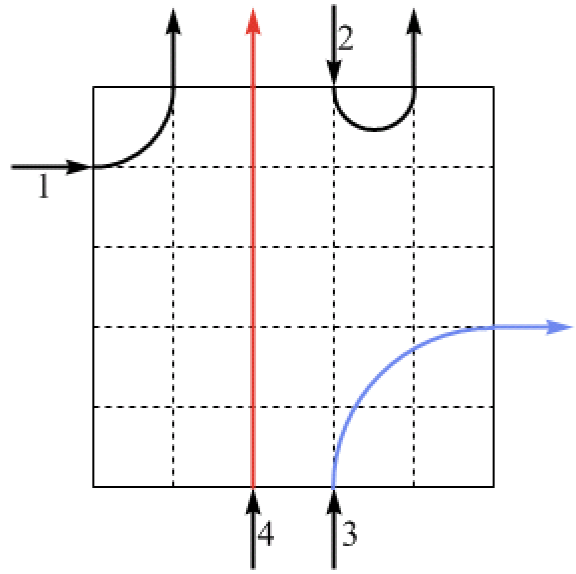
PROBLEM 1 – 20 points



Four particles pass through a square region of uniform magnetic field. The magnetic field inside the square region is perpendicular to the page, and the field outside the region is zero. The paths followed by particles 1 and 2 are shown; while for particles 3 and 4 the direction of their velocities and the points at which they enter the region are shown.
The paths of all particles lie in the plane of the paper.

Particle 1 has a mass *m*, a speed *v*, and a positive charge +*q*.

[3 points] (a) In which direction is the uniform magnetic field in the square region?

[**X**] into the page [ ] out of the page

Apply the right-hand rule to particle 1. When the velocity is right the force is up, so the field is into the page.

[3 points] (b) Assume that the only thing acting on the particles as they move through the magnetic field is the field. As particle 1 moves through the field its kinetic energy:

[ ] increases [ ] decreases [**X**] stays the same

The magnetic force is always perpendicular to the velocity. There is no force component parallel to the velocity (which would speed it up) or opposite to the velocity (which would slow it down). The force can only change the direction of the velocity, not the magnitude.

[2 points] (c) What is the sign of particle 2's charge?

[**X**] positive [ ] negative

Apply the right-hand rule again, or recognize that it goes counterclockwise just like particle 1 do the sign of 2's charge must be the same as that of 1.

[3 points] (d) If particle 2's mass is *m* and its charge has a magnitude of *q*, what is its speed?

[ ] $\frac{v}{4}$ [**X**] $\frac{v}{2}$ [ ] v [ ] 2v [ ] 4v

The radius of the path is given by $r = \frac{mv}{qB}$. Particle 2's radius is half that of particle 1, but the particles have the same mass, the same magnitude charge, and they're in the same field. To get half the radius the speed of particle 2 must be half that of particle 1.

[3 points] (e) Particle 3 has a mass 2*m*, a speed 2*v*, and a charge -2*q*. On the diagram above sketch its path through the region of magnetic field. Be as precise as you can in showing where the particle leaves the field and what direction it is traveling in at that point.

Doubling mass, speed, and the magnitude of the charge gives a radius twice that of particle 1. Because the charge is negative it follows a clockwise path, bending to the right. Draw a circular path bending right with a radius of two units.

[3 points] (f) Particle 4 has a mass 2*m*, a speed 2*v*, and no charge. On the diagram above sketch its path through the region of magnetic field. Be as precise as you can in showing where the particle leaves the field and what direction it is traveling in at that point.

If the particle has no charge it is unaffected by the field, so it follows a straight path through the magnetic field.

[3 points] (g) Which particle feels the largest magnitude force as it passes through the field?

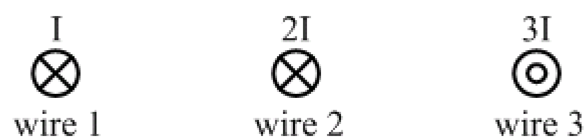
[ ] 1   [ ] 2   [**X**] 3   [ ] 4

The force is given by F = qvB. B is the same for all particles so the particle with the largest value of q*v (the sign on q is irrelevant – we're looking for the largest magnitude force) feels the largest force. 4qv for particle 3 beats all the others.

PROBLEM 2 – 5 points

Three equally spaced long straight wires are shown in the diagram. The currents in the wires are as follows:

Wire 1 carries a current I into the page.
Wire 2 carries a current of 2I into the page.
Wire 3 carries a current of 3I out of the page.



[3 points] (a) Each wire experiences a net force because of the other two wires. Rank the three wires based on the magnitude of the net force per unit length they experience, from largest to smallest.

[ ] 1>2>3   [ ] 1>3>2   [ ] 1=3>2   [ ] 2>1>3   [**X**] 2>3>1   [ ] 2>1=3

[ ] 3>1>2   [ ] 3>2>1   [ ] 3=2>1   [ ] 1=2=3   [ ] none of these

Wires carrying currents the same way attract; opposite currents repel.
The force per unit length on a wire is proportional to the product of its current and the current in the wire exerting the force, and inversely proportional to the distance between wires. Let's say wire 2 exerts a force of 2F to the right on wire 1, so wire 3 exerts a force of 3F/2 to the left on wire 1. The net force on wire 1 is 0.5F to the right.
Similarly, wire 2 feels a force of 2F left from wire 1 and 6F left from wire 3, a net of 8F left.
Wire 3 feels a force of 6F right from wire 2 and 3F/2 right from wire 1, a net of 7.5F right.

