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Constants you may find useful

$G = 6.67 \times 10^{-11}$ Nm^2/kg^2

$M_{Earth} = 5.97 \times 10^{24}$ kg

$M_{Sun} = 1.99 \times 10^{30}$ kg

$r_{Earth} = 6.38 \times 10^3$ km

$r_{Sun} = 6.96 \times 10^5$ km

$d_{Sun-Earth} = 149.6 \times 10^6$ km

$g = 9.8$m/s^2

$\varepsilon_0 = 8.85 \times 10^{-12}$ C^2/(Nm^2)

$\mu_0 = 4\pi \times 10^{-7}$ Tm/A

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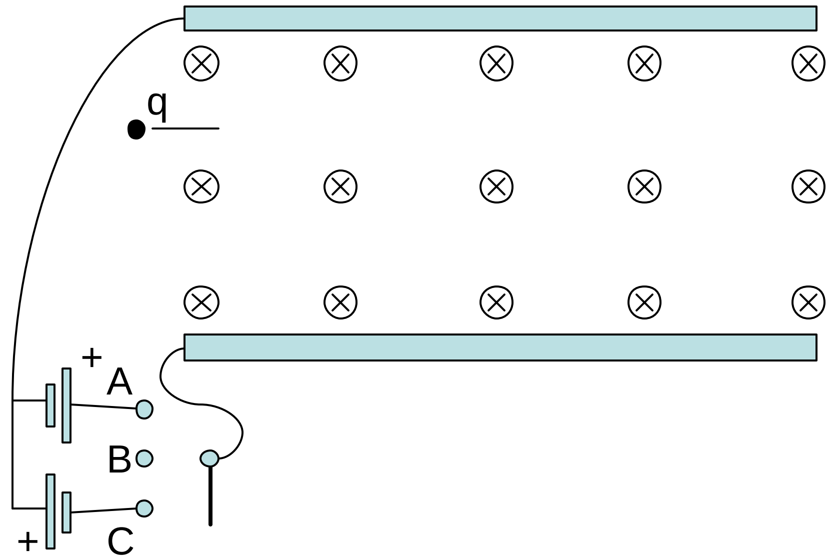

Part I. [30 points] A particle with a charge q is shot through a velocity selector, shown at right. The device is made up of two plates connected to a battery which create an electric field, and is also immersed in a magnetic field, which points into the page. When a particle enters with the correct velocity it will travel in a straight, horizontal line. Ignore gravity. The magnitude of the magnetic field is 0.2 T, and the device is 1.5 m long.

1. [4 points] For the velocity selector to work, the particle q must move in a horizontal line. What position must the switch be in to accomplish this?
   - **A.** A
   - **B.** B (disconnected)
   - **C.** C
   - **D.** A or C
   - **E.** A or B or C
2. [5 points] The device is designed to select particles with a velocity of 500 m/s. Determine the magnitude of the electric field, E.
   - **A.** 0.30 N/C
   - **B.** 100 N/C
   - **C.** 150 N/C
   - **D.** 450 N/C
   - **E.** 750 N/C
3. [5 points] A particle with mass 1.0 x 10^{-3} kg enters at 500 m/s, and travels through in a straight horizontal line. Determine its charge.
   - **A.** 0.0 C
   - **B.** 5.0 x 10^{-3} C
   - **C.** 8.3 x 10^{-3} C
   - **D.** 1.1 x 10^{-2} C
   - **E.** Not possible to determine
4. [3 points] The particle enters with a speed of 400 m/s. Which of the following statements is true?
   - **A.** The magnitude of F_B increases and the magnitude of F_E remains constant.
   - **B.** The magnitude of F_B decreases and the magnitude of F_E remains constant.
   - **C.** The magnitude of F_B remains constant, but the magnitude of F_E increases.
   - **D.** The magnitude of F_B remains constant, but the magnitude of F_E decreases.
   - **E.** The magnitudes of both F_B and F_E decrease.

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The electric field is adjusted to be 230 V/m (and the B field magnitude remains 0.2 T). A particle with charge +0.2 mC enters at 1200 m/s.

5. [3 points] Which of the following best describes the particles trajectory?

