Exam 1 Information

- Exam Date: Wednesday Feb. 14, 6 -7:25 pm.
- Conflict Exam, Thursday Feb. 15, 6 – 7:25 pm.
  - ➢ Available to students with legitimate time conflict with regularly scheduled exam.
  - ➢ You must inform your section professor and Prof. Ciolek by email <u>by 5 pm Monday, Feb. 12</u> that you would like to take the conflict exam and state the reason why.
  - ➢ We reserve the right to deny a student from taking the conflict exam if we determine there is not a legitimate reason for taking the exam at that alternate time, or if they have not informed instructors in advance, as required above.
- Students with accommodations
  - ➢ Submit a copy of your accommodations form to your section instructor. If you have already done so, best to remind instructors of your accommodations.
  - ➢ Exam will be taken in 2C14 of the J-Rowl Science Center.
  - ➢ Start at the regular time and submit at the agreed time.

Exam Information (2)

- Allowed resources –
  - You may use a calculator with capabilities and functions up to the TI-Nspire. Devices with communication/internet capability are not allowed.
  - You are allowed a single $8.5'' \times 11''$ sheet of paper (both sides) formula/crib sheet. <u>Must be a single piece of paper – no taped or stapled pages.</u>
  - Writing instruments (pencils, pens). For pens, darker inks are preferred.

Exam Information (3)

- Exam Structure
  - Multiple choice and numerical short answer questions for ~ 70% to 80% of exam pts.
    - ~ ½ conceptual and scaling questions
    - ~ ½ numerical solution
  - Free response questions for the remaining % of exam pts.
- Good resources
  - MasteringPhysics: Lecture quizzes; Practice Problems; Homework
  - Exam Archives (LMS)
  - Activity worksheets
  - Lecture slides
  - Text
- Monitor your email and LMS announcements for exam information and updates.

Exam Information (4)

- Exam cover page includes table of physical constants.

Physics 1200 -- Physics II   Examination 1A – 14 Feb 2024
You may keep and write on these pages. You need not hand them in.

Exams for each section are given in the rooms listed. **If you are in the wrong section, notify the proctor immediately.**

Section	Instructor	Exam Room
1	Robles Sanchez	West Hall Auditorium
2	Robles Sanchez	West Hall Auditorium
3	Zheng	Amos Eaton 214
4	Zheng	Amos Eaton 214
5	Persans	Sage 3303
6	Schroeder/Ciolek	West Hall Auditorium
7	Schroeder/Ciolek	West Hall Auditorium
8	Martin	Sage 3303
9	Martin	Sage 3303
Accommodations	All	JROWL 2C14

- The total number of pages in this exam, including this cover page, is given in the footer. Check that you have them all.
- Be sure to write and bubble in your RIN on the front of the bubble sheet.
- Use the front of the bubble sheet to record and submit your answers to the multiple-choice questions.
- Submit your answers to the free response questions on the back of the bubble sheet. <u>You must show work and/or logic to get full credit for free response questions.</u>
- This exam should start promptly at <u>6:00 pm</u> and end promptly at <u>7:25 pm</u>
- If you are unclear on any question, ask a proctor.
- You are permitted a single 8.5″ × 11″ sheet for notes (2 sides). Use of any other materials will result in a zero for this examination. You may use a calculator up to the TI-Nspire for math functions.
- Collaboration/cheating on this exam will result in a non-droppable zero grade and a letter to the Dean of Students for all students involved. Use of a communication device (e.g.- cell phone) during the exam will be interpreted as evidence of collaboration.
- Assume three significant figures unless otherwise stated.
- All units are SI/MKSA (meters, kilograms, seconds, amperes (Coulomb/sec)) unless otherwise stated.

Approximate values of some useful constants:

$$\mu_0 = 4\pi \times 10^{-7}\,\frac{\mathrm{T{\cdot}m}}{A} \cong 1.26 \times 10^{-6}\,\frac{\mathrm{T{\cdot}m}}{\mathrm{A}}$$
$$\varepsilon_0 \cong 8.85419 \times 10^{-12}\,\frac{\mathrm{C^2}}{\mathrm{N{\bullet}m^2}}$$
$$k = \frac{1}{4\pi\varepsilon_0} \cong 9 \times 10^9\,\frac{\mathrm{Nm^2}}{\mathrm{C^2}}$$
$$c \cong 3.00x10^8 \quad \mathrm{m/s}$$
$$g \cong 9.81\ \mathrm{m/s}$$
$$h \cong 6.63 \times 10^{-34}\ \mathrm{J\cdot s}$$

$$m_{electron} \cong 9.11 \times 10^{-31}\ \mathrm{kg}$$
$$m_{proton} \cong 1.67 \times 10^{-27}\ \mathrm{kg}$$
$$q_{electron} = -e \cong -1.60 \times 10^{-19}\ \mathrm{C}$$
$$q_{proton} = +e \cong +1.60 \times 10^{-19}\ \mathrm{C}$$

