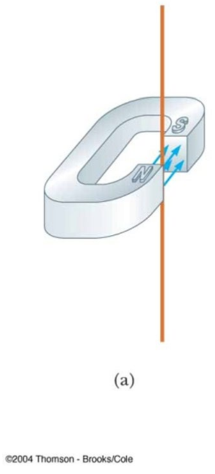
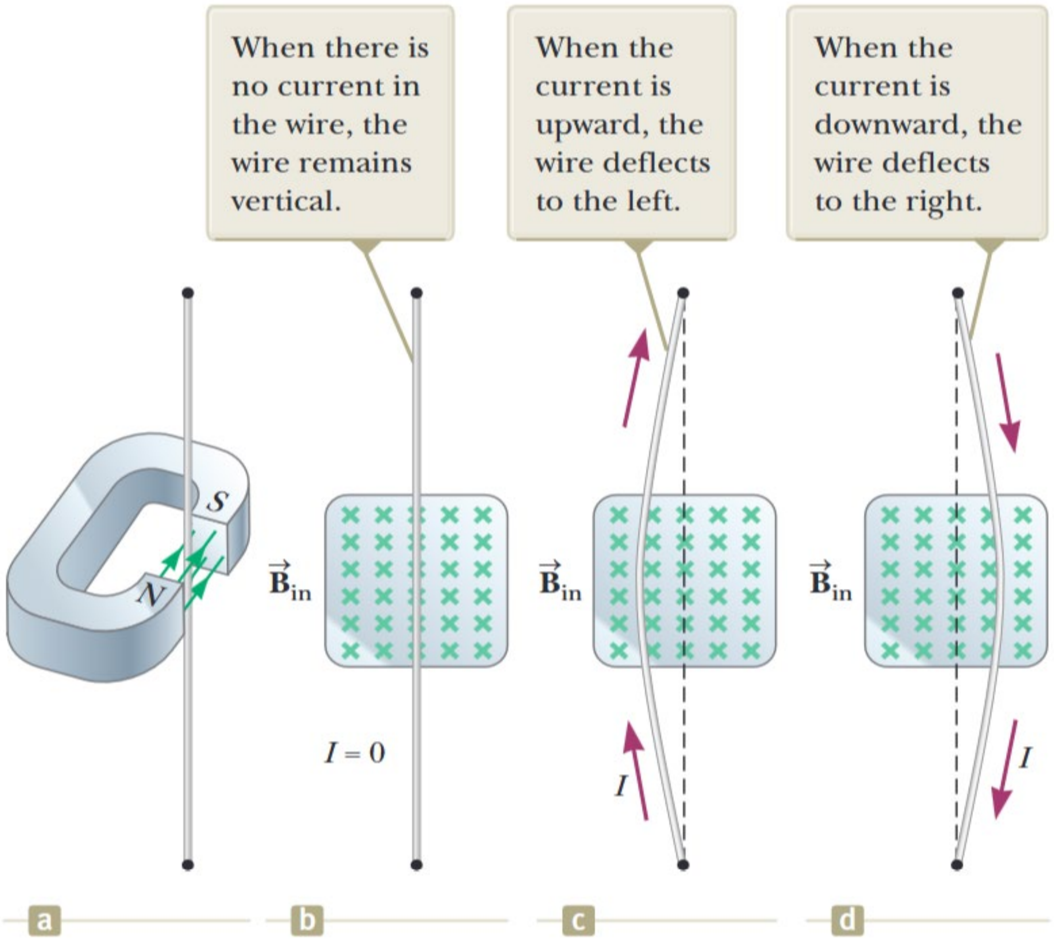
28.4 Magnetic Force acting on a current-carrying conductor



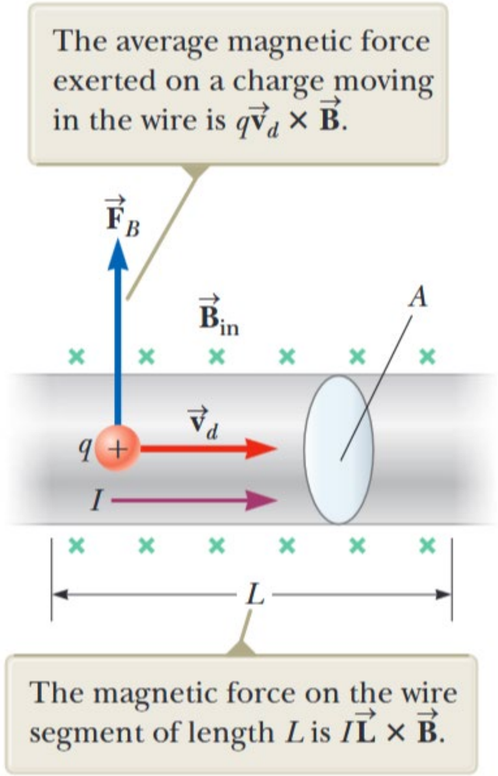
If a magnetic force is exerted on a single charged particle when the particle moves through a magnetic field, it should not surprise you that a current-carrying wire also experiences a force when placed in a magnetic field.

