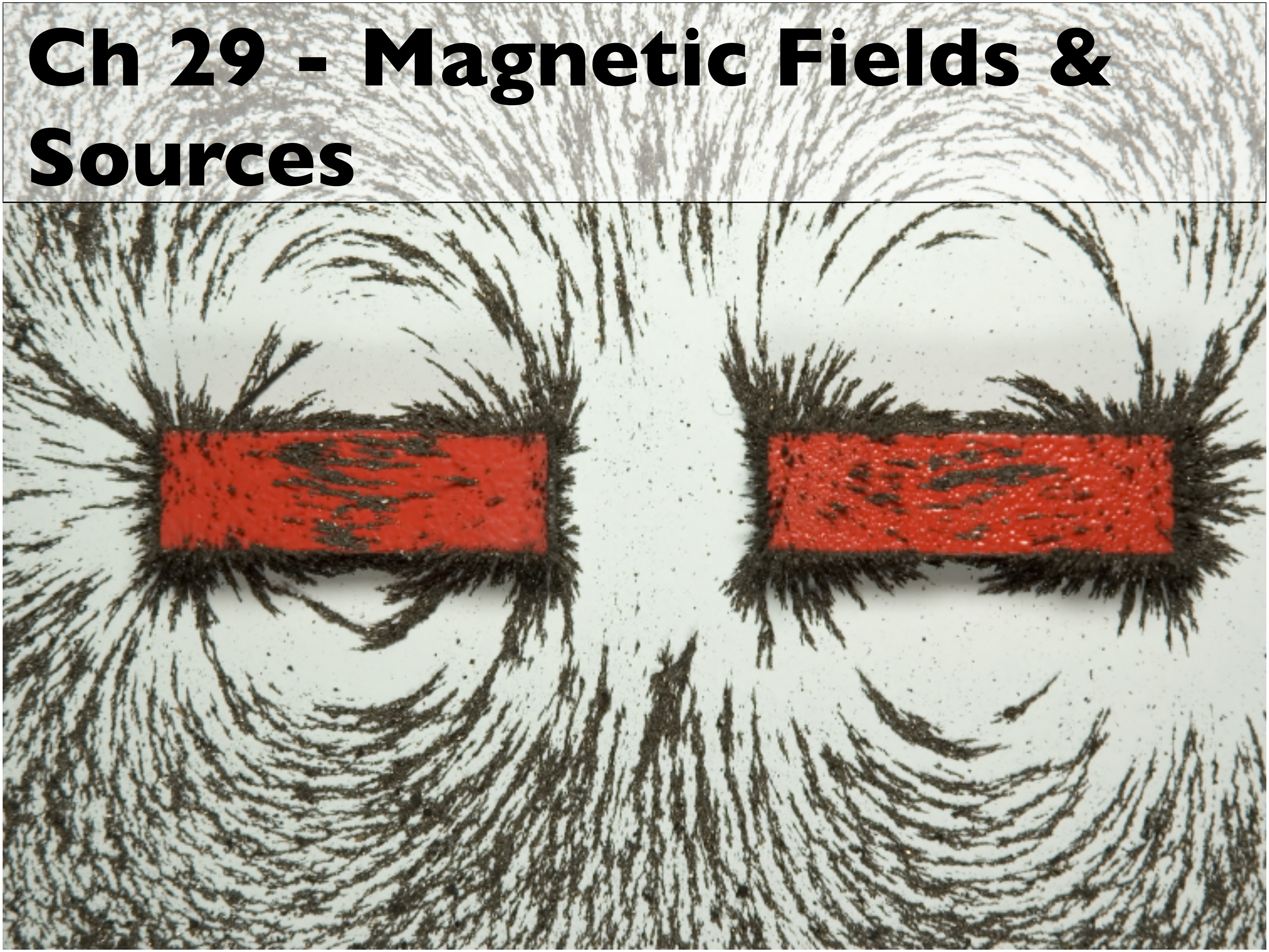
Ch 29 - Magnetic Fields & Sources



Magnets...

...are made of *ferromagnetic* elements: iron, cobalt, nickel, gadolinium...

Magnets have a north pole and a south pole.

Magnetic Fields

1. The magnetic field line has the direction of the magnetic field as its tangent at that point.
2. The number of lines per unit area is proportional to the magnitude of the magnetic field at that point.
3. The direction of the magnetic field is defined as the direction the *north pole* of a compass needle would point when placed at that position.