1 nano-thing=10^{-9} thing
1 micro-thing=10^{-6} thing

Physics 1200
Lecture 09
Spring 2024

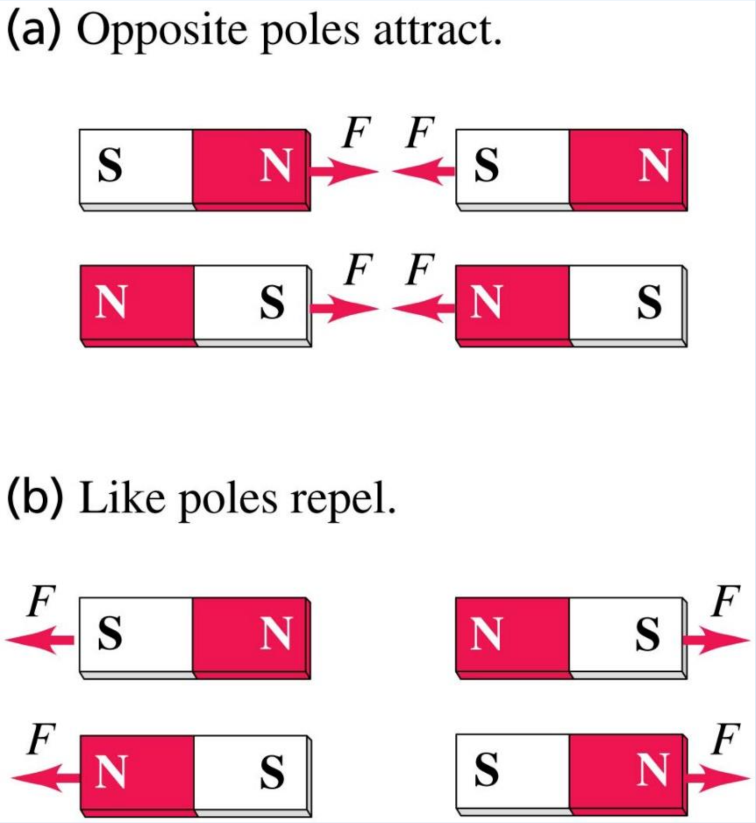
Magnetic Forces and Fields

Magnets & Magnetism: Observations

- Familiar examples of magnetism are permanent magnets, which attract unmagnetized iron objects and can also attract or repel other magnets.
- A compass needle aligning itself with the earth's magnetism is an example of this interaction.
- But the fundamental nature of magnetism is the interaction of moving electric charges.
- We will associate the force with a **new** field: the magnetic field.
- Magnetic fields are often observed as dipole fields: the field strength is proportional to $1/r^3$, where r is the distance from the source of magnetic field.

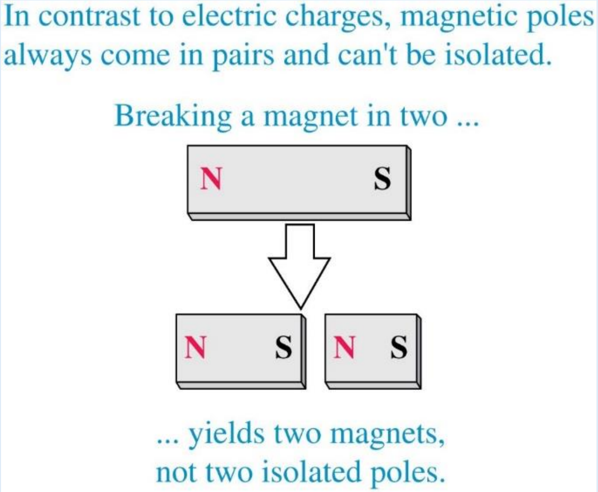
Magnetic Poles

- If a bar-shaped permanent magnet, or bar magnet, is free to rotate, one end points north; this end is called a <u>north pole</u>.
- The other end is a <u>south pole</u>.
- Opposite poles attract each other, and like poles repel each other.



Magnetic Poles (2)

- Magnetic poles always come in pairs



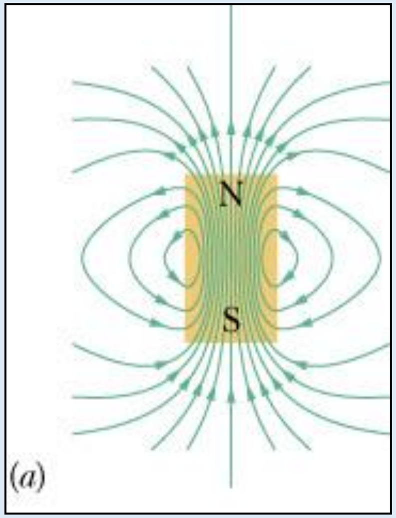
- No experimental evidence for magnetic monopoles.
  - We've looked! Investigated deep-sea floor sediments, meteorites, moon rocks, etc.
  - If only a single magnetic monopole existed – in the entire universe – it would explain quantization of electric charge (Dirac, 1931, 1948).
  - Would also make Maxwell's equations look even more symmetric (we'll learn about those in a few weeks) with the appearance of both electric and magnetic "charges" (i.e., monopoles) in the equations.

