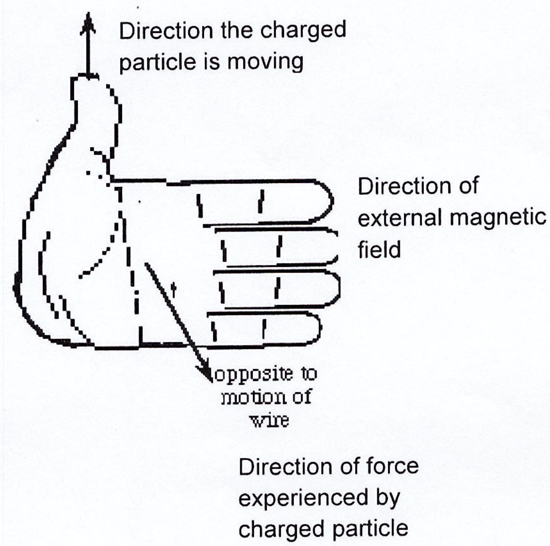
Moving Charges in Magnetic Fields

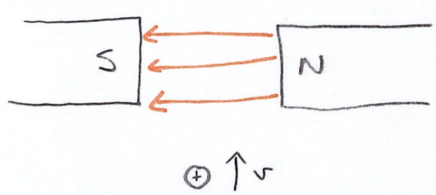
- Recall that a current flowing through a conducting wire (straight or loops) can produce/induce a magnetic field.
  - Therefore, a moving charge can produce its own magnetic field and a charge particle moving through a magnetic field will be deflected due to the interaction between the magnetic field of the charged particle and the external magnetic field

* • To determine the direction a charged particle will be deflected in a magnetic field due to the magnetic force, we need to use the
  <u>Third Left Hand Rule</u>
  - Thumb points in the direction the charged particle is moving
  - Fingers indicate the direction of the external magnetic field lines
  - The palm faces in the direction the charged particle is forced to move (ie. magnetic force)
  - If a positive charge, use the right hand
  - Notice how the *<u>charged particle</u>* must be moving *<u>perpendicular</u>* to the *<u>magnetic field</u>* in order to *<u>experience a force</u>*



- A charged particle moving perpendicular to a magnetic field can be forced in a circular path
  - EXAMPLES:

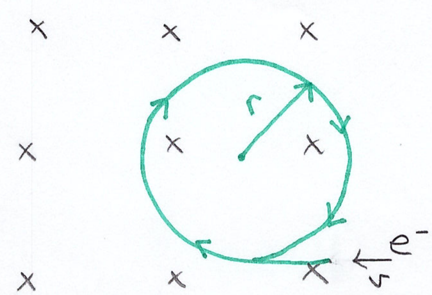
1.)



direction of F_m = ? (initally)

according to 3rd Rule, F_m is out of page (•)

2.)



Predict the path of the e⁻.

* use righ hand for "+" charge

*****Now try pg. 146 #1-13*****

- The strength/magnitude of the force acting on the charged particle moving perpendicular to a magnetic field can also be calculated

$F_m = qvB_\perp$ where F_m is magnetic force (N)
q is charge on particle (C)
v is velocity of the charged particle perpendicular to the magnetic field (m/s)
$B_\perp$ is magnetic field strength (tesla - T)

EXAMPLES

m ↑ ↗ q from data sheet

1. An alpha particle is shot between two parallel plates that have an electric field strength of 9.77×10^{-4} N/C. A magnetic field is applied to the parallel plates so that the magnetic field is perpendicular to the particle's motion. If the magnetic field strength is 4.90×10^{-7} T, what is the speed at which the alpha particle must be traveling so it passes through un-deflected?