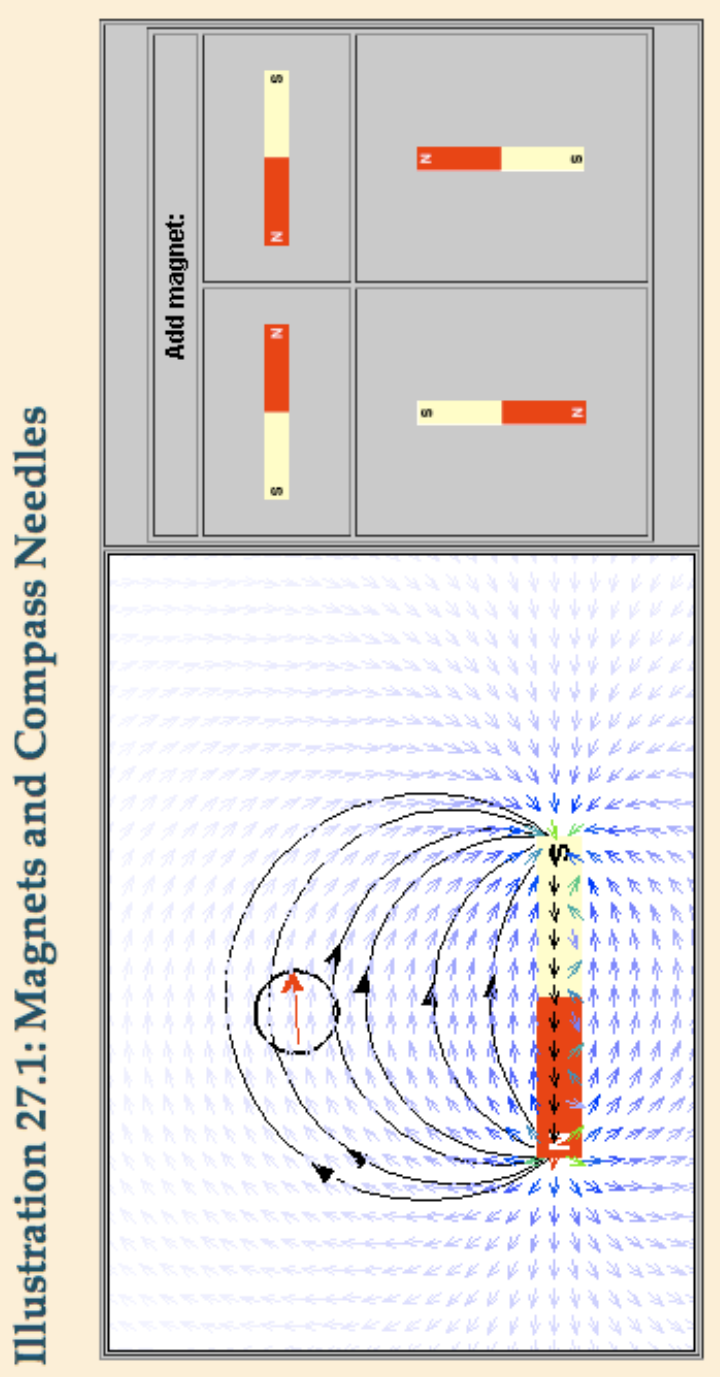
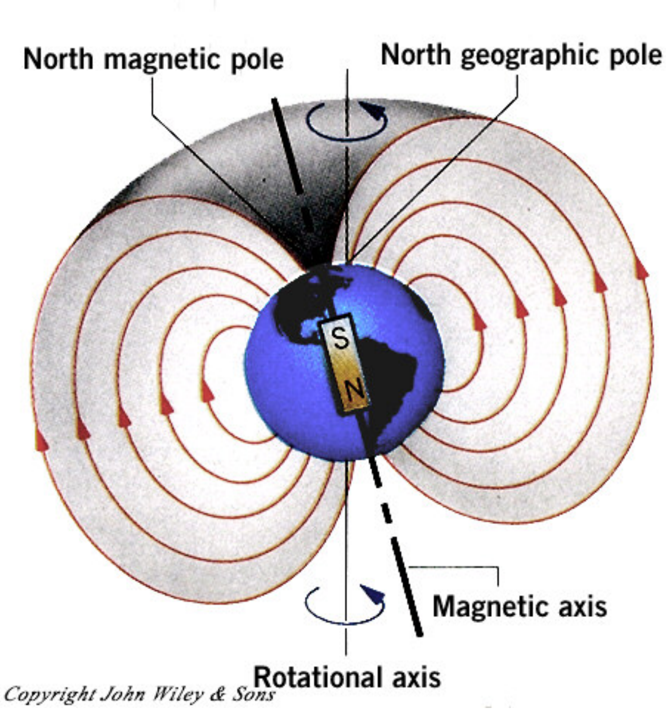
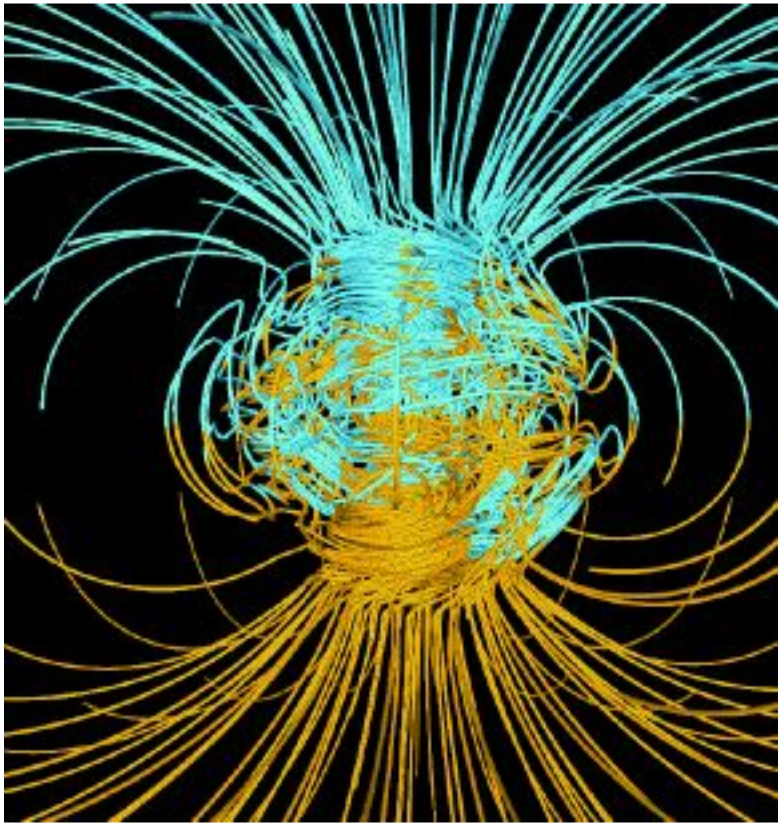


Illustration 27.1: Magnets and Compass Needles

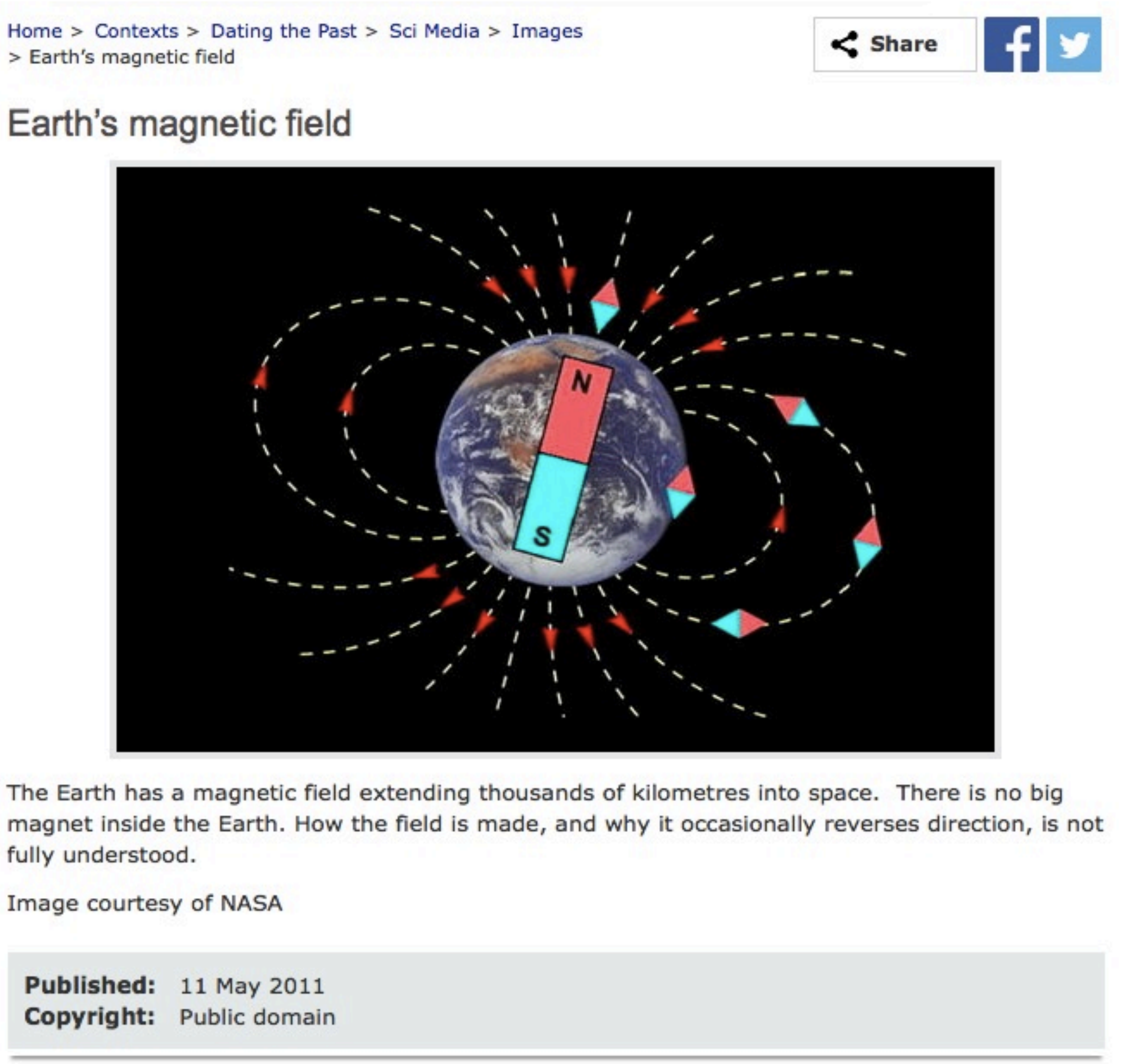
Earth's Magnetic Field





Physlet I.27.2

You’re Doing It Wrong



Home > Contexts > Dating the Past > Sci Media > Images > Earth’s magnetic field

Earth’s magnetic field

The Earth has a magnetic field extending thousands of kilometres into space. There is no big magnet inside the Earth. How the field is made, and why it occasionally reverses direction, is not fully understood.

