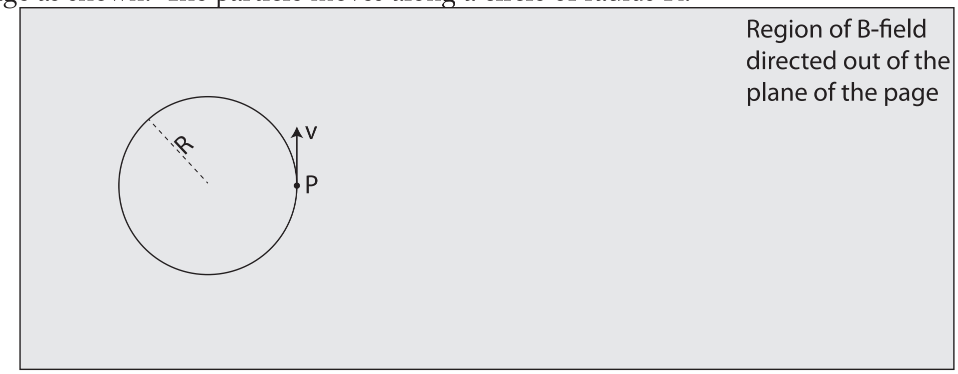
# AP2 Magnetism

A charged particle is projected from point P with velocity v at a right angle to a uniform magnetic field directed out of the plane of the page as shown. The particle moves along a circle of radius R.

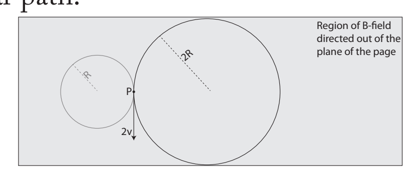



(a) On the diagram, draw a vector representing the magnetic force acting on the particle at point P.
(b) Determine the sign of the charge of the particle. Explain your reasoning.

(c) Explain why the magnetic field does no work on the particle as it moves in its circular path.

(d) A second, identically charged particle is projected at position P with a speed 2v in a direction opposite that of the first particle. On the diagram, draw the path followed by this particle. The drawn path should include a calculation of the radius of curature in terms of the original radius R.

**Answers:**
(a) vector pointing toward center of circle.
(b) negative. In order to apply the hand rule, the fingers of the left hand point in the direction of the particle's velocity, and bend out of the plane of the page, leaving the left-hand thumb pointing toward the center of the circle, creating the centripetal force allowing the particle to move in a circular path.
(c) No work is done because the magnetic force is always perpendicular to the velocity of the particle.
(d) See diagram at right. Radius of the new circle is 2R, since $mv^2/R=qvB$, therefore $R=mv/qB$.




**EK:** 3.C.3 A magnetic force results from the interaction of a moving charged object or a magnet withother moving charged objects or another magnet. 2.D.1 The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity, and the magnetic field vectors.

**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.

**LO:** 3.C.3.1 The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. 2.D.1.1 The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field.

# AP2 Magnetism

Radioactive sources emit alpha, beta and gamma radiation that enter the same uniform magnetic field at velocities measured in terms of the speed of light, c. Rank the magnitude of the magnetic force on each of the particles from lowest to highest for the following situations:

(A) Alpha particle moving .1c at a right angle to the magnetic field.
(B) Beta particle moving .2c, at a right to the magnetic field.
(C) Gamma particle moving at c, at a right angle to magnetic field.
(D) Alpha particle moving .1c, parallel to the magnetic field.
(E) Beta particle moving .1c at a right angle to the magnetic field.

**Answer:** D=C < E < A=B

D & C experience no force. The force is zero for C since gamma particles are uncharged, and the force is zero for D since it is moving parallel to the magnetic field. E comes next since the beta particle has less charge than the alpha particle, and less speed than B. A and B come last and are equal since B has half the charge but twice the speed of A.

**EK:** 2.D.1 The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity, and the magnetic field vectors. 5.G.1 The possible nuclear reactions are constrained by the law of conservation of nucleon number.

**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 3.3 The student can evaluate scientific questions.

**LO:** 2.D.1.1 The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. 5.G.1.1 The student is able to apply conservation of nucleon number and conservation of electric charge to make predictions about nuclear reactions and decays such as fission, fusion, alpha decay, beta decay, or gamma decay.

# AP2 Magnetism

An uniform magnetic field is directed into the plane of the page. A loop of wire is placed in the magnetic field. At no time does the loop leave the magnetic field. Which of the following situations will induce a current in the loop. Select two answers.

(A) rotate the loop along an axis that is directed into the page.
(B) contract to loop to a smaller area.
(C) rotate the loop along an axis that is directed vertically.
(D) move the loop along a line that is parallel to the magnetic field.