↳ $F_{net} = 0.0\,N$

$\vec{E} = 9.77\times10^{-4}\,N/C$

$T = 4.90\times10^{-7}\,T$

$v = ?$

$\vec{F}_{net} = F_m + (-F_e)$
0

$F_e = F_m$

$\vec{E}\cancel{q} = \cancel{q}vB_\perp$

$\dfrac{\vec{E}}{B_\perp} = v$

$\dfrac{9.77\times10^{-4}\,N/C}{4.90\times10^{-7}\,T} = v = 1993.877\ldots\,m/s$

$m = 9.11\times10^{-31}$ kg

$q = 1.60\times10^{-19}$ C

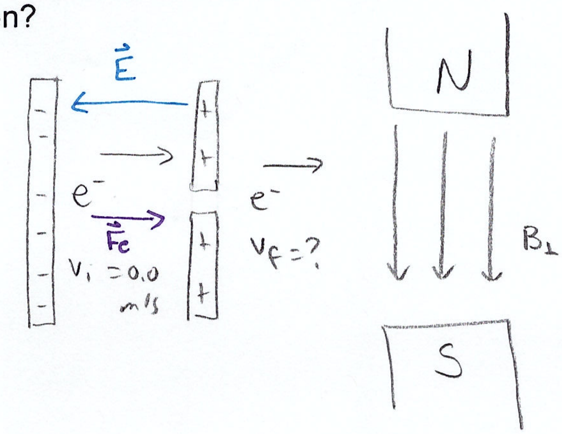
2. An electron at rest is accelerated to the east by a potential difference of 1.70x10³ V. The electron then enters into a 0.250 T magnetic field directed south. What is the magnetic force acting on the electron?

$v_i = 0.0$ m/s

$\Delta V = 1.70\times10^{3}$ V

$B_\perp = 0.250$ T

$F_m = ?$



3rd hand rule

Fm is directed out of page!

(2) $F_m = q v_f B_\perp$

(1) $\Delta V = \frac{\Delta E}{q} = \frac{E_f - \cancel{E_i}^{\,0}}{q}$

$E_k = \frac{1}{2} m v_f^2$

(1) $\Delta V = \frac{\frac{1}{2} m v_f^2}{q} \rightarrow \sqrt{\frac{2\Delta V q}{m}} = v_f$

$\sqrt{\frac{2(1.70\times10^{3}\,\text{V})(1.60\times10^{-19}\,\text{C})}{9.11\times10^{-31}\,\text{kg}}} = v_f$

$24436570.82\ \text{m/s} = v_f$

(2) $F_m = qvB = (1.60\times10^{-19}\,\text{C})(24436570.82\,\text{m/s})(0.250\,\text{T})$

$F_m = 9.774628\ldots\times10^{-13}$ N

$\boxed{F_m = 9.77\times10^{-13}\text{ N, out of page}}$

*****Now try pg. 150 #14, 15, 17, 18 (acceptable), 19 & Practice Problems (intermediate)*****

Practice Problems

1. An alpha particle travelling with a speed of 4.30×10^4 m/s enters a uniform magnetic field of 0.0300T. Determine the magnetic force on the particle if it enters the field
    a. perpendicular to the magnetic field. **[4.13×10^{-16}N]**
    b. 30.0° to the magnetic field. **[2.06×10^{-16}N]**
    c. parallel to the magnetic field. **[0.0N]**

2. A proton is accelerated from rest by a potential difference that exists between two parallel plates. The proton leaves the parallel plates and then enters into a uniform magnetic field that has a field strength of 0.0260T. If the proton experiences a magnetic force of 5.50×10^{-17}N, what was the potential difference between the parallel plates? **[0.912 V]**

3. What speed must a 3+ ion with a mass of 7.28×10^{-21}kg maintain if it is to remain suspended above the earth's surface, as it travels perpendicular through the earth's magnetic field of 50.0μT? **[2.98×10^3 m/s]**

* • As a charged particle travels through an external magnetic field, the magnetic force acting on a charged particle accelerates the particle not in terms of speed, but in terms of direction (ie. circular path)

$r = \frac{mv}{qB_\perp}$

$r \propto m$

$r \propto \frac{1}{q}$

$r \propto v$

$F_c = F_m$

$ma_c = qvB_\perp$

$m\left(\frac{v^{\cancel{2}}}{r}\right) = q\cancel{v}B_\perp$

$\frac{mv}{r} = qB_\perp$

* for any problems dealing with radius of curvature for charged particles in magnetic fields!

m q from data sheet

EXAMPLE: An alpha particle enters a 1.20 T magnetic field, causing it to turn with a radius of 2.34cm. Determine the speed of the alpha particle as it enters the magnetic field.