Image courtesy of NASA

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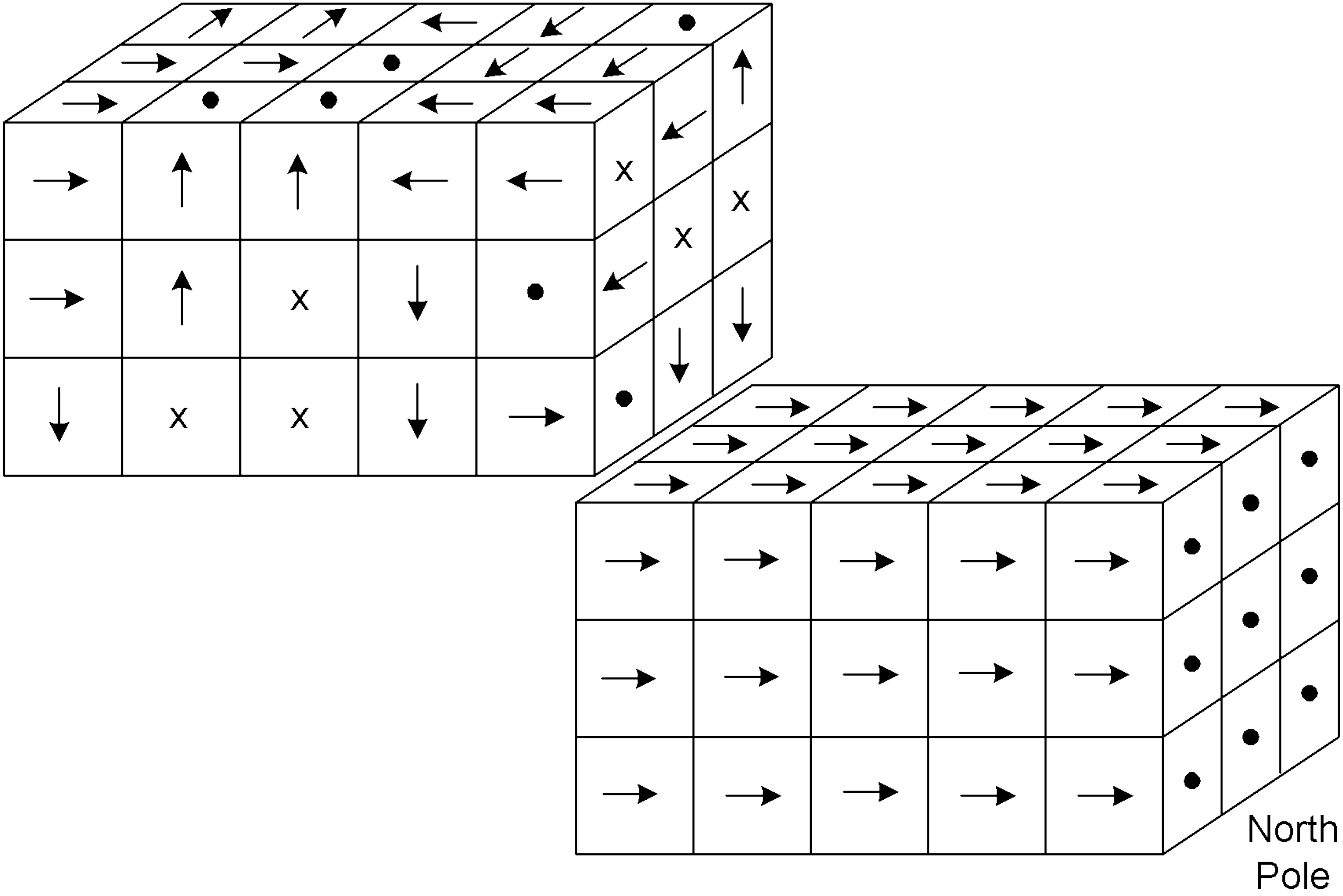
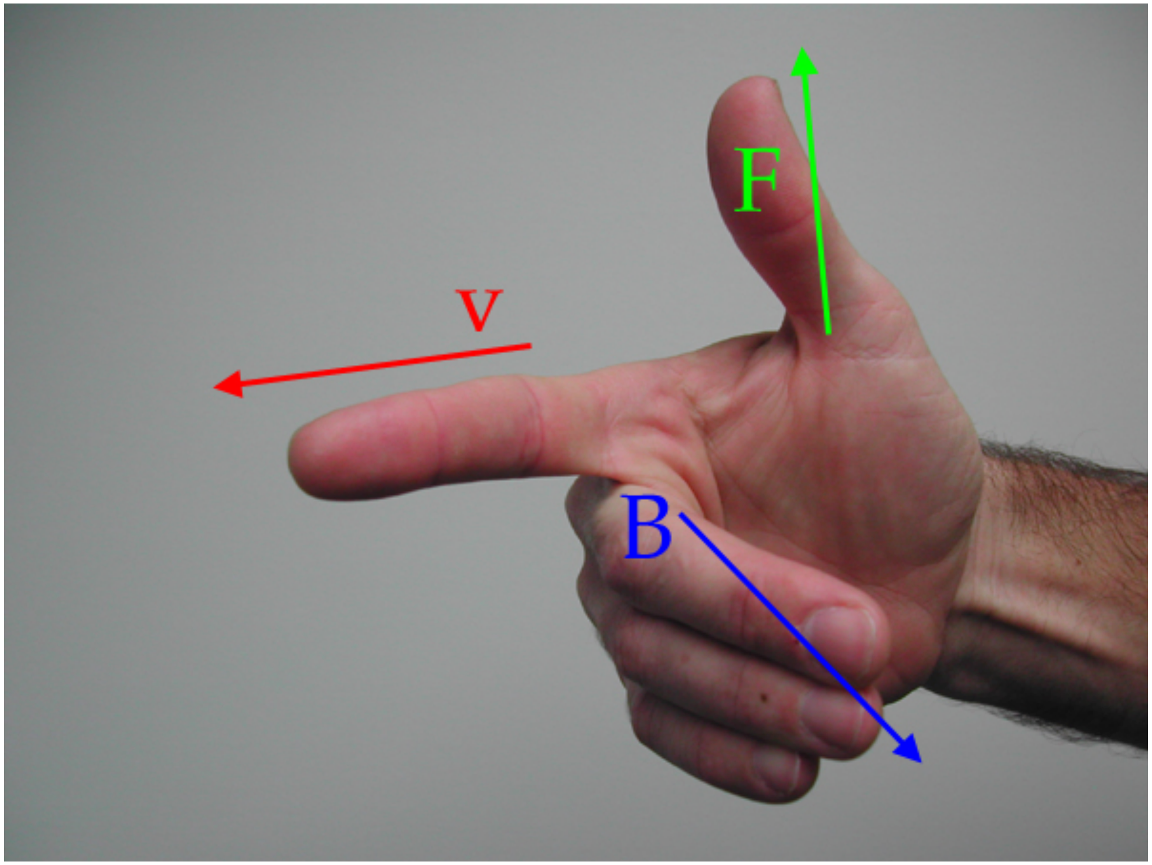
Magnetic Domains



