

FORCE ON A CURRENT CARRYING CONDUCTOR

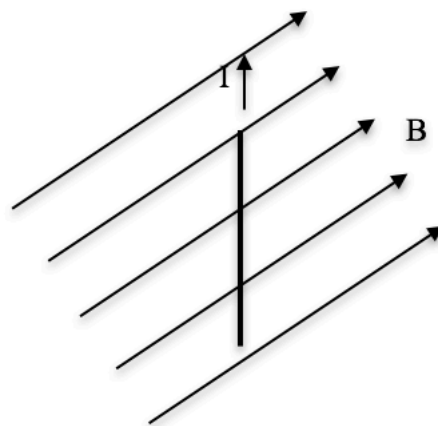
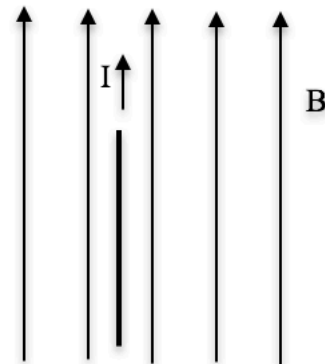
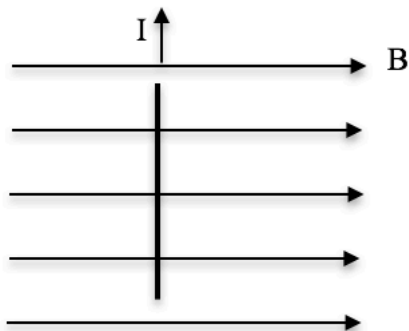
A current carrying conductor has a magnetic field associated with it. This magnetic field will interact with other magnetic fields resulting in a force being applied.

This means a current carrying conductor in an external magnetic field will experience a force.

Magnetic Flux Density - a measure of the magnetic field in terms of a force acting on an element of current.

Note:

1. The force is always mutually perpendicular to B and I.
2. Only the component of B which is perpendicular to the current carrying conductor will contribute to the force.



Electromagnetism #2

DETERMINATION OF DIRECTION OF FORCE

Right-Hand Slap Rule:

-
-
-

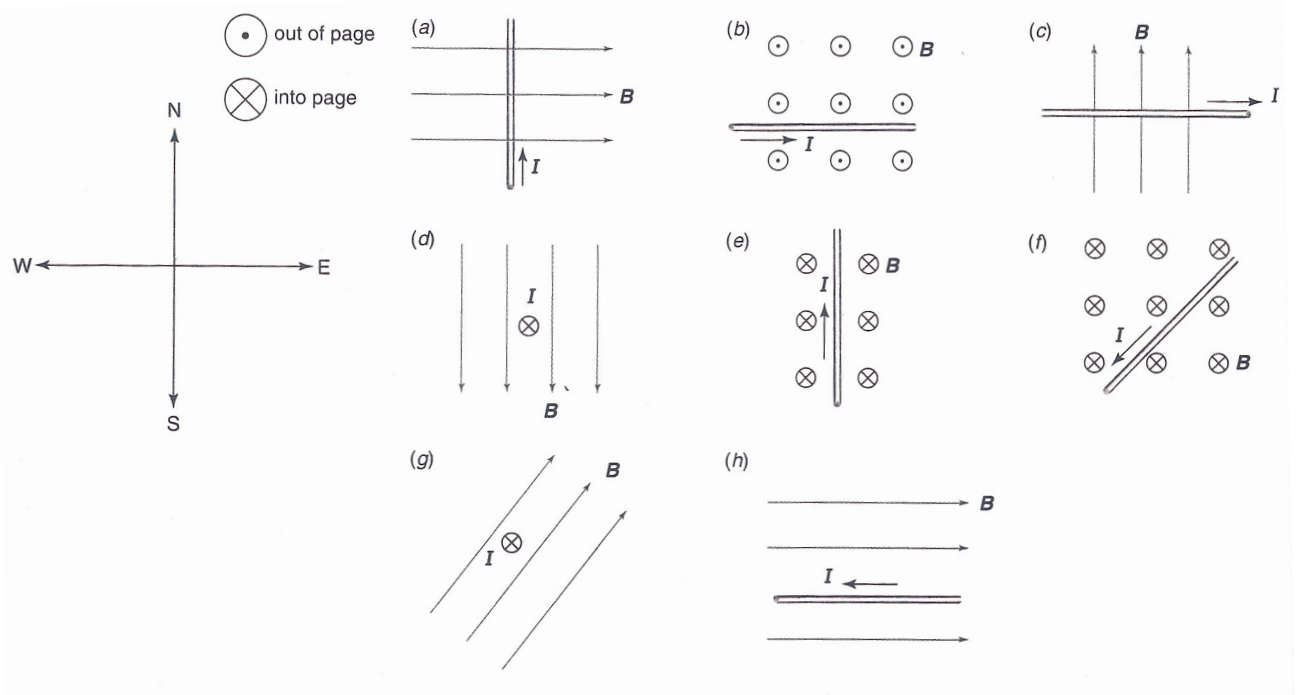
Left-Hand FBI Rule:

