Magnetic force

Select LEARNING OBJECTIVES:

- Explain how magnetic fields can be created without current.
- Use superposition to find the magnetic field at a location when multiple magnets are present.

TEXTBOOK CHAPTERS:

Boxsand :: uniform circular motion in magnetic fields

WARM UP: Magnetic field questions?

In the introduction to magnetic fields there is a walkthrough of an experiment with a positive point charge and a current carrying wire. Take a moment to review that experiment. In addition to the surprise of needing to identify a new type of force, the magnetic force, it was observed that this magnetic force is only present on the positive point particle when the particle had a velocity. In this lecture we will explore the magnetic force on charged particles in the presence of a magnetic field, as well as the magnetic force on current carrying wires in the presence of a magnetic field. Before we dive into finding the magnetic force, it's beneficial if we briefly review the field model in terms of magnetic fields and how they relate to magnetic forces.

Review of the field model

We have already explored how magnetic fields are created: by charged point particles with a velocity, by current carrying wires, and by inherently magnetic materials via quantum mechanics. Remember that the essence of the field model is that something creates a field, and then something else that finds itself in that field experiences some force associated with the interaction with the field. In terms of magnetic fields, let's assume that a current carrying wire creates a magnetic field everywhere in space around it. Then a charged point particle that moves with velocity within the magnetic field created by the wire feels a magnetic force due to the interaction between itself and the magnetic field. Even if the charged point particle didn't exist, the magnetic field from the wire would still be present, just no magnetic forces exists until the charged point particle enters the magnetic field with a velocity.

Magnetic force on moving point particle with charge

Through experiments, one can show that the magnetic force on a charged point particle with velocity turns out to be perpendicular to both the velocity and the magnetic field. This type of perpendicular behavior invites us to use the cross product, a vector operation, to mathematically model the magnetic force. The mathematical model is shown below.

CROSS PRODUCT

$$\boxed{\vec{F}^{B}_{\text{on } q_0} = q_0 \, \vec{V} \times \vec{B}}$$

EXTERNAL MAGNETIC FIELD THAT POINT PARTICLE IS MOVING THROUGH

MAGNETIC FORCE ON q_0

CHARGE OF POINT PARTICLE

VELOCITY OF POINT PARTICLE

SMALLEST ANGLE BETWEEN $\vec{V}$ AND $\vec{B}$ WHEN PLACED TAIL-TO-TAIL

* IN PRACTICE:

- $|\vec{F}^{B}| = |q_0| \, |\vec{V}| \, |\vec{B}| \sin\theta$
- THEN USE RHR FOR CROSS PRODUCTS TO FIND DIRECTION

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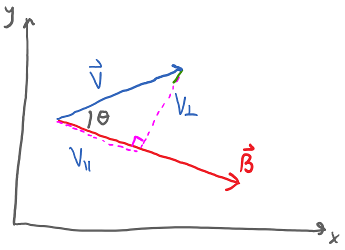
* RECALL: CROSS PRODUCTS "ASKS HOW ⊥ TWO VECTORS ARE TO EACH OTHER".

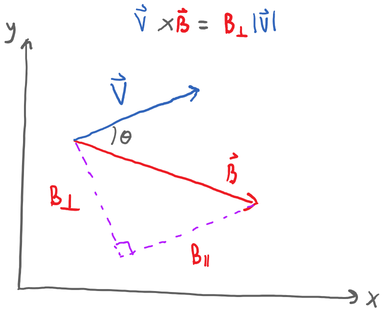
* THE MORE ⊥ $\vec{V}$ AND $\vec{B}$ ARE, THE LARGER THE MAGNETIC FORCE

$\vec{V} \times \vec{B} = V_\perp |\vec{B}|$



$V_\perp = |\vec{V}| \sin\theta$

$\vec{V} \times \vec{B} = B_\perp |\vec{V}|$

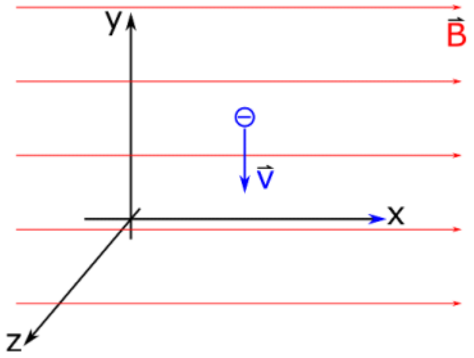


$B_\perp = |\vec{B}| \sin\theta$

Here we wish to find the magnetic force on a charged point particle. Force is a vector thus we must rely on our new skills of finding a vector when cross products are involved. Recall that we first find the magnitude of the vector, then use the right hand rule to find the direction. It's also useful to think in general what the cross product is doing; in essence it is asking how perpendicular two vectors are to each other. When the cross product is its maximum value, the two vectors are perpendicular to each other, when the cross product is zero the two vectors are parallel to each other.

PRACTICE: An electron moves along the *-y* axis with a speed of *1.0×10^7 m/s*. A *0.50 T* magnetic field points in the positive *x-direction*. What is the force on the electron?

1. 8×10^{-13} N, negative z-direction
2. 8×10^{-13} N, positive z-direction
3. 7×10^{-12} N, negative x-direction
4. 7×10^{-12} N, negative y-direction
5. 6×10^{-11} N, negative z-direction



PRACTICE: A beam of electrons enters a region with a magnetic field as shown below. If the beam is deflected upwards, the magnetic field must be oriented

1. downwards