Definition: Magnetic Field

$$\boxed{\vec{\mathbf{F}} = q\vec{\mathbf{v}} \times \vec{\mathbf{B}}}$$

$$F = qvB\sin\theta$$



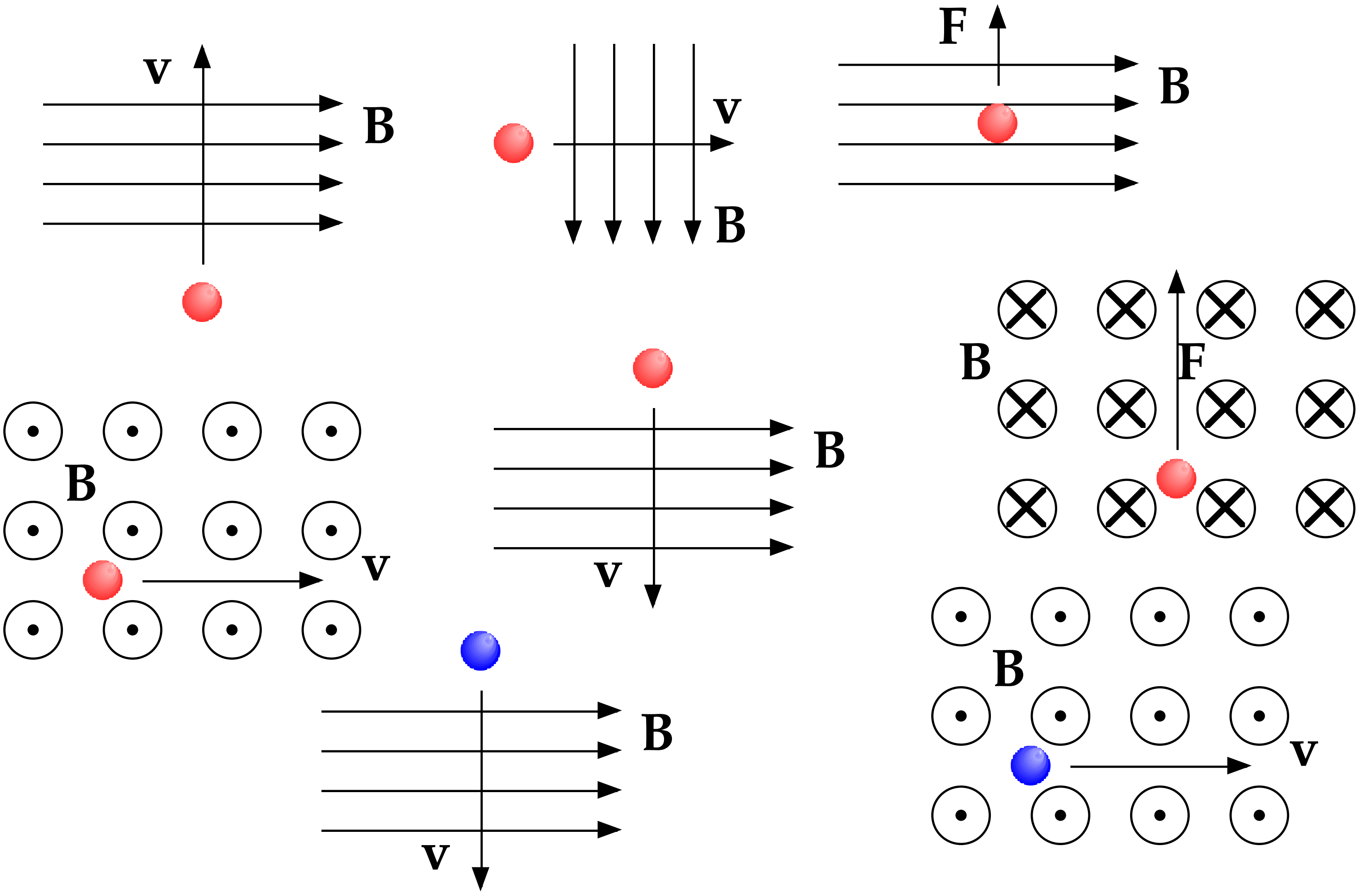
The units of magnetic field are the Tesla, = N/C•m/s. 1 T = 10,000 Gauss. Earth's magnetic field = 30-60 μT.

What happens when a charged particle moves // to the magnetic field?

When a charged particle moves at some angle relative to the magnetic field, the magnetic force acts perpendicular to both **v** and **B**, as predicted by the Right Hand Rule.

Example 1

Identify the missing vector in these diagrams.



qv x B fine print

- The direction of force given by the RHR is for a *positive* test charge. Adjust as necessary to predict the direction of force on a *negative* charge,.

- For electric fields, the F_e was parallel to the E field; for magnetic fields, the F_B is perpendicular to the B field.

- F_B acts only when the charge is in motion.

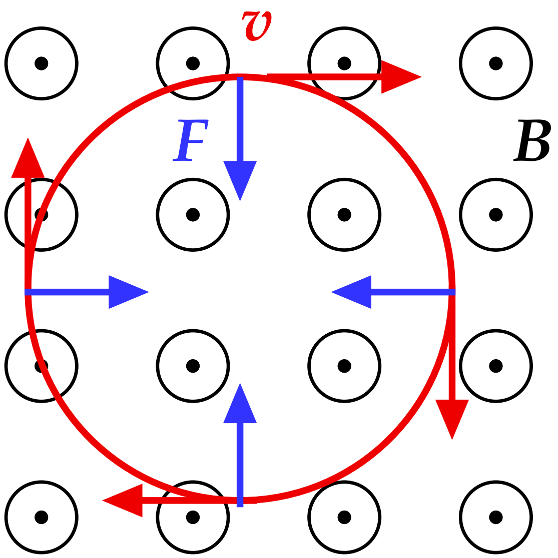
- F_B does *no Work* on the particle when it' s traveling through a constant B field (because F_B and *x* are perpendicular to each other!).

Example 2

A proton moving upward with a speed of 5.0e6 m/s in a magnetic field feels a force of 8.0e-14 N to the west. When moving horizontally to the N, it feels zero force. Find the magnitude and direction of the magnetic field in this region.

Charges moving in B field

Calculate the radius of the circle as a function of **v**, *m*, *q*, and *B*. Then calculate the angular velocity and the period *T*.



$$F_B = qvB\,(when\ v\ \&\ B\ perpendicular)$$

$$F_c = \frac{mv^2}{r}$$

$$r = \frac{mv}{qB}$$

$$r = \frac{mv}{qB},\quad so\quad \frac{v}{r} = \frac{qB}{m}$$

$$\omega = \frac{qB}{m}$$

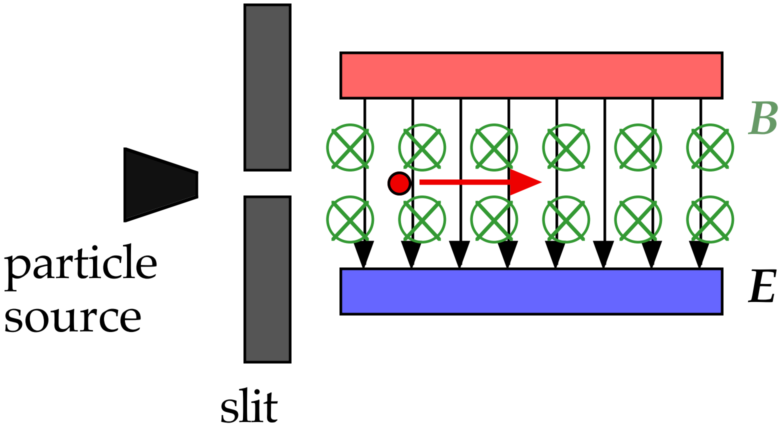
And... since T=2π/ω, you should easily be able to calculate the period.