-
-
-

Beware! – These rules are for:

If you have a negative charge or are dealing with electron current the force will be in the **opposite direction** to what the RH slap and LH FBI rules indicate (you could use a 'back-slap' with the RH slap rule instead).

Using the right-hand-slap rule or left-hand-FBI rule to find the direction of the magnetic force on the wire in each of the cases below. Use the answer key on the left.

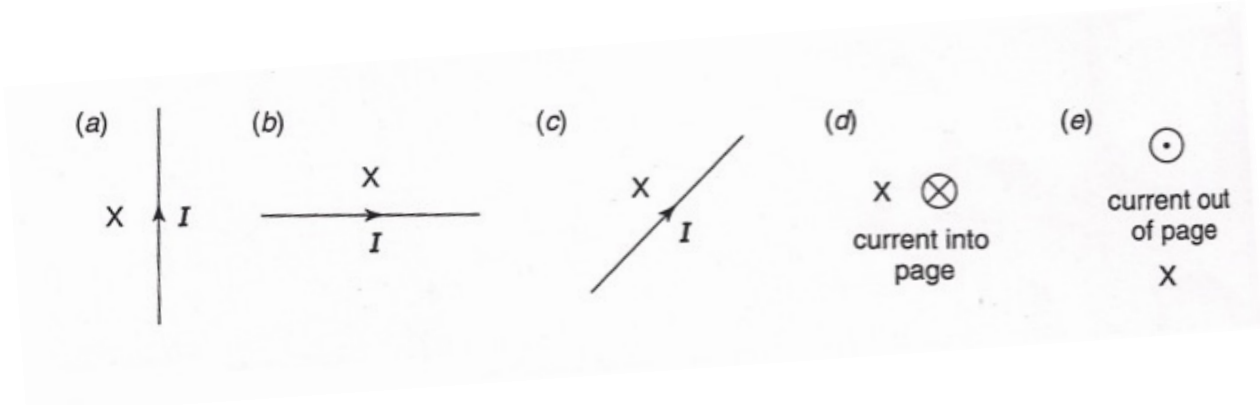


Electromagnetism #2

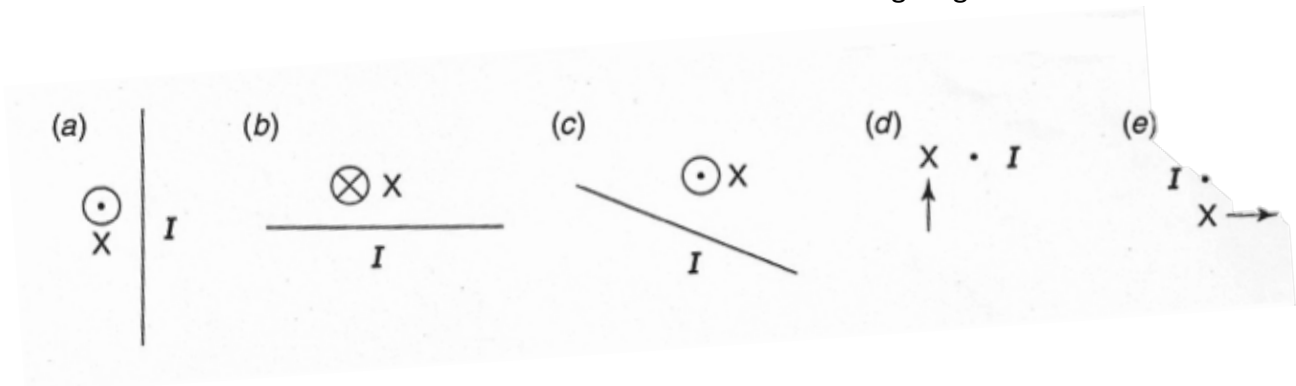
3. A wire of mass 50.0 g carries 2.00 A current horizontally to the south. Calculate the minimum magnetic field required to lift this wire vertically upwards.

