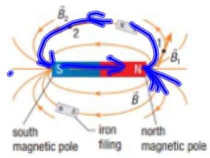
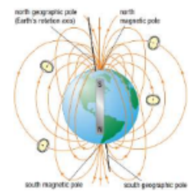
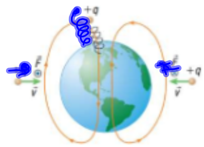
SPH4U 8.1 Magnets and Electromagnets

1. Permanent magnets

Magnetic field:	$\vec{B}$. area that experiences magnetic force.
magnetic field lines	lines showing the strength and direction of a magnetic field.
magnetic poles	north and south; opposites attract, likes repel.
Earth's magnetic field:	magnetic poles ≠ geographic poles. magnetic N is near geographic S. poles move ~60km per year.
causes	Earth's molten core (?).
compass	magnet that aligns with Earth's field.
cosmic rays	charged particles in the atmosphere that are affected by the magnetic field. (Aurora borealis).





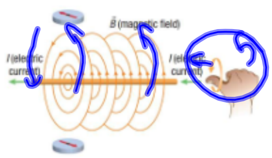


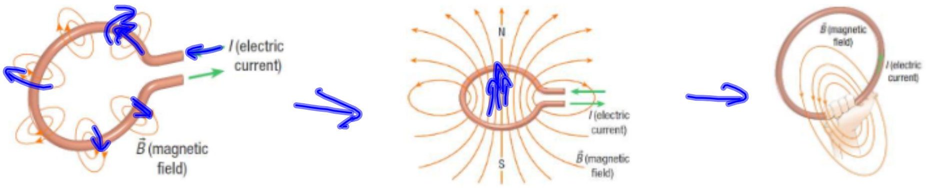
2. Electromagnetism

Principle of electromagnetism:	moving electric charges produce a magnetic field.
~~Right-hand~~ rule for a straight conductor:	see below!

Right-Hand Rule for a Straight Conductor

If your right thumb is pointing in the direction of conventional current, and you curl your fingers forward, your curled fingers point in the direction of the magnetic field lines.

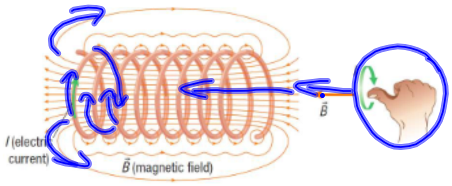




Current loop:	still follows right-hand rule for straight conductors. field inside the loop is stronger (lines are closer together).
Solenoid:	a conducting wire wound into a coil.
Right-hand rule for a solenoid:	See below!

Right-Hand Rule for a Solenoid

If you coil the fingers of your right hand around a solenoid in the direction of the conventional current, your thumb points in the direction of the magnetic field lines in the centre of the coil.



Electromagnet:	magnet that is controlled electrically (solenoid).
factors	solid magnetic core within the coil: field ↑ more coils, tighter wound, more current.
applications	big magnets to pick up cars; doorbell (field pulls a lever against a bell); etc.

Homework: pg. 385 #1-3, 5

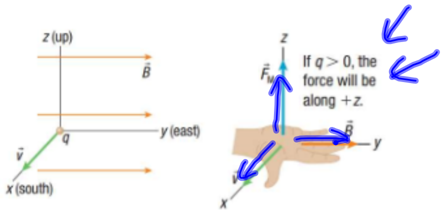
SPH4U 8.2 Magnetic Force on Moving Charges

1. Magnetic force

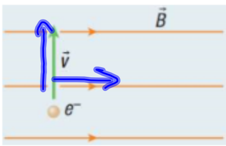
Magnetic field strength:	$\vec{B}$, Units: T (Tesla). $1\ T = 1\ \frac{kg}{C\ s}$.
Magnetic force:	depends on velocity of the charge (unique, not true for gravity/electric).
equation	$F_M = qvB\sin\theta$.
direction	another right-hand rule (#3). always perpendicular to field and velocity

Right-Hand Rule for a Moving Charge in a Magnetic Field

If you point your right thumb in the direction of the velocity of the charge ($\vec{v}$), and your straight fingers in the direction of the magnetic field ($\vec{B}$), then your palm will point in the direction of the resulting magnetic force ($\vec{F}_M$).



The electron shown moves at a sped of 54 m/s through a magnetic field with a strength of 1.2 T. The angle between the electron's velocity and the magnetic field is 90°. Assume the electron's charge is $-e = -1.60 \times 10^{-19}$ C.



a. What is the magnitude of the magnetic force on the electron?