$B_\perp = 1.20\ T$

$r = 2.34cm \times \left(\frac{10^{-2}m}{1cm}\right)$

$r = 0.0234m$

$v = ?$

$F_c = F_m$

$ma_c = qvB_\perp$

$m\left(\frac{v^{\cancel{2}}}{r}\right) = q\cancel{v}B_\perp$

$\frac{mv}{r} = qB_\perp$

$v = \frac{qB_\perp r}{m}$

$v = \frac{(3.2\times10^{-19}c)(1.20T)(0.0234m)}{6.65\times10^{-27}kg}$

$v = 1.3512\ldots\times10^{6}m/s$

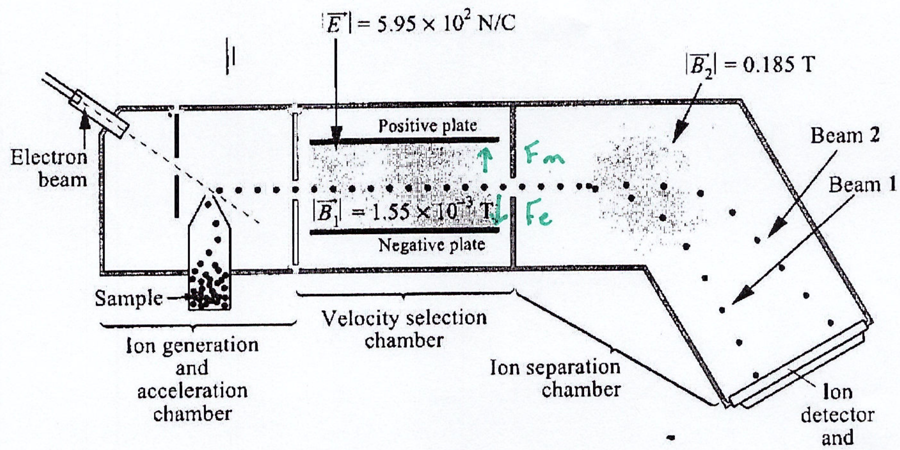
$\boxed{v = 1.35\times10^{6}m/s}$

Use the following information to answer the next two questions.

A Mass Spectrometer

$q = 1.6 \times 10^{-19}$ C for Li^+

A particular lithium sample contains two isotopes. These isotopes are singly charged in an ion generation and acceleration chamber. Since individual atoms are ionized at different points in the acceleration chamber, their speeds vary when they enter the velocity selection chamber. In the velocity selection chamber, the electric field strength is 5.95×10^2 N/C and the magnetic field strength is 1.55×10^{-3} T. The velocity selection chamber allows ions of a certain speed to pass through undeflected. The beam of undeflected ions then enters the ion separation chamber where the magnetic field of 0.185 T splits the beam into two beams. Beam 1 curves through a radius of 0.131 m.



20. The speed of the undeflected ionized lithium ions, Li^+, as they leave the velocity selection chamber is → $F_{net} = 0.0$ N

A. 4.25×10^4 m/s
B. 3.84×10^5 m/s
C. 8.63×10^6 m/s
D. 7.22×10^7 m/s

Use your recorded answer from ***Multiple Choice 20*** *to answer* ***Numerical Response 7.****

Numerical Response

7. The mass of a lithium ion in beam 1, expressed in scientific notation, is $\mathbf{a.b} \times 10^{-\mathbf{cd}}$ kg. The values for **a**, **b**, **c** and **d** are _1_, _0_, _2_, and _6_.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)

***You can receive marks for this question even if the previous question was answered incorrectly.**

$q = 1.6\times10^{-19}\,C$

$\vec{E} = 5.95\times10^{2}\,N/C$

$B_{\perp 1} = 1.55\times10^{-3}\,T$

$B_{\perp 2} = 0.185\,T$

$r = 0.131\,m$

$v = ?$

$m = ?$

$\underbrace{F_{net}}_{0} = F_m + (-F_e) + (-\underbrace{\cancel{F_g}}_{0})$ 0 b/c atomic particle F_g is negligible

