Rules: This exam is to be completed by you unaided by textbook, web, notes, homework solutions, friends etc.... As described in the syllabus, the one external aid you may use during the exam is a single-sided $8\frac{1}{2} \times 11$ 'formula sheet'. You make the formula sheet before the exam to help recall formulae and then turn it in with the exam. (You are of course also encouraged to use a calculator.) If, during the exam, you think you need an additional formula or hint, ask me and I may be willing to provide it. Questions may be asked via personal chat or directly, but note that chat will not be continuously monitored.

Working remote typically takes additional time; you can use up to 50% more time than the last in-person student. When you've completed this assignment, convert all your work to a single pdf and email it to me at `tkirkman@csbsju.edu`. Typically students make a pdf by combining cell phone photos into one pdf using a cell phone app. The file `Assignment_Scanning_Tutorial.pdf` in the same web folder as the exam may provide guidance (but phones & apps differ).

Remotes will enable video and audio (but perhaps turn down their speakers to reduce incidental noise) and be on screen 100% of the time. Zoom should be providing a clear image/sound of you taking the exam. If there is incidental noise in the room you are using, consider moving to a different room. If you need to temporarily mute or leave the room, please explain when making that request.

Clearly the above will hardly deter the determined cheater. Your personal integrity is the only real deterrent to cheating. To engage that, sign the below statement (and turn it in with the exam) just before you turn in the exam.

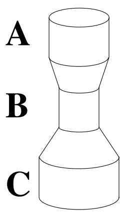
In answering these questions I have not aided any other student or used any external aids other than the 'formula sheet'.

Your Signature: ______________________________

Physical Constants:
proton charge $= e = 1.60 \times 10^{-19}$ C
permittivity $= \varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/(N \cdot m^2)}$
Coulomb constant $= k = 9 \times 10^9\ \mathrm{N \cdot m^2/C^2}$
permeability $= \mu_0 = 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}$

Select the letter of the single best answer. Each answer is worth 1 point.

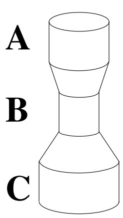
1. A solid bar of copper is machined into the shape shown with: $r_B < r_A < r_C$.



A steady current flows from top to bottom. Circle the location where the drift velocity is a maximum.

D. The drift velocity the same top-to-bottom so there is no maximum.

2. As above, a solid bar of copper is machined into the shape shown with: $r_B < r_A < r_C$.



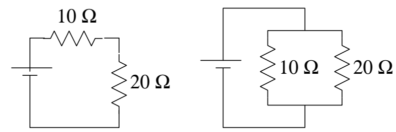
A steady current flows from top to bottom. Circle the location where the current density, J, is a maximum.

D. The current density is the same top-to-bottom so there is no maximum.

3. The following three appliances are connected to a 120 V house circuit: (i) 1200 W toaster, (ii) 1000 W microwave, and (iii) 100 W lamp. Which of the following options is the smallest fuse you could use and still operate all of these devices at the same time?

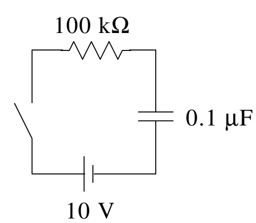
A. 10 A
B. 15 A
C. 20 A
D. 25 A

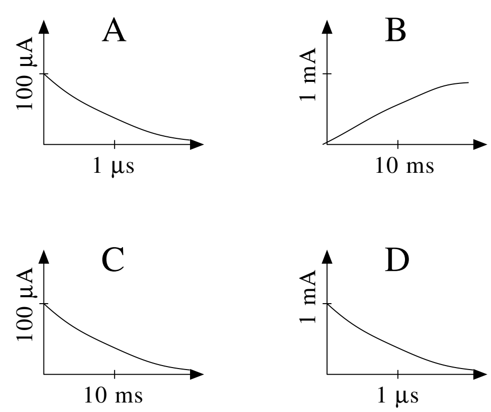
4. The same components (10 Ω and 20 Ω resistors) are used to make a series circuit and a parallel circuit. In each circuit, which resistor draws more electrical power?