[2 points] (b) What direction is the net force experienced by wire 1 due to the other two wires?

[ ] left [**X**] right [ ] into the page [ ] out of the page [ ] down [ ] up

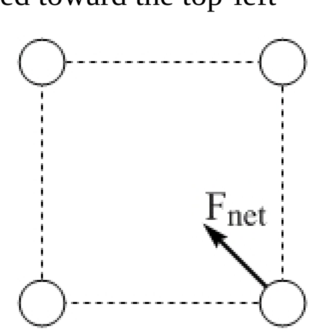
[ ] the net force on wire 1 is zero

Wire 1 feels a force to the right from wire 2, and to the left from wire 3. The force is proportional to the current from the wire exerting the force, and inversely proportional to the distance. Wire 3 has 1.5 times the current of wire 2 but it is 2 times as far away, so wire 3's force is smaller in magnitude than wire 2's, and the net force goes right. You could also just calculate it as above.

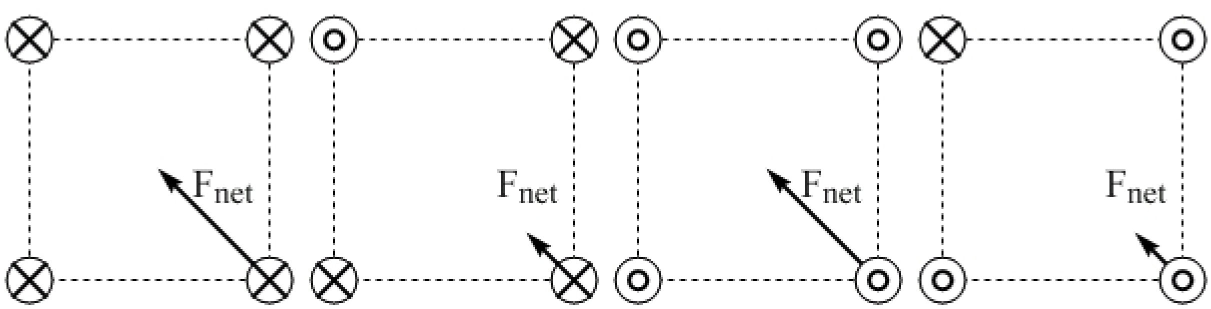
PROBLEM 3 – 12 points

Four long straight parallel wires pass through the corner of a square. **Each wire carries the same magnitude current**, but it is up to you to determine whether the current in any particular wire is directed out of the page or into the page.

[2 points] (a) The net force on the wire in the bottom-right corner is directed toward the top-left corner of the square. By using the symbol ⊙ for out of the page and/or ⊗ for into the page show a possible configuration of current directions that would produce this force. In other words, label each wire with its current direction.



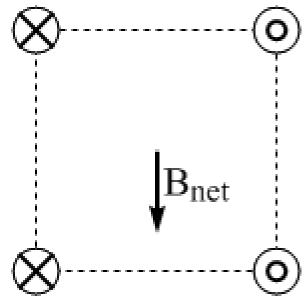
There are four different ways to do this – you just needed to come up with one. The key is that wires carrying currents in the same direction attract one another, so to get a net force directed toward the center of the circle the direction of the current in the wire experiencing the force must be in the same direction as the current in the wire above it, which must be in the same direction as the current in the wire to the lower left. Because it is further away the current in the wire at the top left can be either direction. If it is the same direction as the other three the force is larger, and if it is the opposite direction the force is smaller, but it does not change the direction of the net force which is what we're really interested in here.



[5 points] (b) The net magnetic field at the exact center of the square from the four current-carrying wires is directed straight down. By using the symbols for $\odot$ out of the page and $\otimes$ for into the page show a possible configuration (if there is one) of current directions that would produce the required magnetic field at the center of the square.

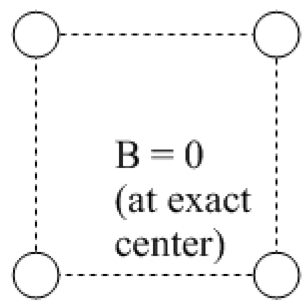
How many different configurations (different combinations of current directions) are there that would produce the required magnetic field?

[ ] 0 [**X**] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 or more



Justify your answer: **To get a net field directed down the field from each wire must have a component directed down at the center of the square. There is only one combination of current directions that does this.**

[5 points] (c) The net magnetic field at the exact center of the square is zero. By using the symbols $\odot$ for out of the page and $\otimes$ for into the page show a possible configuration (if there is one) of current directions that would produce no magnetic field at the center of the square.



How many different configurations (different combinations of current directions) are there that would produce zero net magnetic field at the center?

[ ] 0 [ ] 1 [ ] 2 [ ] 3 [**X**] 4 [ ] 5 or more

Justify your answer: To get a field of zero at the center the fields from diagonally opposite wires must cancel, which happens when those currents are in the same direction. There are two ways to cancel fields from diagonally opposite wires, and there are two sets of diagonally opposite wires, so there is a total of 2*2 = 4 ways to get complete cancellation at the center. These are shown below.