$F_e = F_m$

$\vec{E}\cancel{q} = \cancel{q}vB_\perp$

$v = \dfrac{\vec{E}}{B_\perp} = \dfrac{5.95\times10^{2}\,N/C}{1.55\times10^{-3}\,T} = 3.838\ldots\times10^{5}\,m/s$

$\boxed{v = 3.84\times10^{5}\,m/s}$

unit analysis

$\dfrac{N/C}{\cancel{T}} \times \left(\dfrac{\cancel{T}}{\cancel{N}/(C\cdot m/s)}\right)$

$= \dfrac{1/C}{1/(C\cdot m/s)}$

$= \dfrac{1}{\cancel{C}} \times \left(\dfrac{\cancel{C}\cdot m/s}{1}\right)$

$= m/s$ ✓

$F_c = F_m$

$ma_c = qvB_\perp$

$m\left(\dfrac{v^{\cancel{2}}}{r}\right) = q\cancel{v}B_\perp$

$m = \dfrac{qB_\perp r}{v}$

$m = \dfrac{(1.6\times10^{-19}\,C)(0.185\,T)(0.131\,m)}{(3.84\times10^{5}\,m/s)}$

$m = 1.009\ldots\times10^{-26}\,kg$

$\boxed{m = 1.0\times10^{-26}\,kg}$

unit analysis

$\dfrac{C\cdot T\cdot \cancel{m}}{\cancel{m}/s} = \dfrac{C\cdot T}{1/s} = \cancel{C}\cdot\cancel{T}\times(s/1)\times\left(\dfrac{N/(m/s\cdot\cancel{C})}{\cancel{T}}\right)$

$= \dfrac{s\cdot N}{m/s} = s\cdot N\times(s/m) = \dfrac{\cancel{s^2}\cdot\cancel{N}}{\cancel{m}}\times\left(\dfrac{kg\cdot m/s^2}{\cancel{N}}\right)$

$= kg$ ✓

*****Now try pg. 151 #20, ~~22-25~~, 27, 31-33 & pg. 178 #11 (intermediate)*****

Mass Spectrometry Review Question

Suppose that an ion source in a mass spectrometry produces doubly ionized gold ions (Au^{2+}), each with a mass of 3.27xx10^{-25} kg. The ions are accelerated from rest through a potential difference of 1.00kV. Then, a 0.500T magnetic field causes the ions to follow a circular path. Determine the radius of the path.

$$F_m = F_{net}$$

$$qvB_\perp = ma$$

$$q\cancel{v}B_\perp = \frac{mv^{\cancel{2}}}{r}$$

$$qB_\perp = \frac{mv}{r}$$

(3) $r = \dfrac{mv}{qB_\perp}$ → but $E_k = \frac{1}{2}mv^2$ (2)

↓

$\Delta V = \dfrac{\Delta E}{q}$ (1)

(1) $\Delta E = \Delta V q = (1.00 \times 10^3\ V)(3.2 \times 10^{-19}\ C) = 3.2 \times 10^{-16}\ J$

(2) $E_k = \frac{1}{2}mv^2 \Rightarrow \sqrt{\dfrac{2E_k}{m}} = v$

$$\sqrt{\frac{2(3.2 \times 10^{-16}\ J)}{3.27 \times 10^{-25}\ kg}} = v = 4.424\ldots \times 10^4\ m/s$$

(3)

$$r = \frac{mv}{qB_\perp} = \frac{(3.27 \times 10^{-25}\ kg)(4.424\ldots \times 10^4\ m/s)}{(3.2 \times 10^{-19}\ C)(0.500\ T)}$$