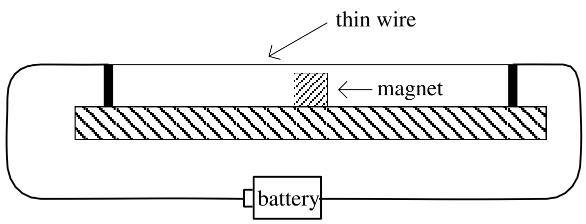
A. The 10 Ω draws the most power in both circuits.
B. The 20 Ω draws the most power in both circuits.
C. The 10 Ω draws the most power in the parallel circuit; the 20 Ω draws the most power in the series circuit.
D. The 20 Ω draws the most power in the parallel circuit; the 10 Ω draws the most power in the series circuit.

5. The below circuit shows a series RC circuit. The switch is closed at $t = 0$. Which graph best represents how the current changes in time?



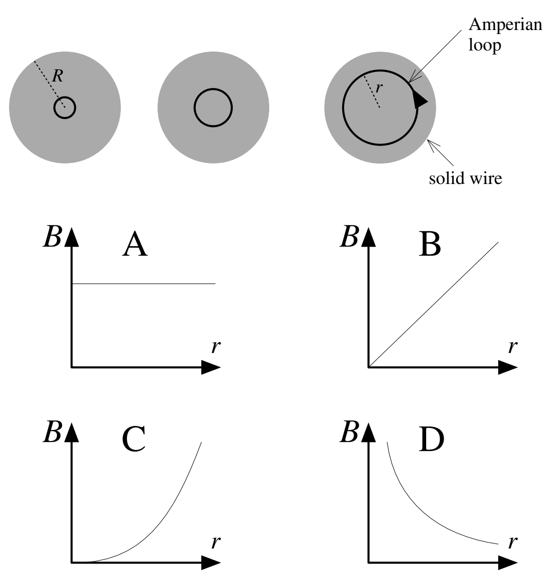


6. The picture below shows a device very similar to one used in class. A battery drives a current through a thin wire which is suspended above a magnet. When the battery is connected the thin wire moves out of the page. What sort of pole is the top of the magnet?

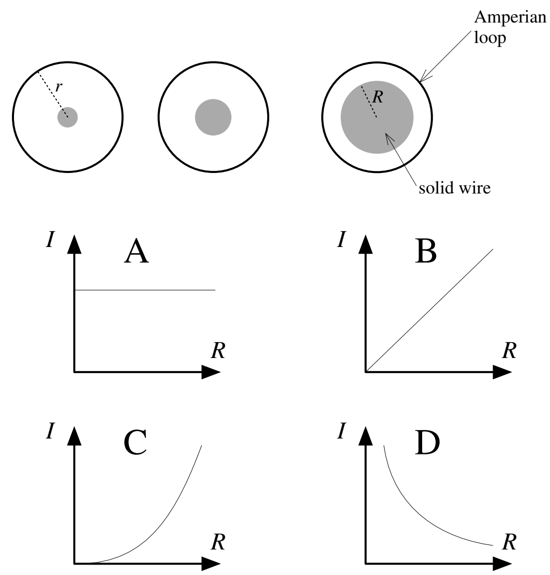


   A. N
   B. S
   C. E
   D. W

7. The below figure shows, in cross section, three identical long solid cylindrical wires of radius R all 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?



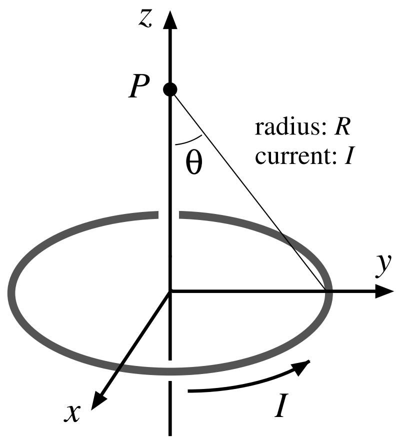
8. The below figure shows, in cross section, three long solid cylindrical wires of increasing radius R all carrying the same uniform current density J. Three identical Amperian loops are entirely outside the wire are also shown. What is the current, I, enclosed by these loops as a function of R? Which of the below plots best displays the relationship between I and R?