$F_M = qvB\sin\theta$
$= (-1.60\times10^{-19})(54)(1.2)\sin 90°$
$= 1.037\times10^{-17}$ N.

b. Use the right-hand rule to determine the direction of the magnetic force.

Direction: out of the page (negative charge).

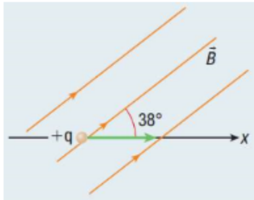
c. Calculate the gravitational force on the electron ($m = 9.11 \times 10^{-31}$ kg).

$F_g = mg = (9.11\times10^{-31})(9.8)$
$= 8.928\times10^{-30}$ N.

d. What is the ratio of gravitational force to magnetic force on the electron?

$\frac{F_g}{F_M} = \frac{8.928\times10^{-30}}{1.037\times10^{-17}} = 8.6\times10^{-13}$.

A proton is moving along the x-axis at a speed of 78 m/s. It enters a magnetic field of strength 2.7 T. The angle between the proton's velocity and the magnetic field is 38°. The mass of a proton is 1.67 x 10^{-27} kg.



a. Calculate the initial magnitude and direction of the magnetic force on the proton.

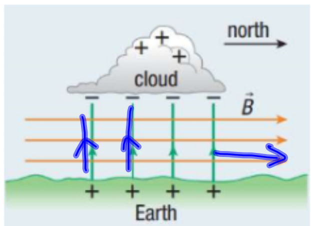
$$F_M = qvB\sin\theta$$
$$= (1.60\times10^{-19})(78)(2.7)\sin 38^\circ$$
$$= 2.075\times10^{-17}\text{ N.}$$

Direction: out of the page.

b. Determine the proton's initial acceleration.

$$F = ma$$
$$a = \frac{F}{m} = \frac{2.075\times10^{-17}}{1.67\times10^{-27}} = 1.2\times10^{10}\text{ m/s}^2$$

During a thunderstorm, positive charge accumulates near the top of a cloud, and negative charge accumulates near the bottom. When the charge buildup is strong enough, negative charge moves rapidly from the cloud to the ground, as a lightning strike. Assume the charge is moving perpendicular to the ground, and Earth's magnetic field is horizontal, directed north. Determine the direction of the deflection of this charge by Earth's magnetic field.



Direction: (into the page)

West.

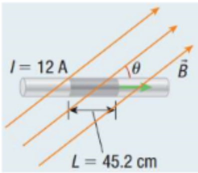
Homework: pg. 391 #1-3, 5-6, 8, 10

SPH4U 8.3 Magnetic Force on a Current-Carrying Conductor

1. Magnetic force and current

Electric current:	a collection of charges moving together.
single charge	$F_M = qvB\sin\theta$
wire with current	$F_M = ILB\sin\theta$ (I: current, L: length of wire).
direction	right-hand rule: thumb with current, fingers with the magnetic field, palm is direction of F_M.

A piece of wire 45.2 cm long has a current of 12 A. The wire moves through a uniform magnetic field with a strength of 0.30 T. Calculate the magnitude of the magnetic force on the wire when the angle between the magnetic field and the wire is:



a. 0°

$F_M = ILB\sin\theta$

$= (12)(0.452\,m)(0.3)\sin 0°$

$= 0\ N$.

b. 45°

$F_M = (12)(0.452)(0.3)\sin 45°$

$= 1.2\ N$.

c. 90°

$F_M = (12)(0.452)(0.3)\sin 90°$

$= 1.6\ N$

Two electrical poles support a current-carrying wire. The mass of a 2.5 m segment of the wire is 0.44 kg, and a 15 A current travels through it. The convential current is due east, horizontal to Earth's surface. Earth's magnetic field is 57 μT and is oriented due north, horizontal to Earth's surface.

a. Determine the magnitude and direction of the magnetic force on the 2.5 m segment of wire.

$F_m = ILB\sin\theta$

$= (15)(2.5)(57\times10^{-6})\sin 90$

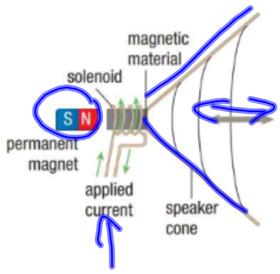
$= 2.1\times10^{-3}\ N$

b. Calculate the gravitational force on the 2.5 m segment of wire.

$F_g = mg = 0.44(9.8) = 4.3N$.

2. Applications

Loudspeakers:	permanent magnet and electromagnet are combined. the strength of the electromagnet is varied, causing it to vibrate back and forth, creating sound waves.