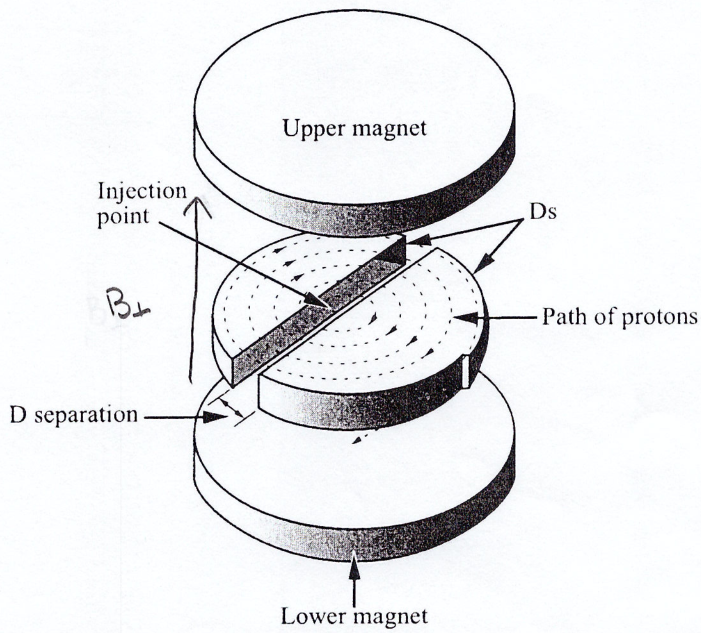
$$\boxed{r = 0.0904\ m \quad \text{or} \quad 9.04\ cm}$$

Review

Use the following information to answer the next question.

Cyclotron

A cyclotron is a particle accelerator that is constructed of two hollow metal shells shaped like Ds in a perpendicular magnetic field created by magnets, as shown below. The entire apparatus is placed in a vacuum. An alternating voltage is maintained across the D separation. Positively charged particles such as protons are injected near the centre of the Ds and travel in circular paths caused by the external perpendicular magnetic field. The frequency of the alternating voltage is adjusted to increase the speed of the particles each time they move across the Ds' separation.



Cyclotron Specifications

Magnetic field intensity	0.863 T
Maximum voltage across D separation	20 000 V
D separation	5.00 cm

Written Response — 15%

2. a.) • Determine the direction of the magnetic field needed to cause protons to circle in the direction shown. Justify your answer. b/c of 3rd hand rule (right hand)

b.) • Calculate the radius of the path of a proton travelling at 2.50×10^6 m/s.

c.) • Calculate the speed of a proton after it passes once between the Ds, if it enters the space between the Ds at 2.50×10^6 m/s.

b.) $F_c = F_m$

$ma_c = qvB_\perp$

$m\left(\frac{v^{\cancel{2}}}{r}\right) = q\cancel{v}B_\perp$

$$r = \frac{mv}{qB_\perp} = \frac{(1.67\times10^{-27}\,\text{kg})(2.50\times10^{6}\,\text{m/s})}{(1.6\times10^{-19}\,\text{C})(0.863\,\text{T})} = 0.030236\ldots\,\text{m}$$

$$\boxed{r = 0.0302\,\text{m} \ \underline{\text{OR}}\ 3.02\,\text{cm}}$$

c.) $E_k = \frac{1}{2}mv^2$ (2)

$\downarrow$

$\Delta V = \frac{\Delta E}{q} = \frac{E_{kf} - E_{ki}}{q}$ (1)

(1) $\Delta E = \Delta V q = (20000\,\text{V})(1.6\times10^{-19}\,\text{C}) = 3.2\times10^{-15}\,\text{J}$

$\Delta E = E_{kf} - E_{ki} \Rightarrow E_{kf} = \Delta E + E_{ki} = \Delta E + \frac{1}{2}m(v_i)^2$

$E_{kf} = 3.2\times10^{-15}\,\text{J} + \frac{1}{2}(1.67\times10^{-27}\,\text{kg})(2.50\times10^{6}\,\text{m/s})^2$

$E_{kf} = 8.41875\times10^{-15}\,\text{J}$

(2) $E_{kf} = \frac{1}{2}m(v_f)^2 \Rightarrow v_f = \sqrt{\frac{2E_k}{m}}$

$$v_f = \sqrt{\frac{2(8.41875\times10^{-15}\,\text{J})}{(1.67\times10^{-27}\,\text{kg})}} = 3.17526\ldots\times10^{6}\,\text{m/s}$$

$$\boxed{v_f = 3.18\times10^{6}\,\text{m/s}}$$