Two very long wires are oriented parallel to the $y$ axis and carry identical but *unknown* currents $I_a$ in the *same* direction. The wires cross the $x$-axis at positions $x = -a$ and $+3a$. The wires produce a magnetic field at the origin with known magnitude $B_0$ and direction $+z$ (*i.e.*, out of the page). Finally, a particle of charge $q$ passes through the origin, with velocity $v$ in the $+y$ direction.
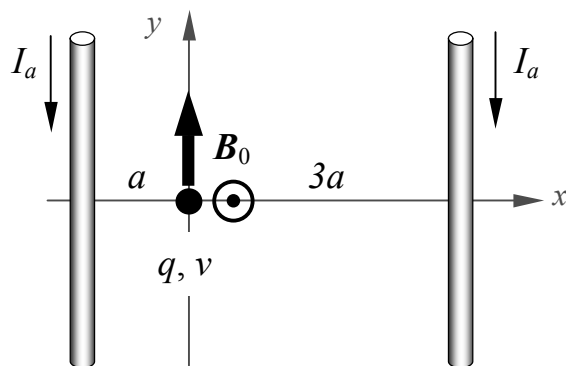


$a = 2$ cm
$B_0 = 5 \times 10^{-7}$ T
$q = 30$ mC
$v = 5 \times 10^{7}$ m/s
$I_a = ?$

NOTE: Whenever you are asked for a **vector** quantity,
give **both** its magnitude **and** direction.

1) Using the given magnitude and direction of the magnetic field $B_0$ at the origin, determine the current $I_a$. Bear in mind that $I_a$ might be *negative*, indicating directions opposite to those shown in the figure. **[6]**

$I_A > 0$
$|B| = 2 \times 10^{-7} I_A (1/a - 1/3a) \rightarrow I_A = 75\text{mA}$

Rubric:
Sign of $I_A$ (2)
Setup problem correctly (2)
Correct value (2)

2) What is the force $F$ on the charged particle as it crosses the origin? **[4]**

$F = qvB = 0.75$ N in the $+x$ direction

Rubric:
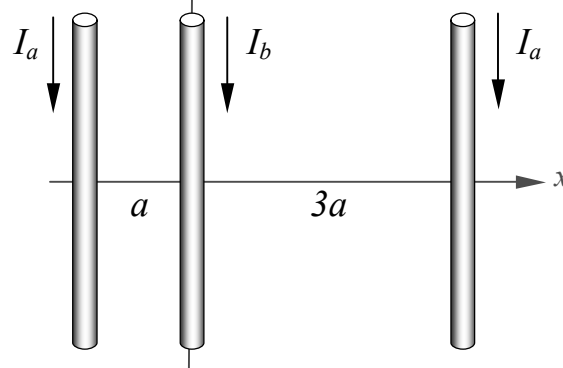Setup problem $F = qvB$ etc (2)
Correct value (1) and sign (1)

3) Now, a third wire is placed at the origin instead of the charged particle. This wire is also parallel to the $y$-axis, and carries current $I_b = 0.5$ A in the negative $y$ direction. What is the force **F** exerted on a segment of length $L = 4$ cm of the third wire by the first two? **[4]**



F = IBL = $10^{-8}$ N in the negative x direction

Rubric:
Problem setup (2)
Correct answer (2) (NOTE: beware of error propagation here. Can give credit to somebody for plugging in the solution of part 1 if that part is incorrect)

4) Two circular coils, **A** of radius $2R$, and **B** of radius $R$, are situated in a region of constant magnetic field $B$ directed into the page as shown in the figure below. Coil **A** has 1 turn while coil **B** has 2 turns. Identical currents $I$ flow in each coil, both in the clockwise direction. Compare the magnitude of potential energies $U_A$ and $U_B$ of coils **A** and **B**. Provide a brief but clear explanation of your answer. **[6]**
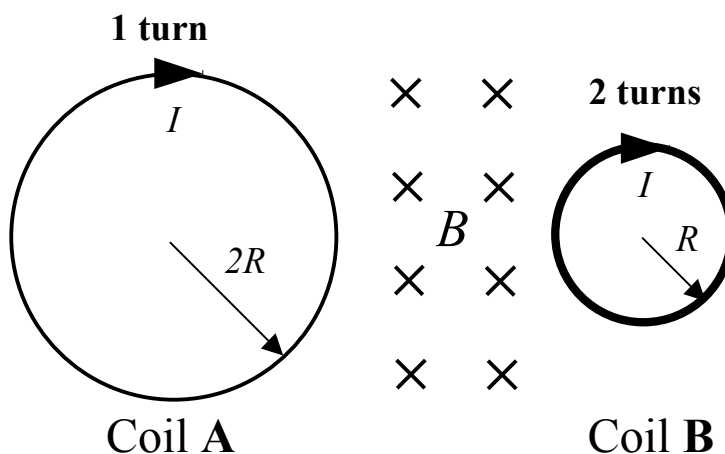


a) $|U_A| < |U_B|$        b) $|U_A| = |U_B|$        **c) $|U_A| > |U_B|$**

$U = \mu B = N I \pi r^2$
$U_A$ increases x4 because of the area
$U_B$ increases x2 because of the turn

Rubric:
Correct choice (2)
Explanation for the area (2)

Explanation for the turn (2)

Explanation for the turn (2)