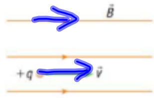


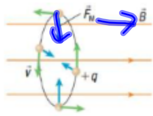
Homework: pg. 396 #1, 3-5

SPH4U 8.4 Motion of Charged Particles in Magnetic Fields

1. Uniform circular motion of charges

Moving parallel to $\vec{B}$:	$\theta = 0°$, $F_M = qvB\sin\theta = 0$. No force.
Moving perpendicular to $\vec{B}$:	$\theta = 90°$, $F_M = qvB$. Force is always perpendicular to movement.
result	circular motion, with a fixed radius.
centripetal force	$F_c = F_M$ $\quad \frac{mv^2}{r} = qvB$.
equation	$r = \frac{mv}{qB}$





An electron (m = 9.11 x 10^{-31} kg) starts from rest. A horizontally directed electric field accelerates the electron through a potential difference of 37 V. The electron then leaves the electric field and moves into a magnetic field with strength 0.26 T, directed into the page.

a. Determine the speed of the electron at the moment it enters the magnetic field.

$\Delta E_K = -\Delta E_E$

$\frac{1}{2}mv^2 = q\Delta V$

$v = \sqrt{\frac{q\Delta V \times 2}{m}}$

$v = \sqrt{\frac{2(1.60\times10^{-19})(37V)}{9.11\times10^{-31}}}$

$= 3.605\times10^{6}$ m/s.

b. Determine the magnitude and direction of the magnetic force on the electron.

$F_M = qvB\sin\theta$

$= (1.60\times10^{-19})(3.605\times10^{6})(0.26)\sin 90° = 1.5\times10^{-13}$ N

Direction: down (charge is −).

c. Determine the radius of the electron's circular path.

$r = \frac{mv}{qB} = \frac{(9.11\times10^{-31})(3.605\times10^{6})}{(1.60\times10^{-19})(0.26)}$

$= 7.9\times10^{-5}$ m.

2. Mass spectrometer

Mass spectrometer:	a beam of ions goes through a magnetic field. the lighter and more positive ions are deflected more, letting us measure their mass and charge.

A researcher using a mass spectrometer observes a particle travelling at 1.6 x 10^6 m/s in a circular path of radius 8.2 cm. The spectrometer's magnetic field is perpendicular to the particle's path and has a magnitude of 0.41 T.

a. Calculate the mass-to-charge ratio of the particle.

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

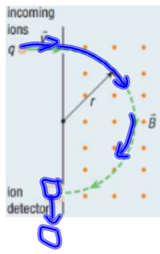
$$\frac{m}{q} = \frac{rB}{v} = \frac{(0.082)(0.41)}{1.6\times10^6} = 2.1\times10^{-8}\ \text{kg/C}.$$

b. Identify the particle using the table provided.

Isotope	m (kg)	q (C)	$\frac{m}{q}$ (kg/C)
hydrogen	1.67×10^{-27}	1.60×10^{-19}	1.04×10^{-8}
deuterium	3.35×10^{-27}	1.60×10^{-19}	2.09×10^{-8}
tritium	5.01×10^{-27}	1.60×10^{-19}	3.13×10^{-8}

∴ the particle is deuterium.

A researcher uses a mass spectrometer in a carbon dating experiment. The incoming ions are a mixture of $^{12}C^+$ and $^{14}C^+$, and they have speed v = 1.0 x 10^5 m/s. The strength of the magnetic field is 0.10 T. The mass of an electron is 9.11 x 10^{-31} kg, and the mass of protons and neutrons is 1.67 x 10^{-27} kg.



The researcher first positions the ion detector to determine the value of r for $^{12}C^+$, then moves it to determine the value of r for $^{14}C^+$. How far must the detector move between detecting the two isotopes?

$$m_{c12} = 6m_p + 6m_n + 5m_e = 2.004\times10^{-26}\ \text{kg}.$$

$$m_{c14} = 6m_p + 8m_n + 5m_e = 2.338\times10^{-26}\ \text{kg}.$$

$$r_{c12} = \frac{m_{c12}v}{qB} = \frac{(2.004\times10^{-26})(1.0\times10^5)}{(1.60\times10^{-19})(0.10)} = 0.1252\ \text{m}.$$

$$r_{c14} = \frac{m_{c14}v}{qB} = \ldots = 0.1461\ \text{m}.$$

$$\Delta d = 2(r_{c14} - r_{c12})$$
$$= 2(0.1461 - 0.1252)$$
$$= 0.04\ \text{m}.$$

Homework: pg. 404 #2-3, 5-6