9. Which one of the below Maxwell's equations displays a displacement current?

   A. $\oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = Q/\epsilon_0$
   B. $\oint \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}} = 0$
   C. $\oint \vec{\mathbf{E}} \cdot d\vec{\ell} = -\dfrac{d\Phi_B}{dt}$
   D. $\oint \vec{\mathbf{B}} \cdot d\vec{\ell} = \mu_0 \left(I + \epsilon_0 \dfrac{d\Phi_E}{dt} \right)$

10. 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 $P = (0, 0, z)$. Which of the below correctly derives the formula for $B(z)$?



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

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

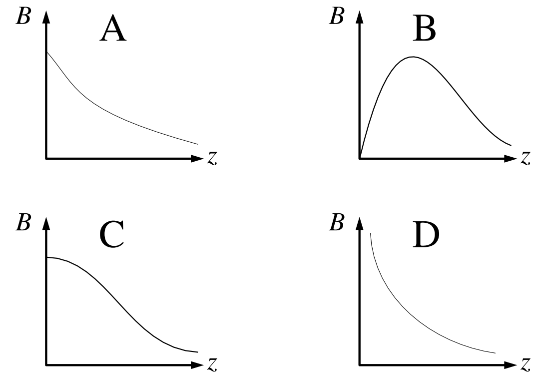
C. Since the net B field is in the z direction we need to include the angle:

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

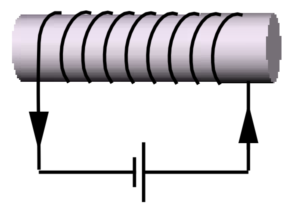
D. Since the net B field is in the z direction we need to include the angle:

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

11. Which of the below plots best displays how the magnetic field depends on z in the previous problem.



12. N turns of wire are tightly 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 true?



- The magnetic field inside the solenoid points to the left.
- 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.
- If the solenoid is "long" (i.e., $L \gg r$) the magnetic field in the center of the solenoid is proportional to N/L.
- 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. one

B. two

C. three

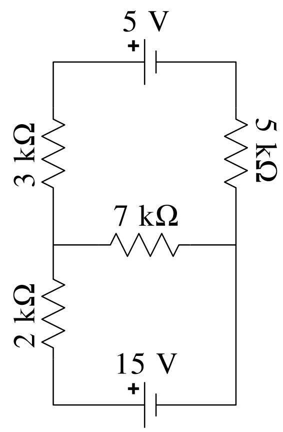
D. four

The following problems are worth 12 points each

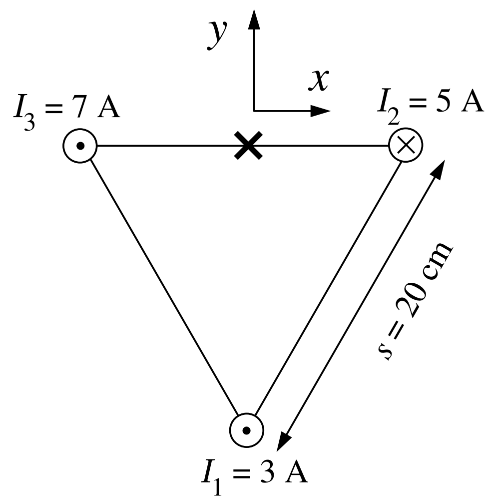
Record your steps! (Grade based on method displayed not just numerical result)

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

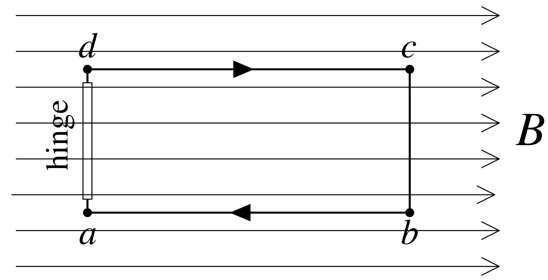
13. Using Kirchhoff's Rules find the current flowing in each wire of the following circuit. Name/label current directions in each wire by writing directly the following circuit diagram. Apply the loop rule to various loops around this circuit. For each such loop used, clearly show (by writing directly on the following circuit diagram) the loop followed (including direction) and the resulting equation. Feel free to solve these equations using direct calculator methods, but record exactly what data (equations) you intended to type into your calculator. (Otherwise it is very difficult to give partial credit.)