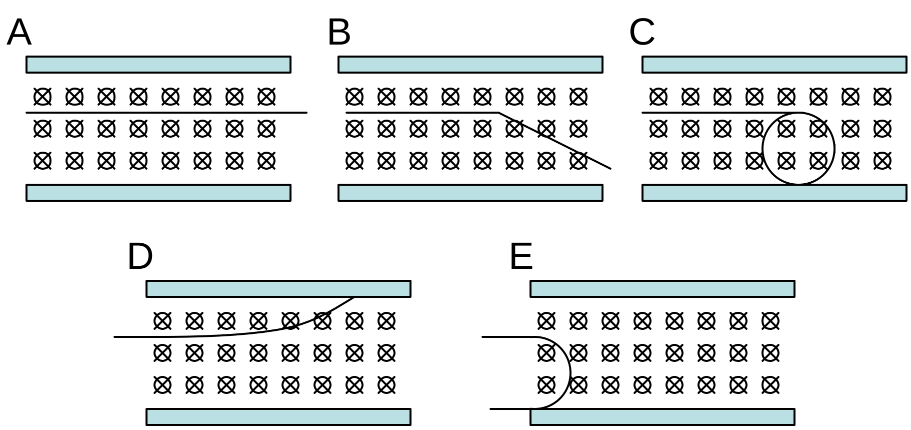
   A. The particle curves towards the top plate.
   B. The particle curves towards the bottom plate.
   C. The particle travels in a horizontal line through the velocity selector
   D. Not enough information given to determine.

6. [3 points] As the particle starts to travel through the velocity selector,

   A. Its net velocity will increase.
   B. Its net velocity will decrease.
   C. Its net velocity will decrease exponentially.
   D. Its net velocity will remain the same

The electric field is now shut off, leaving only the magnetic field. A negatively charged particle is shot into the magnetic field directly between the two plates (which are separated by 5 cm). The particle's initial velocity is 600 m/s, its charge is 0.2 mC, and its mass is 1.0×10^{-9} kg.

7. [3 points] Which trajectory best represents the possible path of the particle?



8. [4 points] What is the radius of curvature of the particle?

   A. 1.0×10^{-2} m
   B. 1.5×10^{-2} m
   C. 2.5 m
   D. 9.0 m
   E. It moves in a straight line, so there is no radius of curvature!

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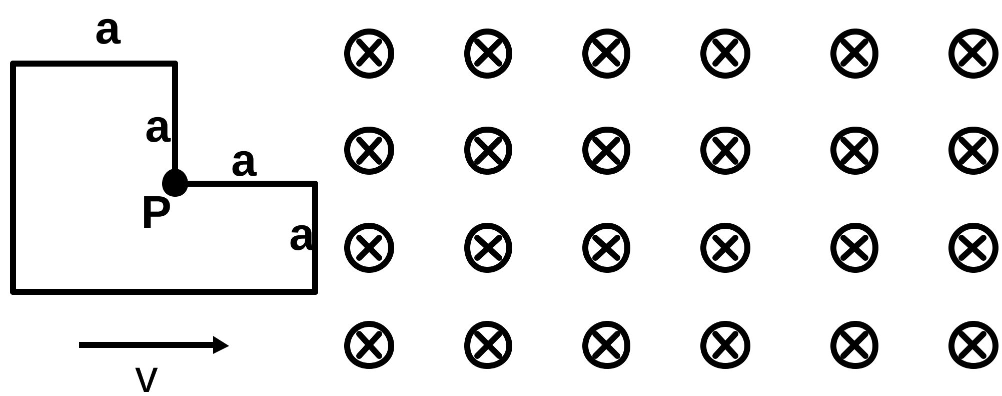


Part II. [25 points] Consider the wire loop next to the magnetic field area at left. The length a is 5 cm. The point P is fixed to the loop at the position shown. The loop is moving to the right with a speed of v = 3 m/second. The magnetic field is 2.5 T.

9. [4 points] Just before point P enters the magnetic field, which of the following statements is true?