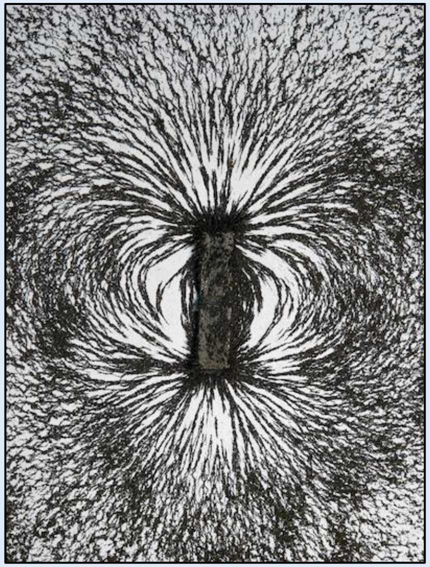
Magnetic Poles (3)

- Experiment has <u>never</u> found any magnetic monopoles.
- No monopoles has consequences for magnetic fields.
    - Electric fields: found that electric fields come out of positive charges (positive electric monopoles) and end in negative charges (negative electric monopoles). That is, electric fields can have starting and ending points.
    - Magnetic fields: no monopoles mean no start and end points for magnetic fields. <u>Magnetic field lines must always be closed loops!</u> In some cases, the loops must close very far away from the magnet (i.e., at infinity).

Magnetic field lines of a permanent magnet

The lines pass through the body of the magnet and form **closed** loops.



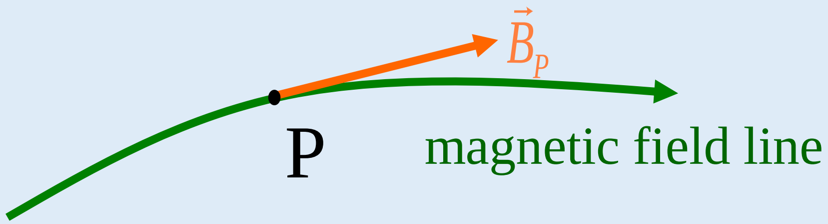


The Magnetic Field and Magnetic Field Lines

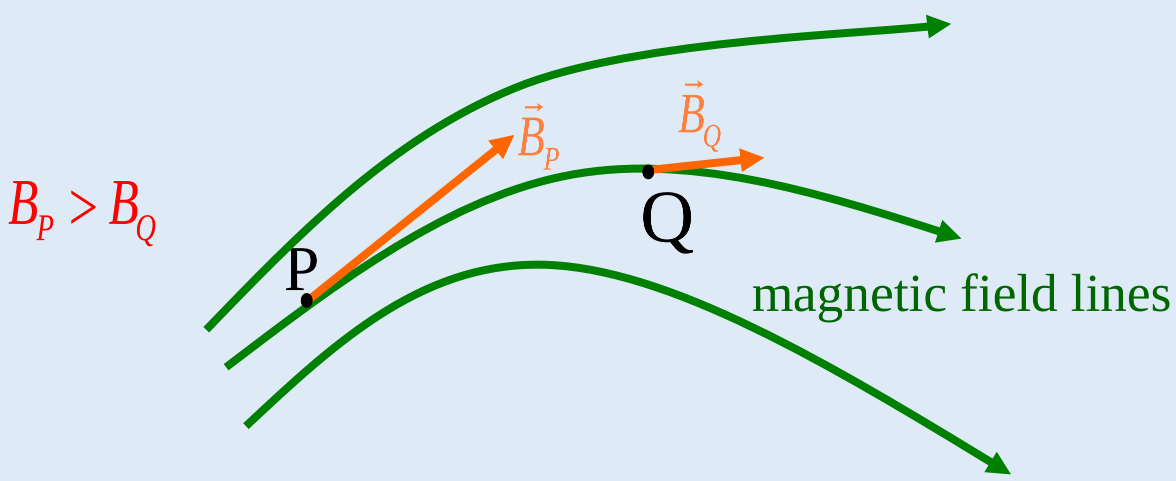
- Standard notation for magnetic field vector (“magnetic induction”) is $\vec{\boldsymbol{B}}$.
- Another quantity frequently used – associated with magnetic media – also known as the magnetic field vector $\vec{\boldsymbol{H}}$. Won’t be dealing with that in this course.
- At any position, direction of $\vec{\boldsymbol{B}}$ is defined as the direction that the north pole of a compass points.
- Like an electric field, a magnetic field is a vector field—i.e., a vector quantity associated with each point in space.
- A magnetic field exerts a force on any moving charge (or current) present in the field.
- Moving charges (including currents) are sources of magnetic fields. To be discussed in the next couple of lectures.

The Magnetic Field and Magnetic Field Lines (2)

- Similar to electric fields, magnetic fields can also be understood in terms of <u>magnetic field lines.</u>
  - At any point P the magnetic field vector is tangent to the field lines