CURRENT CARRYING CONDUCTORS - QUESTIONS

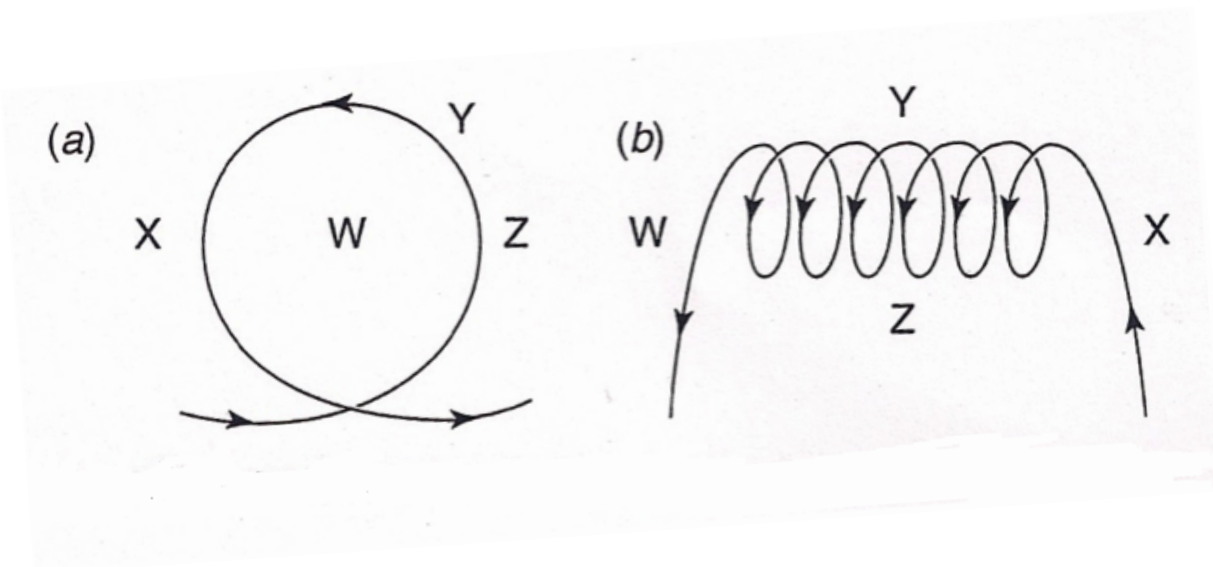
1. Determine the direction of the magnetic field at point X in the following diagrams.