The Lorentz Force

$$\vec{\mathbf{F}}_{Lorentz} = \vec{\mathbf{F}}_E + \vec{\mathbf{F}}_B$$

$$\vec{\mathbf{F}}_{Lorentz} = q\vec{\mathbf{E}} + q\vec{\mathbf{v}} \times \vec{\mathbf{B}}$$

Velocity Selector



By adjusting the magnitudes of E and B, we can get:

$$qvB = qE$$

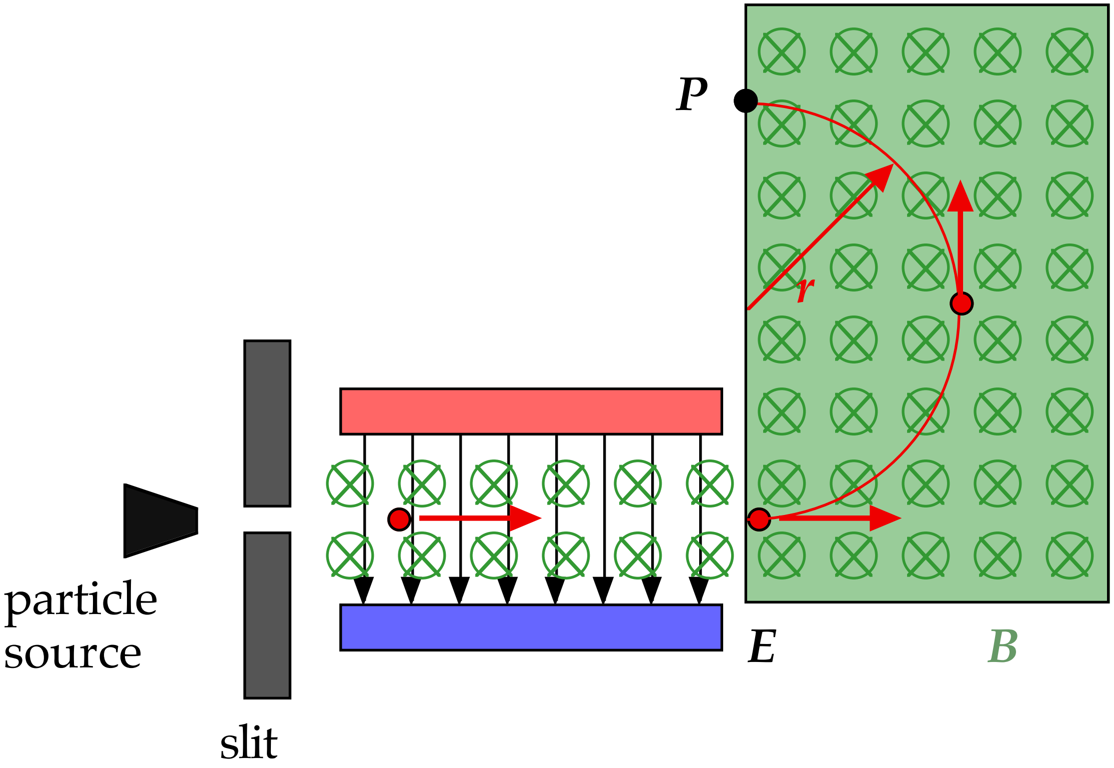
$$v = \frac{E}{B}$$

Mass Spectrometer

$$v = \frac{E}{B_1}$$

$$r = \frac{mv}{qB_2}$$

$$\frac{m}{q} = \frac{rB_1B_2}{E}$$

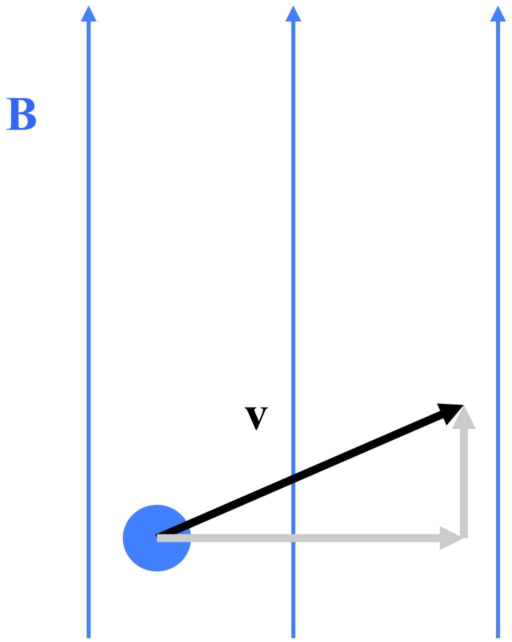


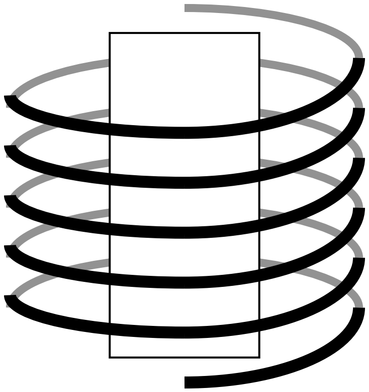
Physlet I.27.3

Cyclotron

Helical motion

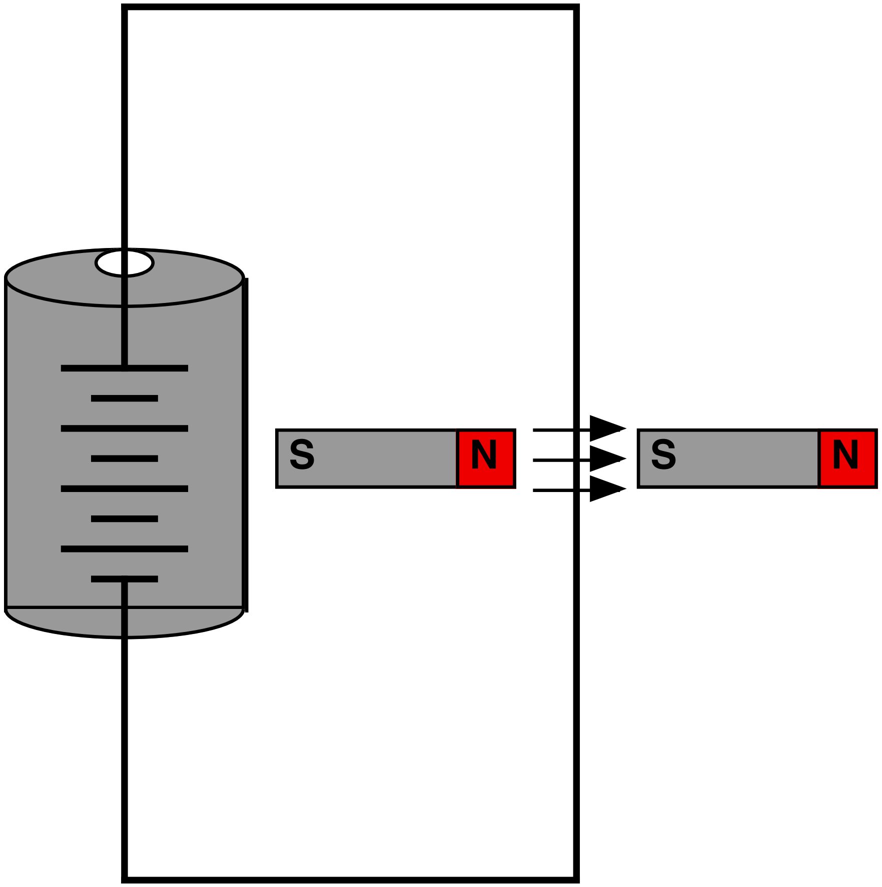
Most of our examples of moving charge have involved particles with a velocity perpendicular to the magnetic field. What if this velocity is *not* perpendicular to the field?