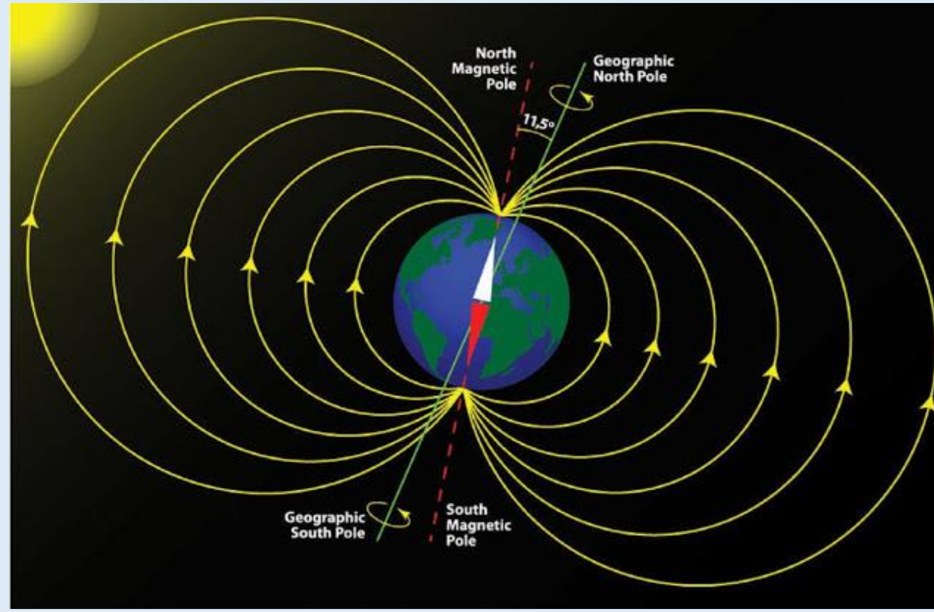


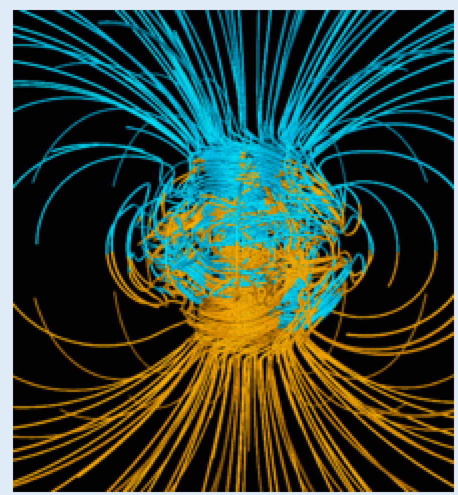
  - Density of lines (spacing) is proportional to the field strength



The Earth’s Magnetic Field

- Earth is itself a magnet.
- The north geographic pole is close to a magnetic south pole, which is why the north pole of a compass needle points north.
- Earth’s magnetic axis is not quite parallel to its geographic axis (the axis of rotation), so a compass reading deviates from geographic north.
- This deviation varies with location; called the magnetic declination or magnetic variation.
- The magnetic field is not horizontal at most points on Earth’s surface; the angle up or down is called magnetic inclination.





Magnetic Field Units

- SI unit of magnetic field is the tesla (T), named after Nikolai Tesla.
- $1\ \mathrm{T} = 1\,\frac{\mathrm{N}}{\mathrm{m}\cdot\ \mathrm{A}}$.
- Another unit of magnetic field is the gauss (G). $1\ \mathrm{G} = 10^{-4}\ \mathrm{T}$.
- The Earth's magnetic field is $\sim 10^{-4}\ \mathrm{T} = 1\ \mathrm{G}$.

Magnetic Force on Moving Charges

- Experiment reveals that there is a magnetic force on a charged particle when it moves within a magnetic field.
- The force can be written as a vector cross product of the particle's charge q, velocity $\vec{\boldsymbol{v}}$, and the magnetic field $\vec{\boldsymbol{B}}$ that the particle is moving in:

$$\boxed{\vec{\boldsymbol{F}} = q\vec{\boldsymbol{v}} \times \vec{\boldsymbol{B}}}\,.$$

- Recall property of vector cross products: <u>the resultant force $\vec{\boldsymbol{F}}$ is perpendicular to both $\vec{\boldsymbol{v}}$ and $\vec{\boldsymbol{B}}$</u>.

Vector Cross Product

- Direction of resultant cross-product vector can be found using a right-hand rule (RHR).
- Recall result for magnitude of a cross product vector:

  $\boxed{|\vec{\boldsymbol{c}}| = |\vec{\boldsymbol{a}}| \left|\vec{\boldsymbol{b}}\right| \sin\theta}$, where θ is the acute angle between $\vec{\boldsymbol{a}}$ and $\vec{\boldsymbol{b}}$, directed from $\vec{\boldsymbol{a}}$ toward $\vec{\boldsymbol{b}}$.

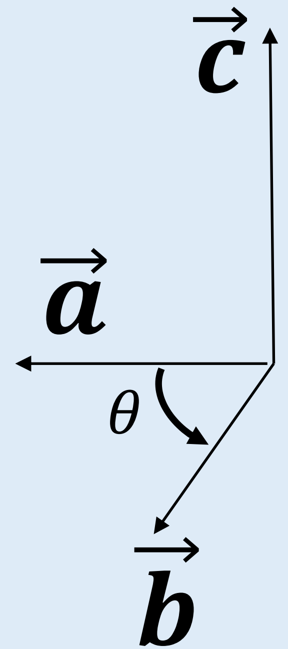
- Magnitude $F = qvB\sin\theta$.
- $F = 0$ for: (i) $q = 0$,

  (ii) $v = 0$,

  (iii) $B = 0$,

  and/or (iv) $\theta = 0$ or $180°$.

