cdot \mathrm{m}^2/\mathrm{s}$
D. $\mathrm{V} = \mathrm{Wb} \cdot \mathrm{m}^2/\mathrm{s}$

The following problems are worth 12 points each

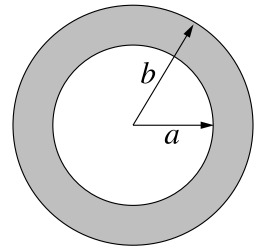
Record your steps! (Grade based on method displayed not just numerical result)

To receive full credit your answers should have exactly three significant figures

13. As shown in the diagram, three long parallel wires run perpendicular to this sheet of paper and pierce this sheet in an equilateral triangle with side 10 cm. The currents I_1 and I_3 come directly out of this page; I_2 goes into the page. Sketch directly on the diagram the net magnetic field vector at X (i.e., the midpoint of the horizontal segment); be sure to properly show its direction! Find the magnitude of that net magnetic field vector at the spot marked with an X.



14. A current I flows through a long copper pipe with inner radius a and outer radius b. The current is distributed uniformly over the cross section of the pipe, and is directed out of this sheet of paper in the below diagram. Using Ampere's Law



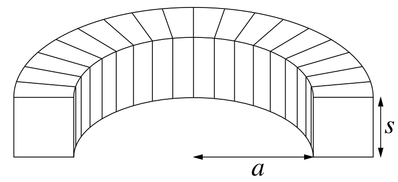
A. Find the formula for magnetic field for $r < a$

B. Find the formula for magnetic field for $r > b$

C. For an amperian loop within the copper ($a < r < b$) report the enclosed current. Show that for $a < r < b$ the magnetic field is given by:

$$B = \frac{\mu_0 I}{2\pi r} \frac{r^2 - a^2}{b^2 - a^2}$$

15. A toroid has a square cross section (side s), an inner radius of a, and a total of N turns each carrying a current I. (The diagram to the left shows half of this toroid.)



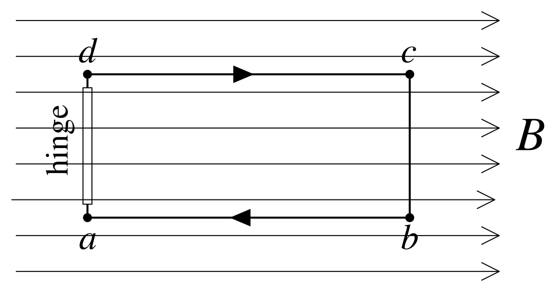
   A. Report the formula for the magnetic field inside the toroid as a function of the distance from the axis of the toroid.

   B. By integration, show that the magnetic flux through a single square turn around the torus is given by

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

   C. Find the induced (self) emf of this toroid if: $N = 200$, $a = 0.5$ cm, $s = 0.5$ cm, and $dI/dt = 1000$ A/s.

16. The 45 cm $\times$ 20 cm rectangular circuit $abcd$ shown below is hinged along the side ad. It carries a clockwise 12 A current and is located in a uniform magnetic field $B = 0.5$ T parallel to the long sides (e.g., ab).



A. Draw a clear diagram showing the direction of the force due to the magnetic field B on each segment of the circuit (ab, bc, cd, da)

B. Calculate the torque on the circuit about the hinge due to the magnetic field B.

C. The rectangular circuit can be thought of as a magnetic dipole. Report the direction and magnitude of that dipole.

D. We have shown that the torque on a dipole is given by $\vec{\boldsymbol{\tau}} = \vec{\boldsymbol{\mu}} \times \vec{\mathbf{B}}$. Calculate the direction and magnitude of the torque according to this formula.