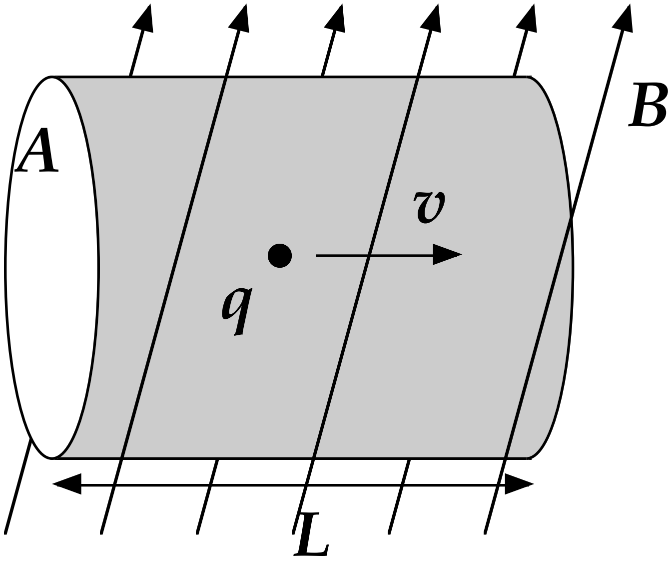


Demo

Based on what we've already learned, what do you think happens in this situation?



Force on current-carrying wire

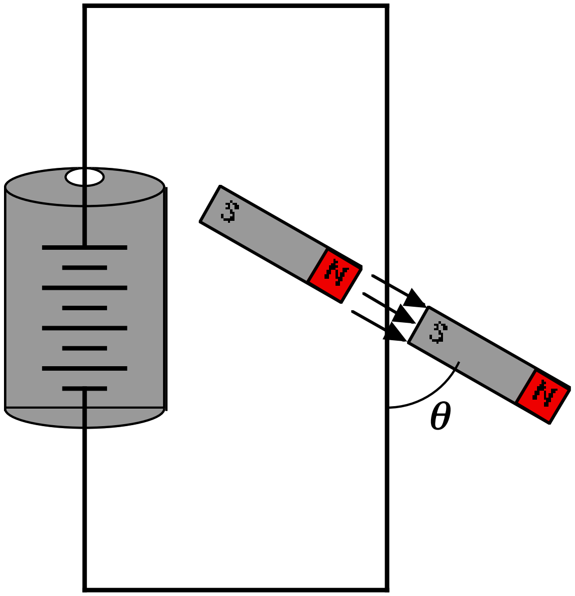


$$F = Qv_{drift} \times B$$

$$Q = qnAL$$

$$F = qnALv_{drift} \times B$$

$$I = nqv_{drift}A$$

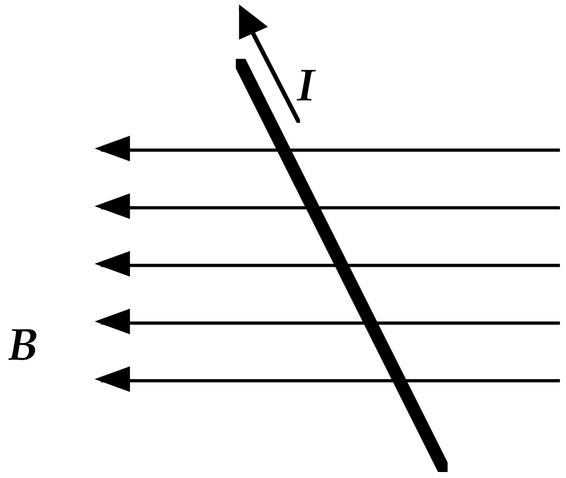


$$F = IL \times B$$

$$F = ILB\sin\theta$$

Example 4

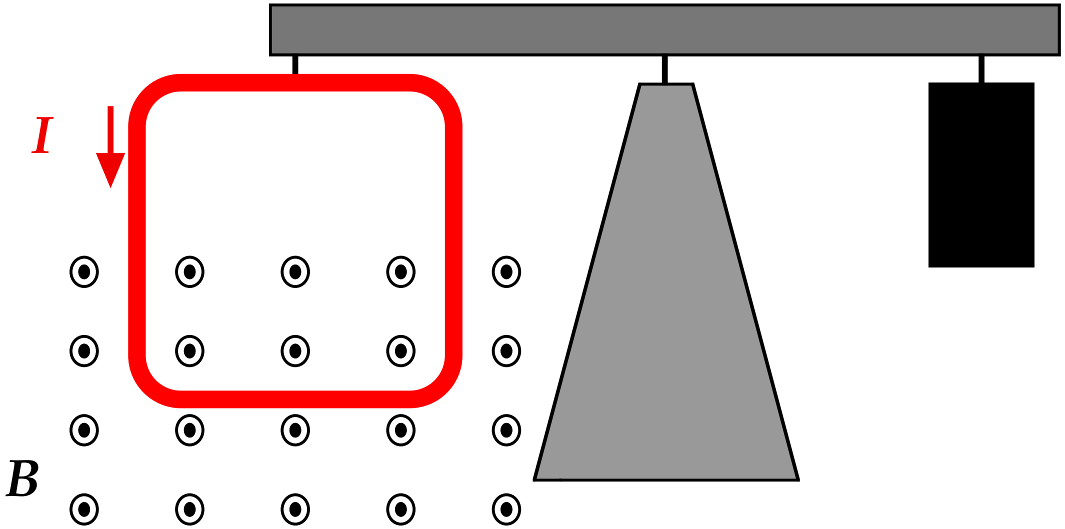
A 12 cm length of wire carrying a 30-Amp current runs through the poles of a magnet at an angle of 60° relative to the magnetic field (as shown). If the magnetic field is 0.90 T between the poles of the magnet, what force does the wire feel, and in which direction?



$F = ILB\sin ø=(30)(0.12)(0.9)(\sin 60)=2.81N$

Example 5

A square loop of wire(10-cm each side) hangs vertically, as shown here. When the current in the wire is 0.245 A counterclockwise, a scale supporting the wire measures a downward force of 3.48e-2N down. Find the magnitude of the magnetic field.