**Answers:** B & C. A & D induce no current in the loop because there is no change in magnetic flux.

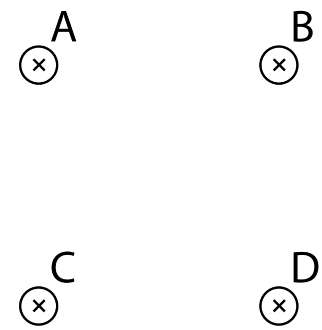
**EK:** 4.E.2 Changing magnetic flux induces an electric field that can establish an induced emf in a system.

**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

**LO:** 4.E.2.1 The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area.

# AP2 Magnetism

Four identical current-carrying wires are arranged at the corners of a square as shown. A current, I, flows through each wire as shown. What is the direction of the net force on wire A due to wires B, C, and D?




(A) Up
(B) Up and to the right
(C) Right
(D) Down and to the right
(E) Down

**Answer:** D. Wires with current flowing in the same direction attract each other, so the net force on A is down and to the right. You could also determine this by first finding the direction of the net magnetic field at A due to B, C, and D, then using the right-hand rule to determine the force on the charges flowing in wire A.

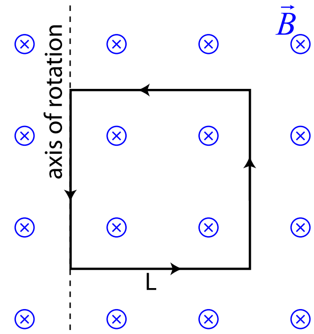
**EK:** 2.D.1 The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity, and the magnetic field vectors. 2.D.2 The magnetic field vectors around a straight wire that carries electric current are tangent to concentric circles centered on that wire. The field has no component toward the current-carrying wire.

**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 3.3 The student can evaluate scientific questions.

**LO:** 2.D.1.1 The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. 2.D.2.1 The student is able to create a verbal or visual representation of a magnetic field around a long straight wire or a pair of parallel wires.

# AP2 Magnetism

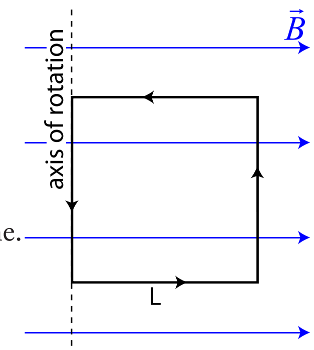
A square loop of wire with side length L and one side attached to an axis of rotation is situated in a uniform magnetic field directed into the page as shown. The magnetic field strength is B and a current I flows through the wire in a counter-clockwise direction.




(a) Determine the net torque on the loop of wire.

(b) The magnetic field strength is now increased uniformly over a short period of time. Describe what happens to the current flowing in the wire during this period.

(c) The magnetic field is again set to strength B and is rotated 90 degrees such that it now points to the right, as shown. Determine the new net torque on the loop of wire.




(d) Again, the magnetic field strength is increased uniformly over a short period of time. Describe what happens to the current flowing in the wire during this period.

**Answers:**

(a) net torque is zero as force on each segment of wire is toward the center of the loop.
(b) The current in the wire increases. An increasing magnetic flux through the loop creates a counter-clockwise current opposing the change in the magnetic flux. This induced current augments the initial current I.
(c) Only the segment of wire on the right side contributes to the net torque of the loop:
$\tau = Fr = (BIL)r = BILr$
(d) The flux through the loop doesn't change, so the current in the wire remains the same.

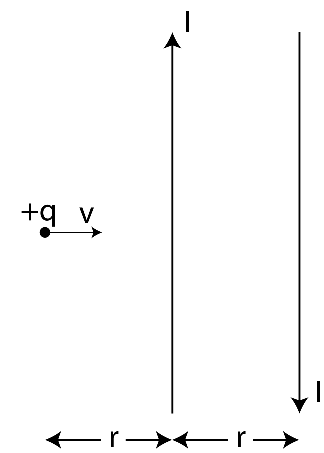
**EK:** 2.D.1 The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity, and the magnetic field vectors. 4.E.2 Changing magnetic flux induces an electric field that can establish an induced emf in a system.

**SP:** 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

**LO:** 2.D.1.1 The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. 4.E.2.1 The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area.

# AP2 Magnetism

A particle of charge +q moves toward two long current-carrying wires at a right angle as shown in the diagram at right. If the distance between the wires is r, find the force on the particle when the particle is a distance r away from the nearest wire.




