1. The figure shows two long parallel wires carrying currents $I_1 = 15$ A and $I_2 = 32$ A (notice the currents run in opposite directions).

![Diagram of two parallel wires with currents I1 and I2]

1.A Use the diagram above to draw (approximately to scale).

- The vector magnetic field at P due to the current $I_1$.
- The vector magnetic field at P due to the current $I_2$.
- The net magnetic field vector at P due to both currents.

**Note:** “P” is the origin of the system of coordinates.

1.B The magnitude of the net magnetic field at “P” is equal to (in units of $\mu$T)

- a) 47
- b) 0.4
- c) 190
- d) 16
- e) NA

2. 2.A A certain wire has a resistance R. What is the resistance of a second wire, made of the same material, that is half as long and has half the diameter.

- a) $(1/2)R$
- b) 4 $\Omega$
- c) 2R
- d) $(1/4)R$
- e) NA
2.B The figure shows a wire carrying current. The wire has three sections with different radii.

Rank the sections according to the following quantities (greatest first):

Magnitude of the current density: ___S > U > P___________________

Magnitude of electric field: _____ S > U > P ____________

________________________________________________________________________

3. The figure shows a top-view and a side-view of a rectangular current loop PSUT in a uniform magnetic field \( B \). The dimension of the sides of the loop are 5.4 cm and 8.5 cm. The current circulating in the loop is \( I = 15 \) mA.

3.A In both diagrams above, draw the vector forces acting on each of the 4 sides of the loop.
3.B The loop is placed in a configuration shown in the figure below

Calculate the magnetic torque acting on the loop (in units of $10^{-3}$ A m$^2$)

a) 0.12  

b) 1.72  

c) 81  

d) 0  

e) NA

4. A parallel plate capacitor is 50% filled with a dielectric of dielectric constant $\epsilon=2.5$, while the remaining volume is empty (see figure below.) The area of the plates is $A=3$ cm$^2$ and the separation distance between the parallel plates is $d=3.5$ mm. After charging the capacitor with a 14 Volts battery, the battery is disconnected.

4A The capacitance of the capacitor is equal to (in units of $10^{-12}$ F)

a) 1.3  

b) 0.2  

c) 207  

d) 61  

e) NA

4B The figure above also shows a couple of point “P” and “S” where we want to evaluate the corresponding electric field. Which of the following expression(s) is(are) correct?

a) The magnitude of the electric field at P is greater than at S  

b) The magnitude of the electric field at P is weaker than at S  

c) The magnitude of the electric field at S is equal to $4 \times 10^3$ N/C  

d) The electric field magnitude at P is equal to $10^4$ N/C
e) All the expressions above are incorrect

5. A square loop of wire PSUT with side \( a = 2 \text{ cm} \) and resistance \( R=10 \text{ Ohms} \) carries an current \( I_2=3 \text{ mA} \). The loop is placed near an infinitely long wire carrying current \( I_1=10 \text{ mA} \), as shown in the figure. The distance from the long wire to the center of the loop is also “a”.

![Diagram of a square loop and long wire with currents](image)

5A Calculate the magnitude of the net force (in Newtons) acting on the square loop:

a) \( 2.1 \times 10^{-12} \)  

b) \( 6.6 \times 10^{-12} \)  

c) \( 8 \times 10^{-12} \)  

d) 0  

e) NA

5B Calculate the magnitude of the force acting on the segment PS (in units of \( 10^{-12} \) Newtons)

a) 2.1  

b) 6.6  

c) 8  

d) 0  

e) NA

6. A positive point charge \( q = 1 \mu\text{C} \) is located at the center of a spherical metal shell of inner radius \( R=2 \text{ cm} \) and thickness \( \Delta t = 0.3R \).

The net charge of the shell is \( Q_{\text{shell}} = -2 \mu\text{C} \). (This does not take into account the charge at the center of the shell).

![Diagram of a spherical metal shell with a point charge](image)

6A Sketch the charge distribution everywhere in or on the shell AND indicate:
Total charge on the inner wall = -1 \mu C
Total charge inside the bulk of the shell = 0
Total charge on the outer wall = -1 \mu C

6B The electric field at a point P located 3 cm from the center is equal to (in units of 10^6 N/C)

a) 25  
b) 10  
c) 49  
d) 40  
e) NA

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7A The figure at the right shows portions of two large, parallel, non-conducting sheets, each with a fixed uniform charge. The surface charge densities are \(\sigma_1 = +12 \ \mu C/m^2\) and \(\sigma_3 = +12 \ \mu C/m^2\), respectively. The separation between the plates is 0.5 mm.

The Electric potential difference between the plates is equal to (in units of 10^3 V)

a) 4.4  
b) 14  
c) 0  
d) 0.67  
e) NA

7B The figure at the right shows portions of two large, parallel, non-conducting sheets, each with a fixed uniform charge. The surface charge densities are \(\sigma_1 = +12 \ \mu C/m^2\) and \(\sigma_4 = -12 \ \mu C/m^2\), respectively. The separation between the plates is 0.5 mm.

The Electric potential difference between the plates is equal to (in units of 10^6 V)

a) 4.4  
b) 14  
c) 0  
d) 0.67  
e) NA
8. **8A** The figure shows two perspective views of the same magnet moving away from a circular metal loop.