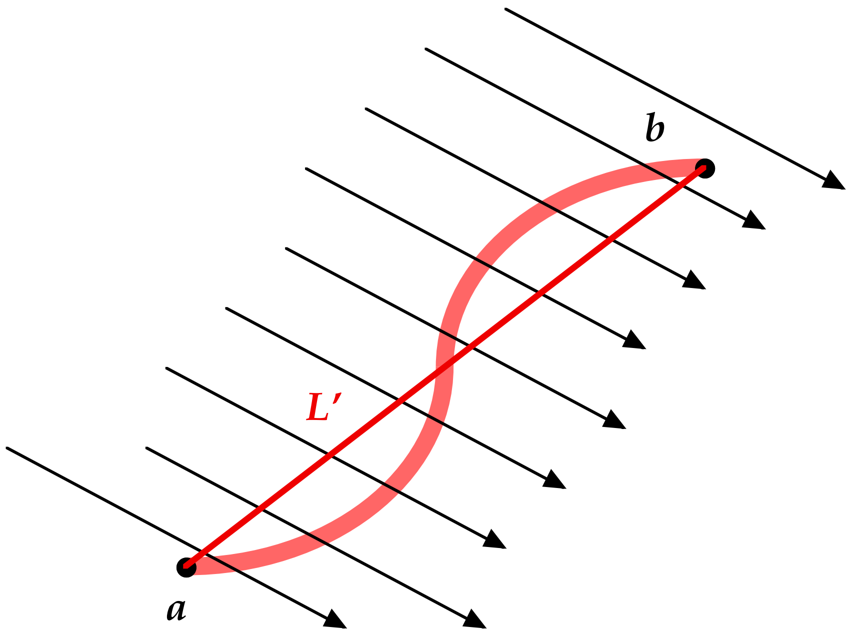


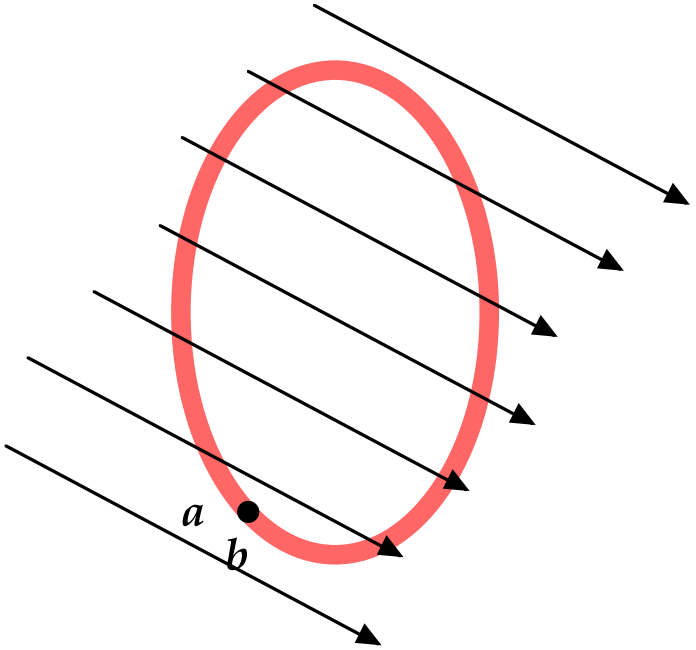
F=ILB -> 0.0348=(0.245)(0.10)(B) -> B=1.42T

Limitations of F=ILxB

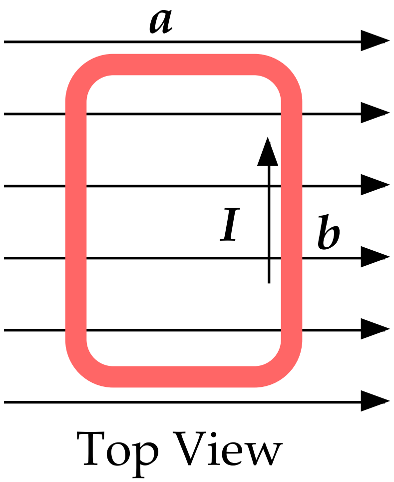
$$dF = I ds \times B \quad or \quad dF = IL \times dB$$

$$F = \int_a^b I ds \times B \quad or \quad F = \int_a^b IL \times dB$$





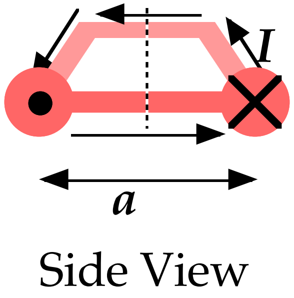
Torque on a Current Loop



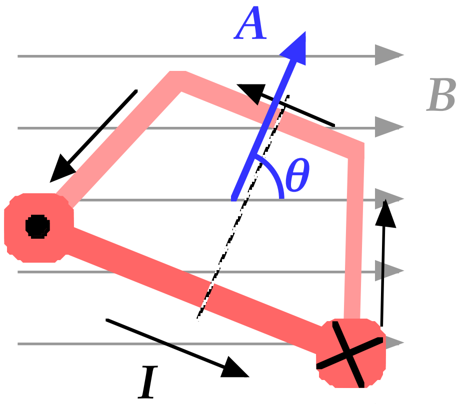
$$F = ILB = IbB$$

$$\tau = r \times F$$

$$\tau = 2\left(\frac{a}{2}\right)F = aIbB = IAB$$



Torque on a Current Loop



$$F = ILB = IbB$$

$$\tau = rF\sin\theta$$

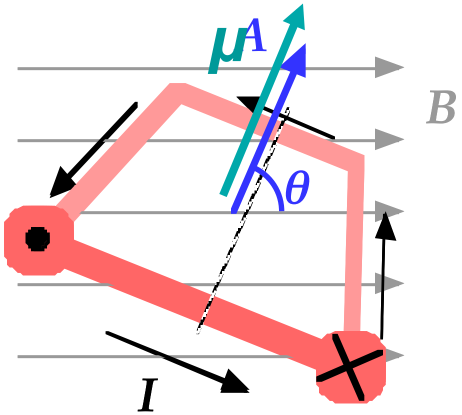
$$\tau = 2\left(\frac{a}{2}IbB\sin\theta\right)$$

$$\vec{\tau} = IAB\sin\theta = I\vec{\mathbf{A}}\times\vec{\mathbf{B}}$$

Torque on a Current Loop

Another way of expressing this torque is by using the expression $\vec{\tau} = \vec{\mu} \times \vec{\mathbf{B}}$, where **μ** is the *magnetic moment* of the coil:

$$\vec{\mu} = I\vec{A}$$



If the loop of wire has more than a a single coil, the magnetic moment becomes

$$\vec{\mu} = NI\vec{A}$$

with the torque still expressed as $\vec{\tau} = \vec{\mu} \times \vec{\mathbf{B}}$

Example 6

A rectangular coil of dimensions 5.40 cm x 8.50 cm consists of 25 turns of wire, carrying a current of 15.0 mA.