(A) $qV\dfrac{\mu_0 I}{4\pi r}$ up

(B) $qV\dfrac{\mu_0 I}{4\pi r}$ down

(C) $qV\dfrac{\mu_0 I}{2\pi r}$ up

(D) $qV\dfrac{\mu_0 I^2}{\pi r^2}$ down

**Answer:** B. First find the magnetic field strength at the point of interest by adding up the contributions to the magnetic field from each of the wires.

$$B_{net} = \frac{\mu_0 I}{2\pi r}\text{ out} + \frac{\mu_0 I}{4\pi r}\text{ in} = \frac{\mu_0 I}{4\pi r}\text{ out}$$

Next find the force on the charged particle, using the right-hand-rule to determine the direction as down (toward the bottom of the page).

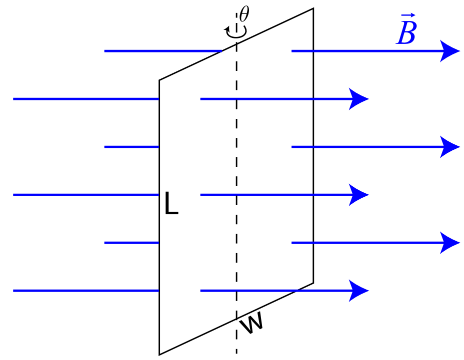
$$\vec{F} = q\vec{v}\times\vec{B} \rightarrow \left|\vec{F}\right| = qvB\sin\theta \xrightarrow[\sin\theta=1]{\theta=90^\circ} \left|\vec{F}\right| = qv\frac{\mu_0 I}{4\pi r}$$

**EK:** 2.D.1 The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity, and the magnetic field vectors. 2.D.2 The magnetic field vectors around a straight wire that carries electric current are tangent to concentric circles centered on that wire. The field has no component toward the current-carrying wire. 3.C.3 A magnetic force results from the interaction of a moving charged object or a magnet with other moving charged objects or another magnet.

**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 3.3 The student can evaluate scientific questions.

**LO:** 2.D.1.1 The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. 2.D.2.1 The student is able to create a verbal or visual representation of a magnetic field around a long straight wire or a pair of parallel wires. 3.C.3.1 The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor.

# AP2 Magnetism




A magnetic field of strength B is oriented perpendicular to a rectangular loop of wire as shown. The width of the wire is w, and its length is L. The wire has a resistance per unit length of X ohms per meter. The wire is then uniformly rotated through an angle of $\theta$ about a vertical axis in a time period t. Assume $\theta$ is less than 90°.

(a) Determine the resistance of the loop of wire.

(b) Determine the emf induced in the wire while the wire is rotating.

(c) Determine the induced current in the wire while the wire is rotating.

(d) Assume the given magnetic field strength B is uncertain. Describe a quick method / experiment to verify its accuracy. Specifically highlight any additional equipment you would require.

**Answers:**

(a) $R = X(2L + 2w) = 2X(L + w)$

(b) $\varepsilon = \dfrac{\Delta\Phi_B}{\Delta t} = \dfrac{\Phi_{B_f} - \Phi_{B_i}}{t} = \dfrac{LwB\sin\theta - LwB}{t} = \dfrac{LwB}{t}(\sin\theta - 1)$

(c) $I = \dfrac{\varepsilon}{R} = \dfrac{LwB}{t}\dfrac{(\sin\theta - 1)}{2X(L + w)} = \dfrac{LwB(\sin\theta - 1)}{2Xt(L + w)}$

(d) There are a number of possible correct answers. One implementation could involve inserting an ammeter into the loop of wire (in series, of course) and running the exact scenario described, recording the angle through which the rectangle of wire is rotated, the time it takes to do so, and recording the ammeter reading. Magnetic field strength could then be determined from:
$B = \dfrac{2IXt(L + w)}{Lw(\sin\theta - 1)}$

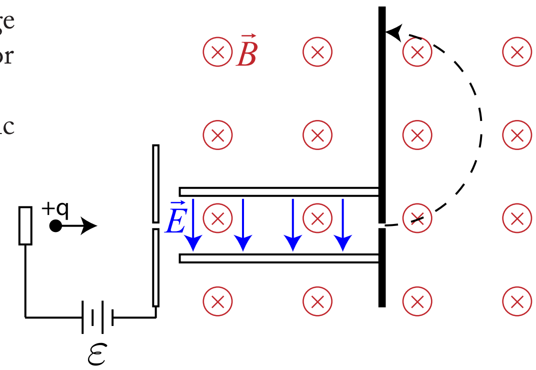
**EK:** 4.E.2 Changing magnetic flux induces an electric field that can establish an induced emf in a system. 4.E.4 The resistance of a resistor, and the capacitance of a capacitor, can be understood from the basic properties of electric fields and forces, as well as the properties of materials and their geometry.

**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 4.2 The student can design a plan for collecting data to answer a particular scientific question.