2. Determine the direction of the current in the wire in the following diagrams.

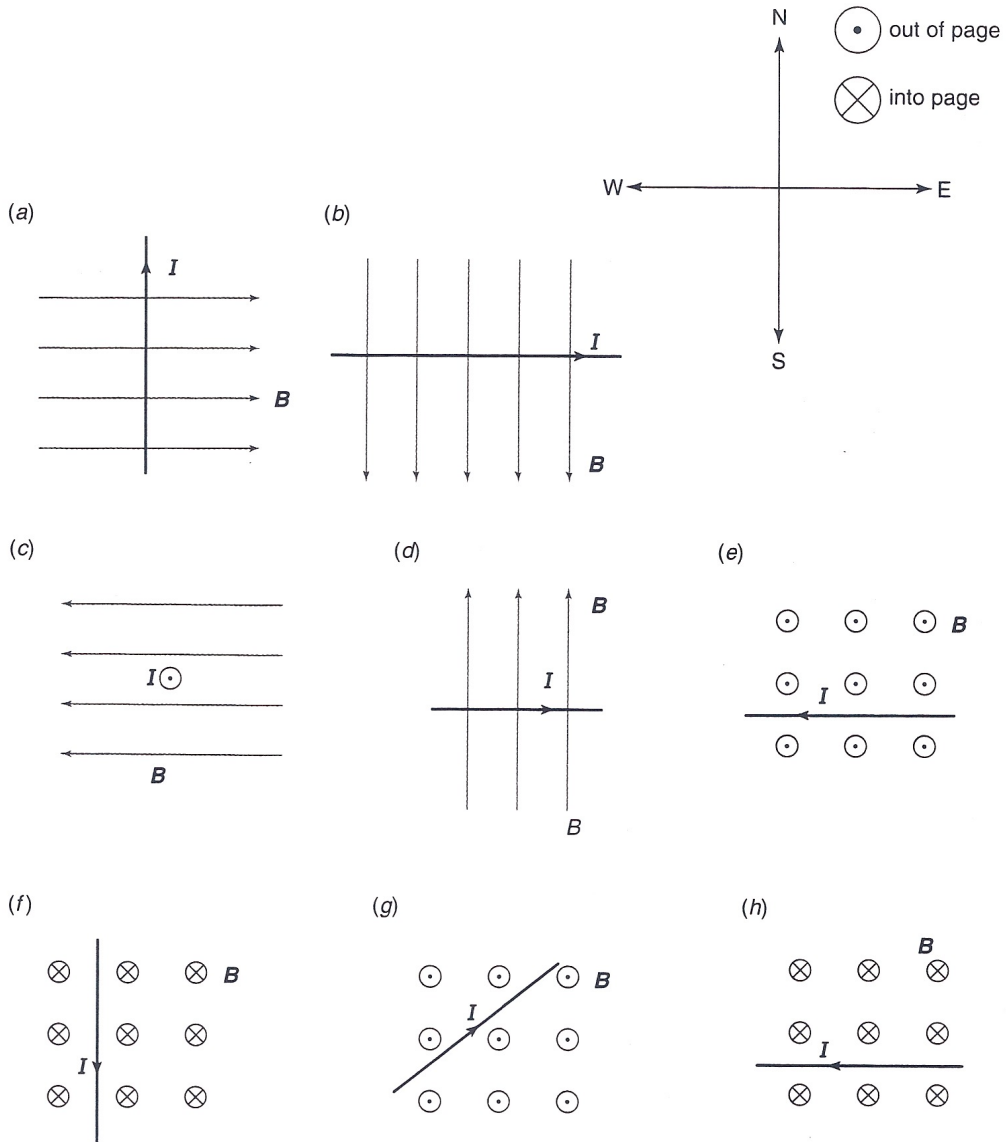


3. Determine the direction of the magnetic field at W, X, Y and Z in the diagrams below.



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4. Use the answer key on the right to determine the direction of the force on the current carrying conductor in the diagram below.



5. A small piece of wire 0.0400 m long, carrying 50.0 A is placed at right angles to a magnetic field and it experiences a force of 4.00×10^{-4} N. Calculate the magnitude of the magnetic flux density.
 [2.00 x 10⁻⁴ T]

Electromagnetism #2

6. 0.0500 m of wire at right angles to a magnetic field experiences a force of 1.20×10^{-4} N. If the magnitude of the magnetic flux density is 8.00×10^{-6} T, calculate the current the wire is carrying.
[3.00×10^2 A]
7. Calculate the size of the force on a wire of length 0.0500 m in a magnetic field of strength 0.300 T, if the wire is at right angles to the field and it carries a current of 4.50 A.
[0.0675 N]
8. Calculate the size of the force on a wire carrying a current of 1.80 A at right angles to a magnetic field of strength 40.0 mT, if the length of the wire is 8.00 cm.
[5.76×10^{-3} N]

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9. Calculate the size of the force exerted on a loudspeaker coil of radius 1.50 cm and 500 turns which carries a current of 15.0 mA in a radial magnetic field of 2.00 T. [Hint – consider the circumference of the loudspeaker coil]

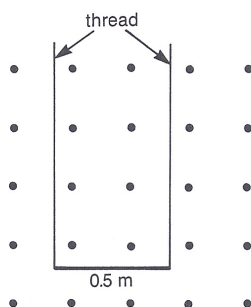
[1.41 N]

10. Calculate the angle at which 0.100 m of wire carrying a current of 150.0 mA must be placed to a magnetic field of strength 1.00×10^{-4} T if it is to experience a force of $1.41 \mu\text{N}$.

[70.1°]

11. A wire of length 0.500 m and mass 3.00 g is suspended by two threads in a magnetic field of flux density 0.100 T (as shown below). Calculate the magnitude and direction of the current needed so that there is no tension in the threads.