$$\boxed{\vec{\boldsymbol{c}} = \vec{\boldsymbol{a}} \times \vec{\boldsymbol{b}}}$$

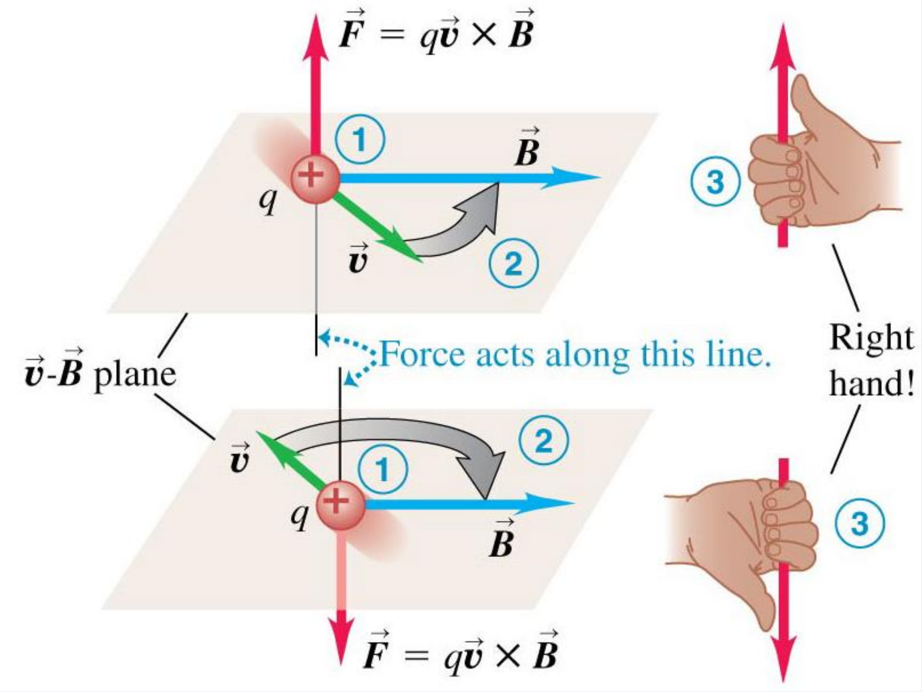


Right-Hand Rule (RHR) for Magnetic Force

Positive charge $(q > 0)$: force is in the same direction as the cross product.

Steps used to find force direction:

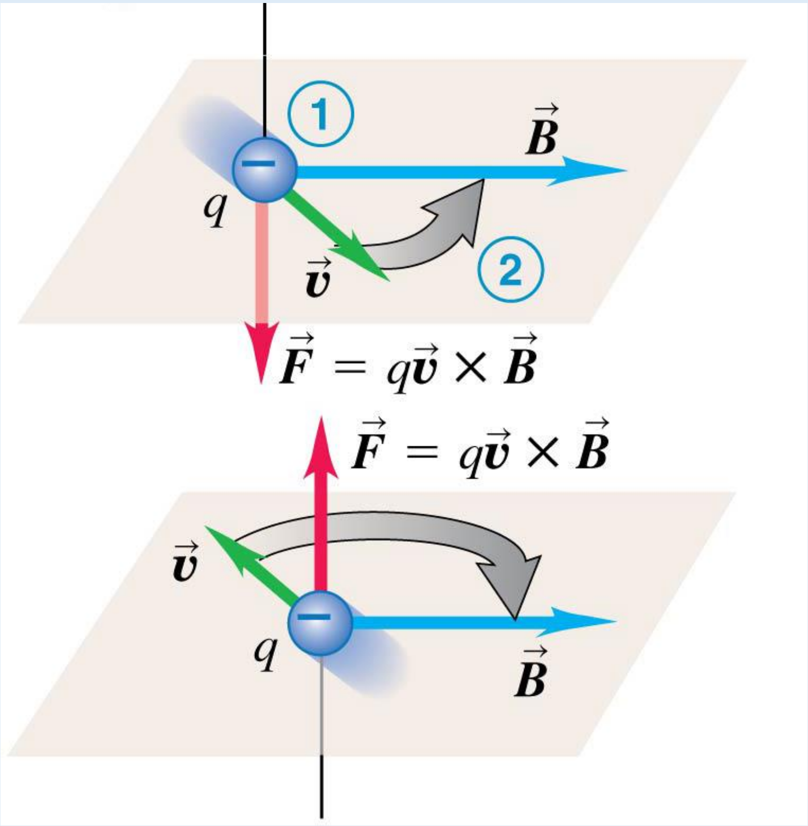
1. Bring $\vec{\boldsymbol{v}}$ and $\vec{\boldsymbol{B}}$ vectors together so that they touch tail-to-tail.
2. Curl your fingers from direction of $\vec{\boldsymbol{v}}$ toward $\vec{\boldsymbol{B}}$, along the acute (i.e., interior) angle between the two vectors.
3. Resulting direction thumb points is the direction of $\vec{\boldsymbol{F}}$ for $q > 0$.



Right-Hand Rule (RHR) for Magnetic Force (2)

Negative charge $(q < 0)$: force is in the opposite direction to the cross product.

For that case, follow same three steps as shown on the last slide. Then add step 4: take the force to be in the opposite direction that your thumb points.