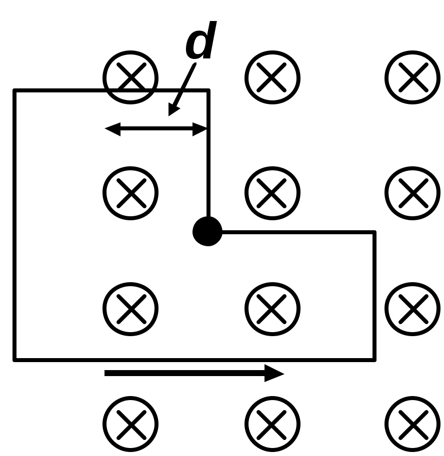
   A. The induced magnetic field is in the opposite direction field already present, and is only present in the interior of the loop already in the field.
   B. The current flow in the loop is counter clockwise.
   C. The induced magnetic field points into the page, and the current flows counter clockwise.
   D. The induced magnetic field is present throughout the interior of the loop, and points into the page.
   E. None of the above.

10. [6 points] At the same point – just before the point P enters the magnetic field - calculate the induced EMF in the loop.

   A. 6.3×10^{-3} V
   B. 1.9×10^{-2} V
   C. 1.3×10^{-1} V
   D. 3.8×10^{-1} V
   E. 1.2 V

11. [5 points] Calculate the induced EMF as the second half of the loop enters the magnetic field. l is the distance the second part of the loop is in the magnetic field.

   A. $1.3\text{x}10^{-2}\, d + 6.3\text{x}10^{-3}$ V
   B. $3.8\text{x}10^{-2}\, d$ V
   C. $3.8\text{x}10^{-2}$ V
   D. $7.5\text{x}10^{-1}$ V
   E. $7.5\text{x}10^{-1}\, d$ V



12. [6 points] While the loop is completely inside the field, the magnetic field is uniformly reduced down from 2.5 T to 1.0 T over a period of 2 seconds. The induced EMF in the loop is

    A. 1.9×10^{-3} V
    B. 3.8×10^{-3} V
    C. 5.6×10^{-3} V
    D. 7.5×10^{-3} V
    E. 1.1×10^{-2} V

13. [4 points] The wire loop is cut, and a resistor with resistance R is used to rejoin the cut bits of the loop. The resistor, R, is much greater than the intrinsic resistance of the wire loop. Which of the following would be true:

    A. It would require less force to pull the wire into the magnetic field, but not out of.
    B. It would require more force to put the loop both into and out of the magnetic field.
    C. It would less force to both pull the loop into and out of the magnetic field.
    D. It would require more force to pull the loop out of, but not into the magnetic field.
    E. There would be no change.

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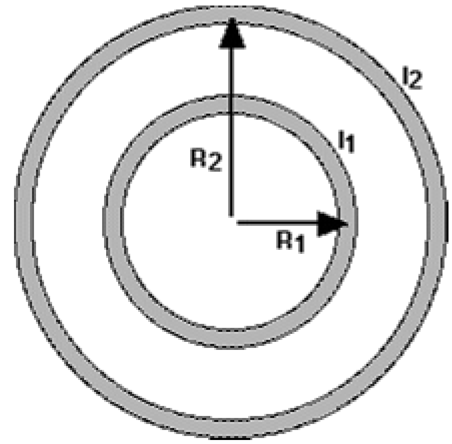

Part III. [25 points] A thin, infinitely long cylindrical conducting **shell** of radius R_1 = 3 cm carries a current I_1 = 21 *mA* in the +*z*-direction (out of the page). This current is uniformly distributed in the azimuthal direction about the *z*-axis. A second thin, infinite cylindrical shell of radius R_2 = 8 *cm* carries a current I_2 = 26 *mA*, also in the +*z*-direction, also uniformly distributed in the azimuthal direction. The two conducting shells are very thin.

14. [5 points] What is the magnitude of the net magnetic field at a distance *r* = 1.5 cm from the axis of symmetry? Explain.

15. [4 points] What is the magnitude of the magnetic field at a distance *r* = 16 cm from the axis of symmetry?

16. [5 points] What is the magnitude of the magnetic field due to the current I_1 alone at $r = R_2$?

17. [7 points] Calculate the magnitude of the magnetic force *per unit area* on the outer shell due to current I_1.

18. [4 points] Calculate the magnitude of the net magnetic force *per unit length* in the *z*-direction on the outer shell due to current I_1. Explain.