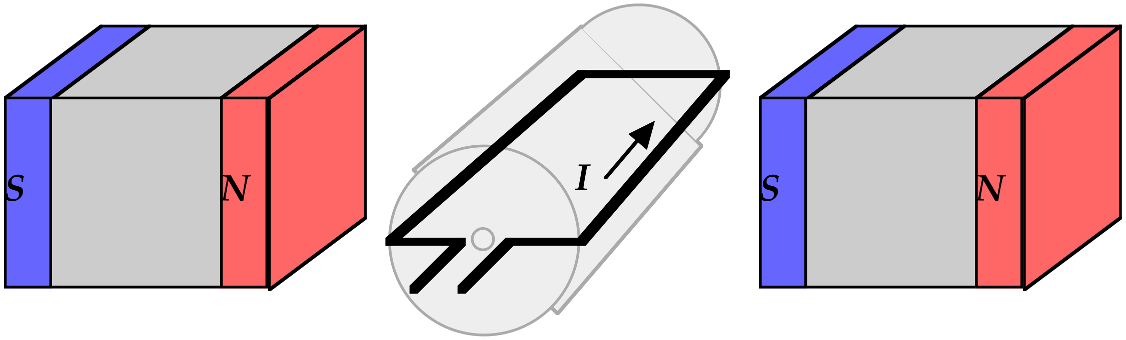
a. Calculate the magnetic moment of the coil **1.72e-3 Am^2**

b. If a magnetic field of 0.350 T is applied parallel to the plane of the loop, what is the magnitude of the torque acting on the loop? **6.02e-4 Nm**

c. Calculate the magnitude of the torque on the coil when the 0.350 T magnetic field makes angles of 60° and 0° with $\boldsymbol{\mu}$. **5.21e-4 Nm, 0**

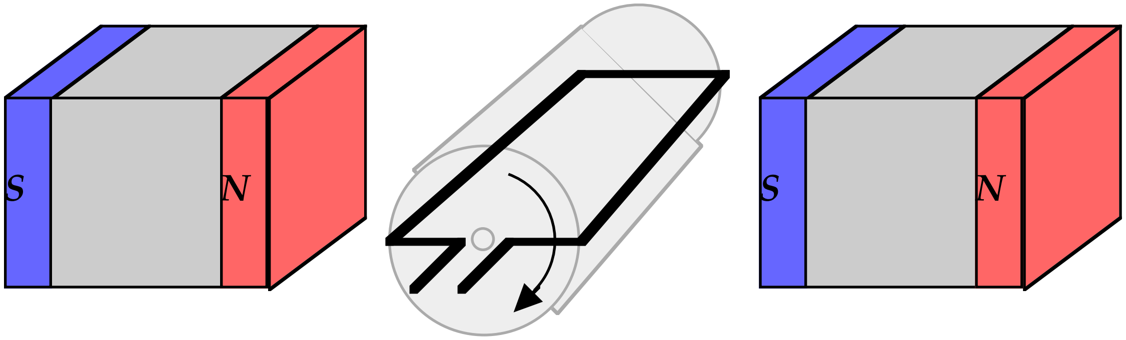
Electric Motors

Electric motors convert electrical energy to kinetic energy, and are created by placing a current-carrying loop in an external magnetic field. There are a number of different ways of doing this, but here is one common type:



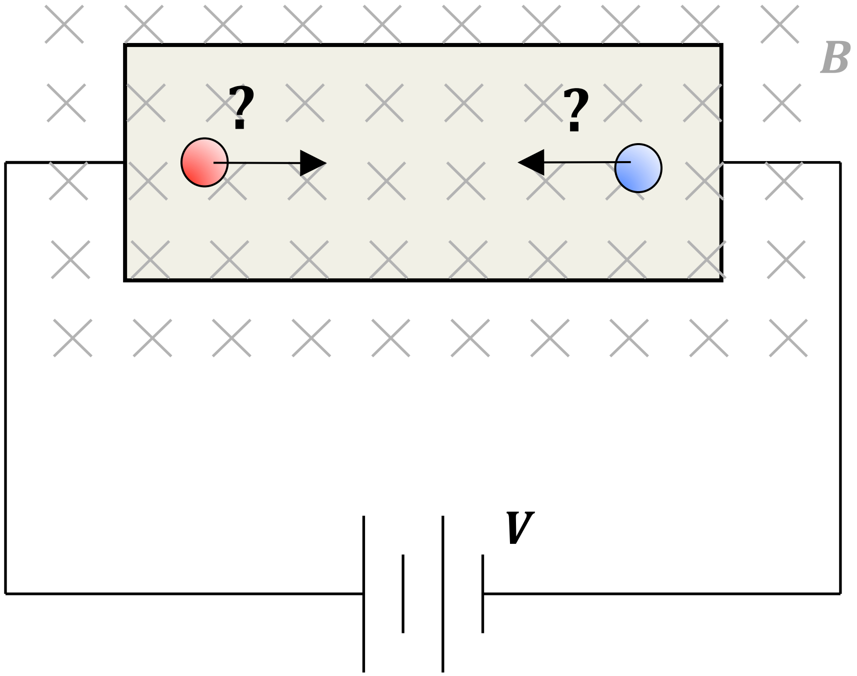
Electric Generators

Electric generators convert mechanical energy (work provided by an external source) to electrical energy. Motors and generators, in most cases, have the same physical structure.



The Hall Effect

How can we determine which charges are *actually* moving in a conductor: positive or negative? What is the polarity of the "charge carriers?"



If charge carriers are positive, they will migrate in presence of magnetic field. Where would they migrate, vertically? Where would the high potential be?

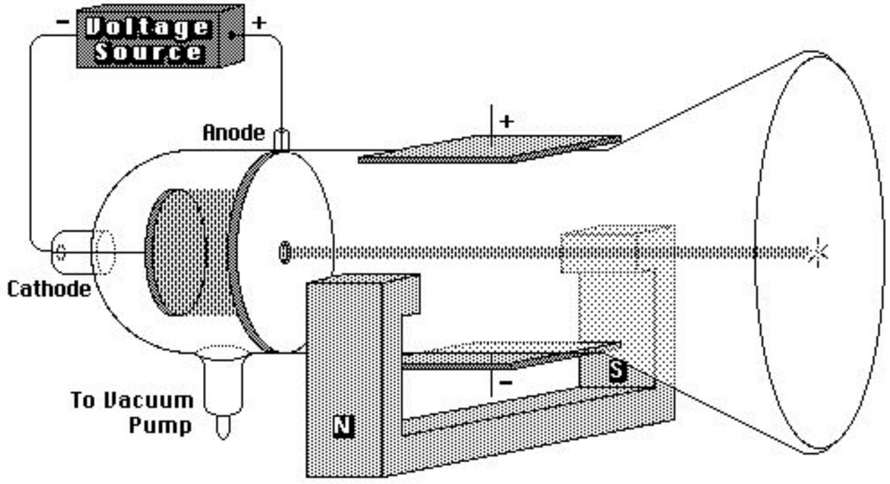
If charge carriers are negative, they will migrate in presence of magnetic field. Where will the high potential be?

The Hall Effect describes the magnitude and orientation of the potential difference between the top and bottom of the conducting plate.

The electron & its properties

Chemistry & physics students readily talk about the electron, the negatively charged particle that surrounds the nucleus of the atom and which is responsible for carrying charges through wires. Its existence wasn't even suggested until the 1890s, however.

A vacuum tube such as the one shown here can be used to demonstrate that the cathode (negative) terminal produces "cathode rays"... but what are those rays, really?



3 Types of Magnetism

Ferromagnetism - material has a permanent “magnetic moment”, due to microscopic “domains” in which moments are aligned.

Paramagnetism - materials has a small magnetic susceptibility, that only becomes evident when placed in an external magnetic field

Diamagnetism - material does <u>not</u> have permanent magnetic moments. In the presence of an external magnetic field, a weak magnetic moment is induced in a direction opposite to the external field.