The current is a collection of many charged particles in motion; hence, the resultant force exerted by the field on the wire is the vector sum of the individual forces exerted on all the charged particles making up the current.

The force exerted on the particles is transmitted to the wire when the particles collide with the atoms making up the wire.



We have learned that a charged particle is affected by a magnetic force when it is placed in magnetic field, called eq. (29.1)



$$\vec{F}_B = q\ \vec{v} x \vec{B} = q|\vec{v}||\vec{B}|\ \sin\theta$$

So, for N charged particle that moves in the wire of length l and cross-section A (see figure below) the magnetic force can be written as,

$$\vec{F}_B = Nq\ \vec{v} x \vec{B}$$

Or,

$$\vec{F}_B = n.A.l\ q\ \vec{v} x \vec{B}$$

But, we know that $I = nqv_dA$.

Then,

$$\boxed{\vec{F}_B = I\ \vec{l} x \vec{B}}$$

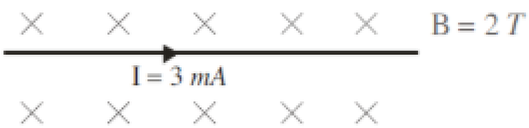
This equation represents the magnetic force exerted on a wire of length l and carrying current I.

Examples:

1- A straight wire 10 m long carries a current of 50A placed in a perpendicular uniform magnetic field. If the force per unit length on this wire is 4 N/m, what is the magnitude of the magnetic field? **(Answer: B= 0.08 T)**

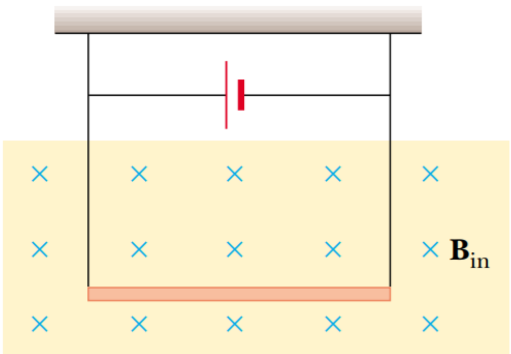
2- A conductor 3 m long carries a current of 5A and is placed in a region parallel to a uniform magnetic field of 2 T. What is the magnetic force acting on the conductor?

3- If the magnetic force acting on the wires equals 9 mN, what is the length (l)? **(Answer: L = 1.5 m)**



4- When a proton moves with a speed of 4×10^6 m/s through a magnetic field of 1.7 T, it experiences a magnetic force of 9.4×10^{-13} N. What is the angle between the proton's velocity and the magnetic field? (**Answer:** $\theta \approx 60^0$)

5- A conductor suspended by two flexible wires has a mass per unit length of 0.04 kg/m. A uniform magnetic field of magnitude 3.60 T is directed **into the page**. What current must exist in the conductor so that the **tension in the supporting wires becomes zero**? Also, determine the **required direction of the current** in the conductor.



When the tensions are zero, the upward magnetic force equals the weight of the bar.

Magnetic force on a straight wire: $F_B = I\,L\,B\,(\sin\theta)$. Here $\theta = 90° \Rightarrow \sin\theta = 1$.

Weight of the bar: $W = m\,g = (\mu\,L)\,g$.

$$Set\ F_B = W \Rightarrow I\,B = \mu\,g \Rightarrow I = (\mu\,g)/B$$

$$I = (0.0400\times9.80)/3.60 = 0.1089\ A \approx 0.109\ A$$

Direction: With B into the page, the current must be to the right so that I × B points upward.

Answer: I ≈ 0.109 A, directed to the right.

Conceptual questions

Q1. Zero force (orientation only)

A straight wire carries current III in a **uniform** magnetic field B. **Given that I and B are fixed and nonzero**, the magnetic force on the segment is zero when the wire is:

A) Perpendicular to B
B) At 45° to B
C) **Parallel to B**
D) In a region with nonuniform B
E) Curved rather than straight

Q2. Force direction (right-hand rule)

A long straight wire runs east–west and carries current **east**. A uniform magnetic field points **north**. The magnetic force on the wire points:

A) North
B) South
C) East
D) West
E) **Out of the page**

Q3. Increasing the force (one parameter)

A straight segment of length L carries current I in a uniform magnetic field B. **With I, L, and the angle θ held fixed**, which action increases the force magnitude?

A) Halve B
B) Reverse I
C) Decrease θ from 90° to 60°
D) **Increase B**
E) Rotate the wire about its axis without changing θ