The Vector Product $\vec{c} = \vec{a} \times \vec{b}$ in terms of Vector Components

$$\vec{a} = a_x \hat{i} + a_y \hat{j} + a_z \hat{k}$$

$$\vec{b} = b_x \hat{i} + b_y \hat{j} + b_z \hat{k}$$

$$\vec{c} = c_x \hat{i} + c_y \hat{j} + c_z \hat{k}$$

The vector components of vector $\vec{c}$

are given by the equations:

$$c_x = a_y b_z - a_z b_y$$

$$c_y = a_z b_x - a_x b_z$$

$$c_z = a_x b_y - a_y b_x$$

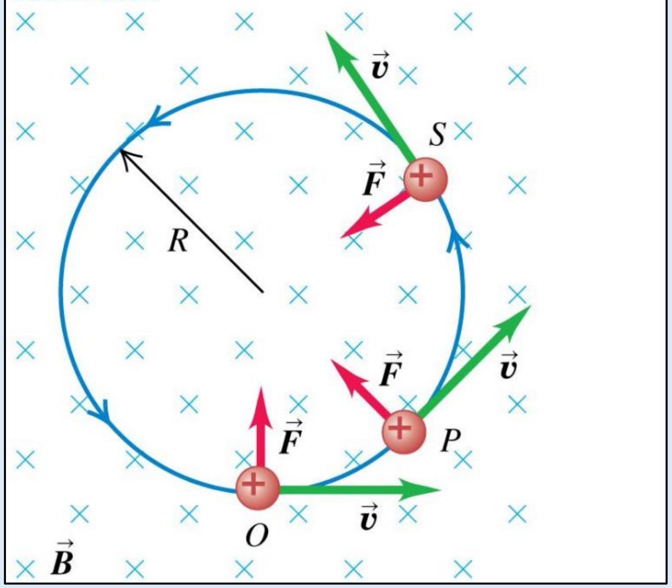
Note : Those familiar with the use of determinants can use the expression

$$\vec{a} \times \vec{b} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$

Motion of Charged Particles in a Uniform Magnetic Field

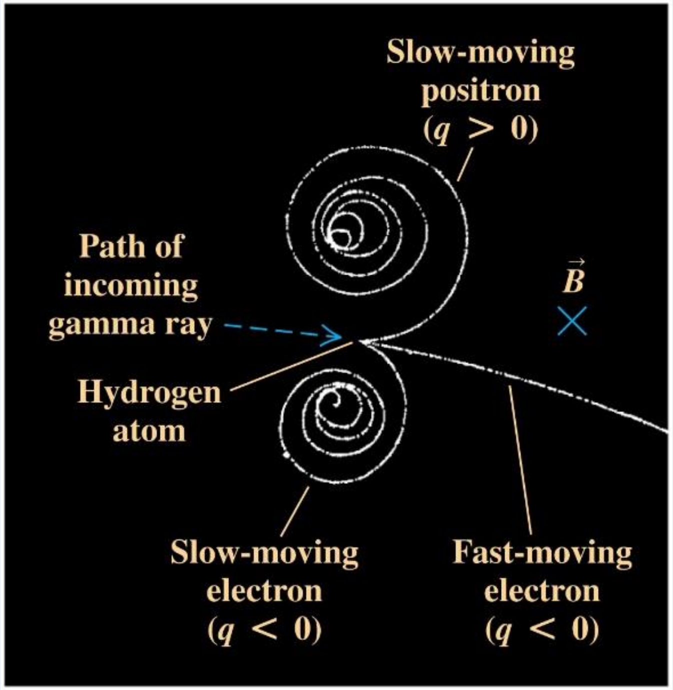
- A charged particle moving in a magnetic field can be acted on by a magnetic force.
- The force is always perpendicular to the velocity.
  - ∴ <u>Magnetic force does no work on the particle</u>.
    - Magnetic force doesn't change a particle's kinetic energy.
    - Magnetic force can't change the speed v of a particle.
    - Since v is constant, if field is uniform (constant in space), the magnitude of magnetic force is also constant.
    - Result: <u>uniform circular motion of the particle in a plane perpendicular to the magnetic field direction</u>.

A charge moving at right angles to a uniform $\vec{B}$ field moves in a circle at constant speed because $\vec{F}$ and $\vec{v}$ are always perpendicular to each other.



Motion of Charged Particles in a Uniform Magnetic Field (2)

- Shown are bubble tracks from a chamber filled with liquid hydrogen, for a magnetic field directed into the plane of the photograph.
- Tracks show that a high-energy gamma ray (which does not leave a track) collided with an electron in a hydrogen atom.
- The electron flew off to the right at high speed.
- Some of the energy in the collision led to the creation of a second electron and a positron (the antimatter counterpart to an electron). Called “electron-positron pair production.”