On the right side figure: Indicate, using the conventional notation $\bullet$ and $\times$, the induced current that circulates along the loop. Draw also the magnetic field lines established by the induced current, indicating explicitly the direction of those lines.

8B The figure shows two perspective views of the same magnet approaching a circular metal loop.

On the right side figure: Indicate, using the conventional notation $\bullet$ and $\times$, the induced current that circulates along the loop. Draw also the magnetic field lines established by the induced current, indicating explicitly the direction of those lines.

9. The figure shows the cross section of a family of parallel equipotential surfaces and three paths along which we (as an external agent) shall move an electron from one surface to another (at constant velocity).
9A Use the graph above to draw the electric field lines everywhere in between the surfaces.

9B The external work done in each case (P, S, U) is, respectively

a) +, +, +     b) +, +, -     c) - , - , -     d) - , - , +     e) NA

BONUS

B1 (3 points)
A capacitor is charged with a 2V battery. The battery remains connected. Subsequently, an external agent (not shown in the figure) increases the distance between the plates.

Which expression describes correctly what happens as the distance between the plates is increased?

a) The electric field remains constant.

b) The electric potential between the plates decreases.

c) The electric potential energy stored in the capacitor decreases.

d) The magnitude of the charge in each plate increases.

e) All the expressions above are incorrect.

B2 (3 points)
The figure shows three situations in which a positively charged particle moves at velocity $\vec{v}$ through a uniform magnetic field $\vec{B}$ and experiences a magnetic force. In each situation, determine whether the orientation of the vectors are physically reasonable.
Some formulas:

- \( \mu = 10^{-6} \)  
  nano = \( 10^{-9} \)
- \( \ln(ab) = \ln(a) + \ln(b) \)  
  \( \ln(a/b) = \ln(a) - \ln(b) \)
- **Electron mass**: \( 9.1 \times 10^{-31} \text{ Kg} \)  
  **Proton mass**: \( 1.67 \times 10^{-27} \text{ Kg} \)
- 1 Gauss = \( 10^{-4} \) Tesla
- Centripetal acceleration: \( a_c = \frac{v^2}{R} \)

**ELECTRICITY**

- Coulomb’s Law: \( \vec{F} = \frac{1}{4\pi \varepsilon_0} \frac{q_2 q_1}{r^2} \hat{u} \)
- Electric field, along the z-axis, due to a charge Q distributed uniformly along a thin ring of radius R.: \( \vec{E} = \frac{1}{4\pi \varepsilon_0} \frac{Q z}{(z^2 + R^2)^{3/2}} \hat{k} \)
- For an infinite uniformly charged sheet: \( E = \sigma / 2\varepsilon_0 \)
- Gauss’ Law: \( \Phi = \int_S \vec{E} \cdot d\vec{s} = q / \varepsilon_0 \), where \( q \) is the net charge inside the gaussian surface \( S \)
- Definition of Electric Potential \( V(r) = \frac{W_{\text{ext}}(\frac{\infty}{q_0} \rightarrow r)}{q_0} \)
  - Electric potential due to a point charge \( q \): \( V = \frac{1}{4\pi \varepsilon_0} \frac{q}{r} \)
  - Relationship between \( E \) and \( V \): \( E_x = -\frac{dV}{dx} \)
- **About capacitance**  
  \( Q = CV \)  
  \( C = A\varepsilon_0 / d \)  
  \( U = CV^2 / 2 = Q^2 / 2C \)
- **RC circuit**: Time constant \( \tau = RC \)

**MAGNETISM**

- \( F = q v \times B \)  
  \( F \) = force, \( q \) = charge, \( v \) = velocity, \( B \) = magnetic field
- Magnetic field produced by a charge \( q \) that moves with velocity \( \vec{v} \)
\[ \mathbf{B} = \frac{\mu_0}{4\pi} \frac{q}{r^2} \mathbf{v} \times \mathbf{r} \]

- \( \Phi = L \, i \) \( \Phi \) = Magnetic flux, \( L \) = inductance, \( i \) = current
- Hall effect \( BI = nqtV_{\text{Hall}} \)
- Inductive reactance \( X_L = \omega L \)
- \( B = \frac{\mu_0}{4} \frac{I}{R} \) Magnetic field at the center of a semi-circle of radius "R"
- \( B = \frac{\mu_0}{4\pi} \frac{I \phi}{R} \) Magnetic field at the center of an arc of angle \( \phi \) (in radians) and radius "R".
- \( B = \frac{\mu_0}{2\pi} \frac{I}{r} \) Magnetic field produced by a infinitely long wire at a distance "r" from it.
- \[ \frac{F}{L} = \frac{\mu_0}{2\pi} \frac{I_a I_b}{d} \] Force per unit length between two parallel long wires, carrying currents \( I_a \) and \( I_b \) respectively, separated by a distance "d"
- Faraday's Law \( \mathcal{E} = -\frac{\partial \Phi}{\partial t} \), where \( \Phi \) = Magnetic flux and \( \mathcal{E} \) = electromotive force
- Definition of the magnetic dipole moment of a loop of area \( A \), carrying a current \( I \):
  \( \mathbf{\mu} = I \, A \, \mathbf{n} \)
  where \( A \) = area, \( I \) = current, \( \mathbf{n} \) = unit vector perpendicular to the loop