14. 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 20 cm. The currents I_1 and I_3 come directly out of this page; I_2 goes into this page. Calculate the magnitude and direction of the net magnetic field vector at X (i.e., the midpoint of the horizontal segment). Begin by calculating the magnitude and displaying the direction (by drawing directly on the diagram) of the magnetic field of each wire separately. (For example, draw the magnetic field vector at X due to I_1 and label it $\vec{\mathbf{B}}_1$.). Draw directly on the diagram the arrow that is net magnetic field vector (the vector sum of the $\vec{\mathbf{B}}_i$); label the angle you've calculated.



15. 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*).

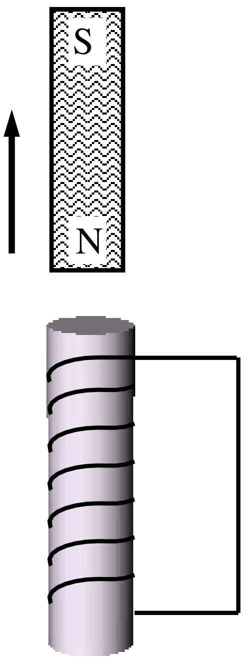


A. Draw a clear diagram showing the direction of the force due to the magnetic field B on each segment of the circuit (ab, bc, cd, da)

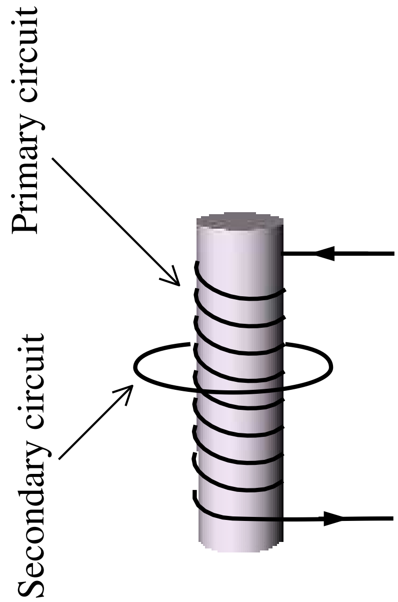
B. The rectangular circuit can be thought of as a magnetic dipole. Report the direction and magnitude of that dipole.

C. 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.

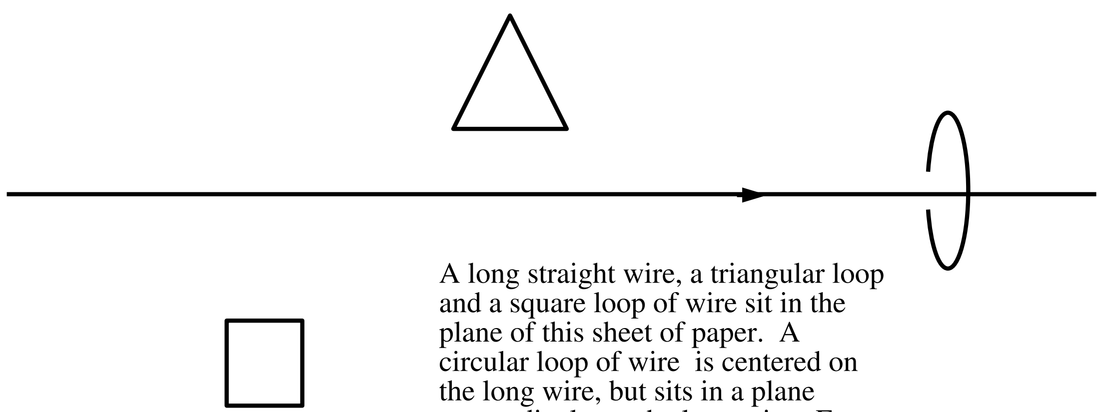
16. The below diagrams show three separate situations with **five** cases of induction. For each case, add an arrow directly on a wire showing the direction of the induced current in that wire. If there is no current flow write “zero”.(Note that the bottom case of the long straight wire has three secondary circuits and hence three separate answers are required.)



The north pole of a bar magnet is moving away from the solenoid



The current shown flowing through the primary circuit is increasing



A long straight wire, a triangular loop and a square loop of wire sit in the plane of this sheet of paper. A circular loop of wire is centered on the long wire, but sits in a plane perpendicular to the long wire. For several minutes there has been a current flowing to the right; that current is now decreasing.