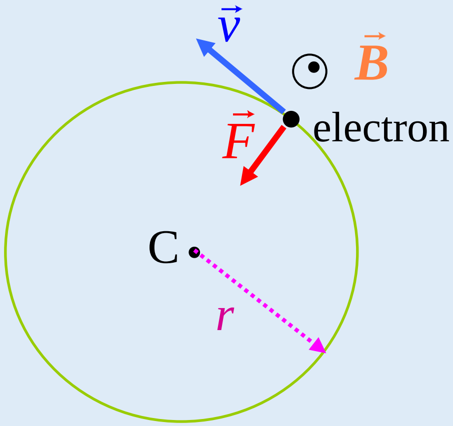
Motion of Charged Particles in a Uniform Magnetic Field (3)

The orbital radius can be found in a straightforward manner, by using Newton's 2nd law:

$$F_B = ma_{\mathrm{cent}} \,,$$

$$F_B = |q|vB \sin 90° = \frac{mv^2}{r}$$

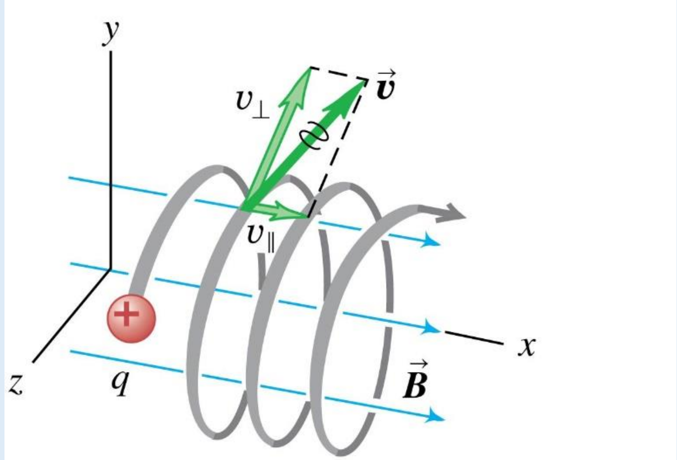
$$\Rightarrow \boxed{r = \frac{mv}{|q|B}}$$



Helical Motion

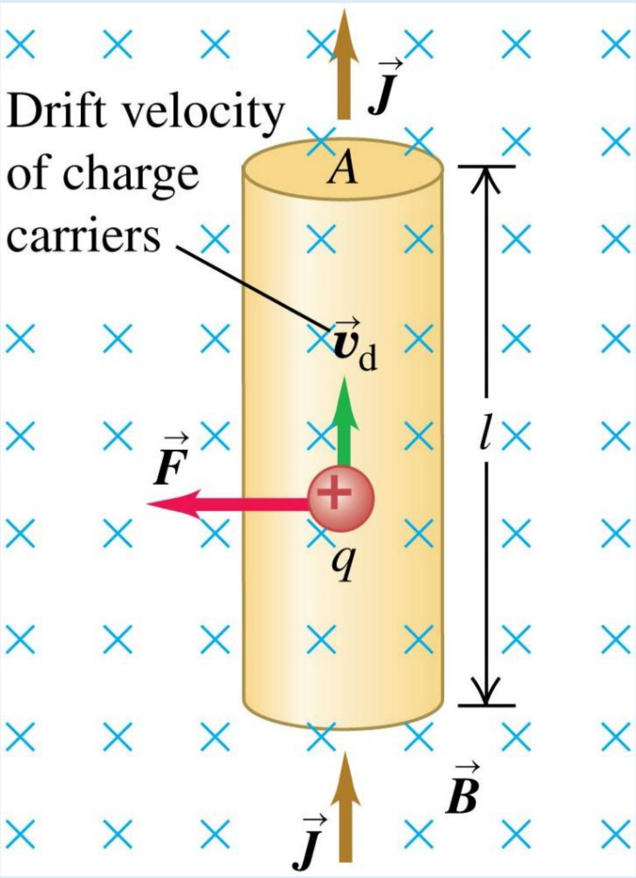
- If a particle has velocity components parallel to and perpendicular to the field, its path is a helix.
- The speed and kinetic energy of the particle remain constant.

This particle's motion has components both parallel ($v_{\parallel}$) and perpendicular ($v_{\perp}$) to the magnetic field, so it moves in a helical path.



Force on a Current-Carrying Conductor

- Shown is a segment of conducting wire of length l and cross-sectional area A. Here, the magnetic field is into the page and perpendicular to the direction of the drift velocity of a charged particle.



- Magnitude of magnetic force on a single charge is

$$F_{q,B} = qv_dB.$$

- If n is the number of charges per unit volume, the <u>total force</u> on all the charges in the segment is

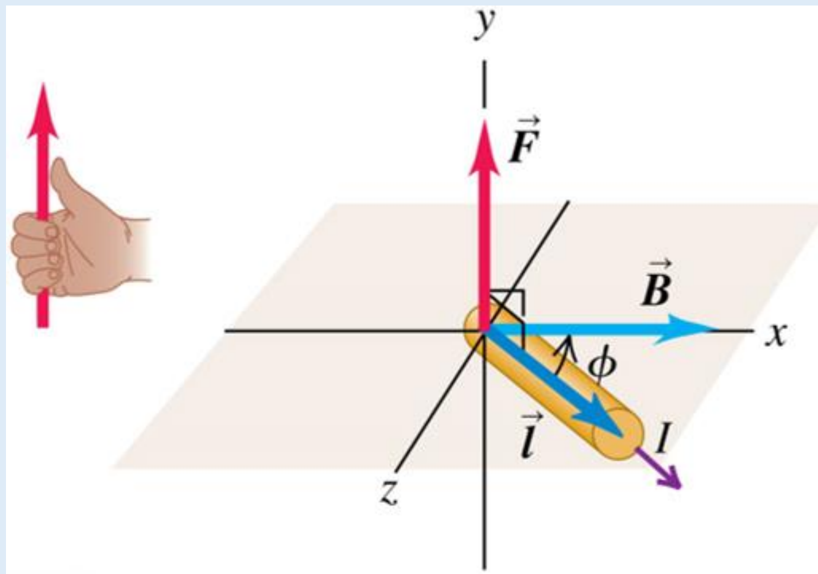
$$F_B = nAl(qv_dB) = (nqv_d)AlB = JAlB = IlB.$$