**LO:** 4.E.2.1 The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area. 4.E.4.2 The student is able to design a plan for the collection of data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors.

# AP2 Magnetism

A mass spectrometer is built such that an ion of known mass with charge +q is accelerated through a small slit such that it enters a velocity selector with speed v. The velocity selector is comprised a uniform electric field of strength E between two plates, placed in a region of uniform magnetic field strength B. A small slit at the end of the velocity selector admits particles that have passed through the region with no deflection into a region with just a uniform magnetic field, causing the ion to move in a circular path of radius r before striking a detector.




Answer parts (a) and (b) in terms of B, E, q, and r.

(a) Derive the speed of the ion such that it passes through the velocity selector undeflected.

(b) Determine the mass of the ion.

Following an equipment malfunction, it is observed that the radius of curvature of ions of the same type is 10% greater than it was when the machine was functioning correctly.

(c) Which of the following are possible causes of this discrepancy? Justify your answers.

_____ The emf of the battery has increased.

_____ The electric field strength has increased.

_____ The magnetic field strength has increased.

# AP2 Magnetism

**Answers:**

(a) The electric force and the magnetic force must have matching magnitudes for the particle to pass through the velocity selector undeflected:

$$\left|F_e\right| = \left|F_B\right| \rightarrow qE = qvB \rightarrow v = \frac{E}{B}$$

(b) Determine the mass of the ion by recognizing that in the deflection chamber, the centripetal force is caused solely by the magnetic force on the moving charged particle:

$$F_c = qvB = \frac{mv^2}{r} \rightarrow qB = \frac{mv}{r} \rightarrow v = \frac{qrB}{m} \xrightarrow{v=\frac{E}{B}} \frac{E}{B} = \frac{qrB}{m} \rightarrow m = \frac{qrB^2}{E}$$

(c)

| | |
|---|---|
| _No__ The emf of the battery has increased. | Increasing the emf of the battery would allow more energetic ions into the velocity selector, but only ions of the original velocity would exit the velocity selector. |
| _Yes_ The electric field strength has increased. | Increasing the electric field strength would allow ions with higher speeds into the deflection chamber, resulting in a larger radius of travel. |
| _No__ The magnetic field strength has increased. | Increase the magnetic field strength would allow ions with lower speeds into the deflection chamber, resulting in a smaller radius of travel. |

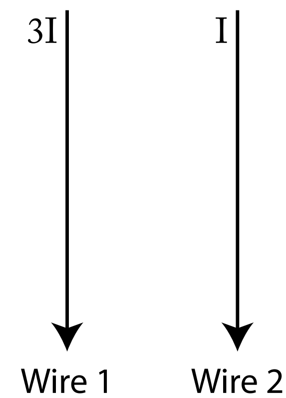
**EK:** 2.C.1 The magnitude of the electric force F exerted on an object with electric charge q by an electric field E is F=qE. The direction of the force is determined by the direction of the field and the sign of the charge, with positively charged objects accelerating in the direction of the field and negatively charged objects accelerating in the direction opposite the field. 2.D.1 The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity, and the magnetic field vectors.

**SP:** 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 3.3 The student can evaluate scientific questions. 5.3 The student can evaluate the evidence provided by data sets in relation to a particular scientific question. 6.5 The student can evaluate alternative scientific explanations. 7.2 The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

**LO:** 2.C.1.1 The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: F=qE; a vector relation. 2.C.1.2 The student is able to calculate any one of the variables - electric force, electric charge, and electric field - at a point given the values and sign or direction of the other two quantities. 2.D.1.1 The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field.

# AP2 Magnetism

The currents in two long parallel wires are I and 3I in the directions shown in the diagram at right. The magnetic force on wire 2 due to the current in wire 1 is F. The magnitude and direction of the force on wire 1 due to the current in wire 2 is




(A) F/3 and to the right
(B) F and to the left
(C) 3F and to the left
(D) F and to the right

**Answers:** (D) F and to the right. Both wires feel the same force regardless of the relative current, consistent with Newton's 3rd Law of Motion. Since the currents are in the same direction, they will attract.

**EK:** 2.D.1 The magnetic field exerts a force on a moving electrically charged object. That magnetic force is perpendicular to the direction of velocity of the object and to the magnetic field and is proportional to the magnitude of the charge, the magnitude of the velocity and the magnitude of the magnetic field. It also depends on the angle between the velocity, and the magnetic field vectors. 2.D.2 The magnetic field vectors around a straight wire that carries electric current are tangent to concentric circles centered on that wire. The field has no component toward the current-carrying wire.

**SP:** 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

**LO:** 2.D.1.1 The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. 2.D.2.1 The student is able to create a verbal or visual representation of a magnetic field around a long straight wire or a pair of parallel wires.