- In vector form, this is

$$\boxed{\vec{\boldsymbol{F}}_B = I\vec{\boldsymbol{l}} \times \vec{\boldsymbol{B}}},$$

Here, $\vec{\boldsymbol{l}}$ is in the direction of the current; l is the length of conductor in the magnetic field region.

Force on a Current-Carrying Conductor (2)



Current

Magnetic force on a straight wire segment $\vec{F} = I\vec{l} \times \vec{B}$ Magnetic field

Vector length of segment (points in current direction)

Lecture Question 9.1

A charged particle is initially moving with velocity $v_x\hat{\boldsymbol{\imath}}$ in a magnetic field pointing in the y-direction. What is the subsequent motion of the particle?

A) It slows down.

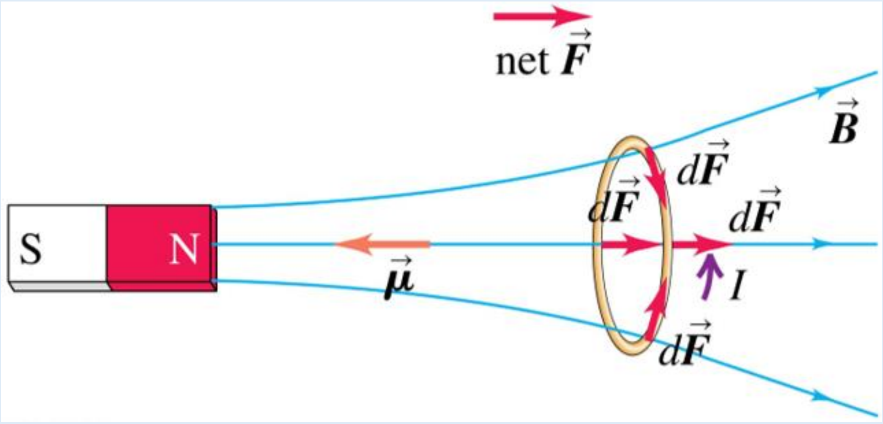
B) It moves at constant speed in a circle in the x-z plane.

C) It curves at constant speed until it travels along the field.

D) It just travels in a straight line at constant speed.

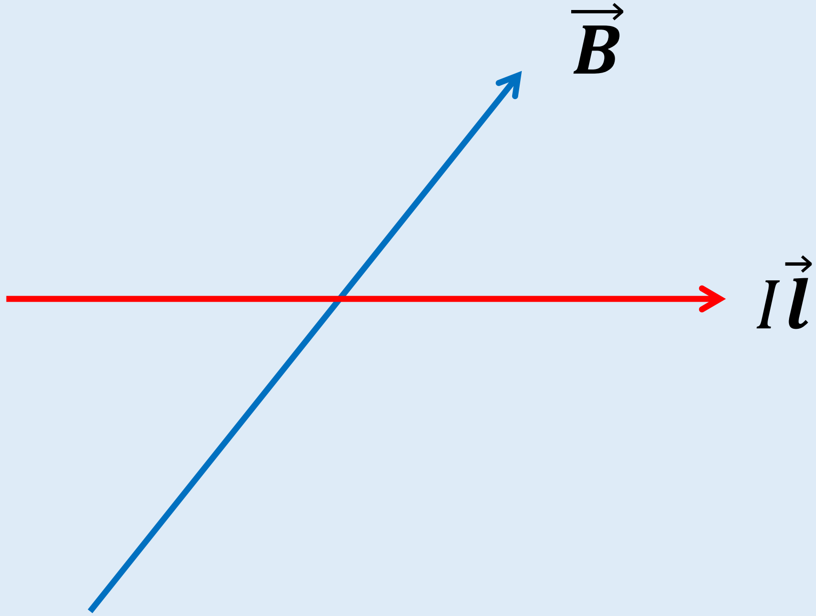
Force of a Non-Uniform Field on a Current-Carrying Conductor

- A current loop is in a magnetic field that decreases in magnitude to the right.
- When forces are summed to find the net force on the loop, radial components cancel yielding a net force to the right, away from the magnet.



Lecture Question 9.2

- A current flows along a wire that is set at an angle of 60 degrees with respect to a magnetic field.
- What is the force on a length of 0.5 m of the wire?



Lecture Question 9.3

- An electron is accelerated from rest through a potential difference of 300 V.

1) How much kinetic energy does it have after acceleration?
2) What is its velocity after acceleration?
3) The electron enters a region of constant magnetic field $B = 2 \times 10^{-3}\ \mathrm{T}$. What is the radius of curvature of the trajectory?