[0.588 A to the left]



FORCE BETWEEN PARALLEL CURRENT CARRYING CONDUCTORS

Beware! -

Currents in opposite direction:



Currents in same direction:



Electromagnetism #2

Magnetic Field due to a Long Straight Wire:

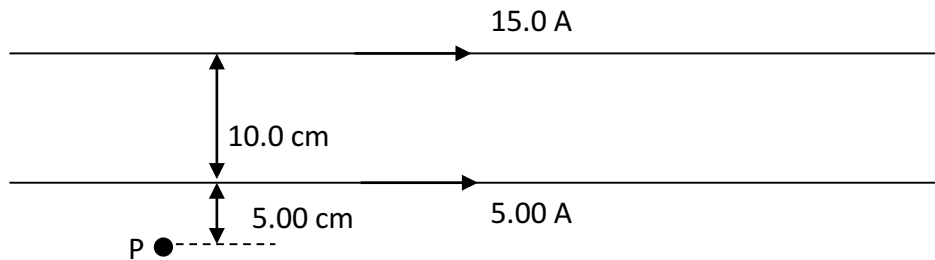
Force Between two Parallel Wires:

Electromagnetism #2

Definition of the Ampere:

1.00 Ampere is a constant current that when maintained in two straight parallel conductors of infinite length, placed 1.00 m apart in a vacuum, produce a force of 2.00×10^{-7} N per unit of length.

1. Two very long straight parallel wires carry currents of 15.0 A and 5.00 A as shown below.



- (a) Calculate at P, the magnitude and direction of the magnetic flux density due to;

- (i) the 5.00 A current

[2.01×10^{-5} T, into the page]

- (ii) the 15.0 A current

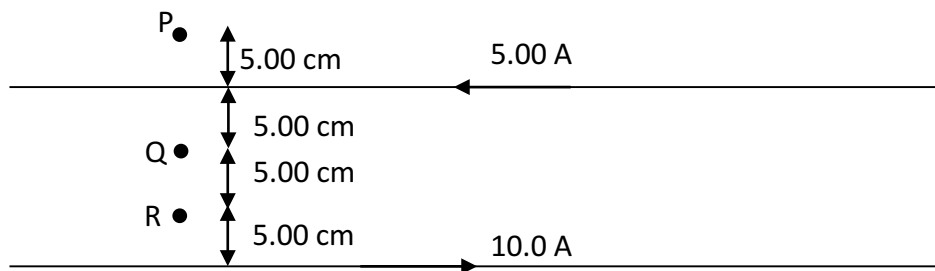
[2.01×10^{-5} T, into the page]

- (b) Calculate the net magnetic flux density at P.

[4.02×10^{-5} T, into the page]

Electromagnetism #2

2. Two parallel, horizontal wires carrying currents of 5.00 A and 10.0 A in opposite direction are 15.0 cm apart, as shown below.



Calculate the magnitude and direction of the magnetic flux density at P, Q and R.

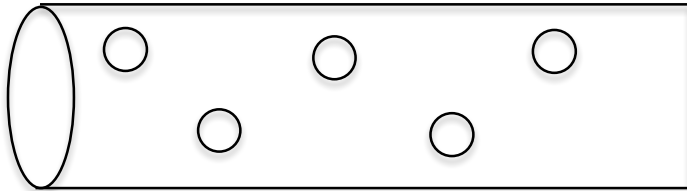
[P = 1.01×10^{-5} T into the page, Q = 4.02×10^{-5} T out of the page,
R = 5.01×10^{-5} T out of the page]

Electromagnetism #2

FORCE ON A CHARGED PARTICLE IN A MAGNETIC FIELD

We have looked at the force on a charged carrying conductor in a magnetic field – but what if there is only one charged particle?

Imagine individual charges moving through a conductor (these individual charges make up the current).

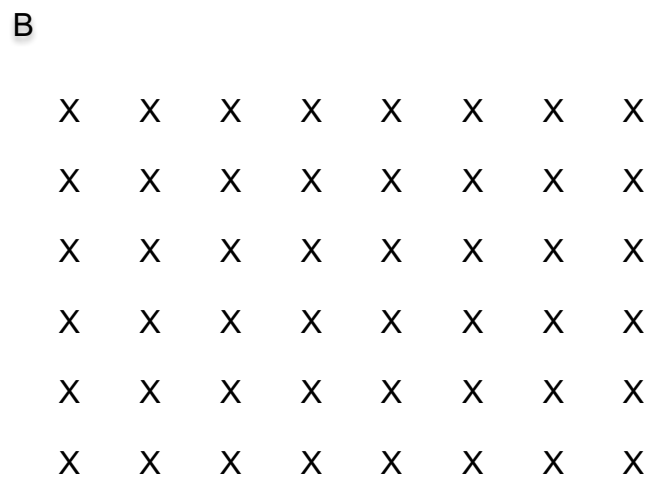
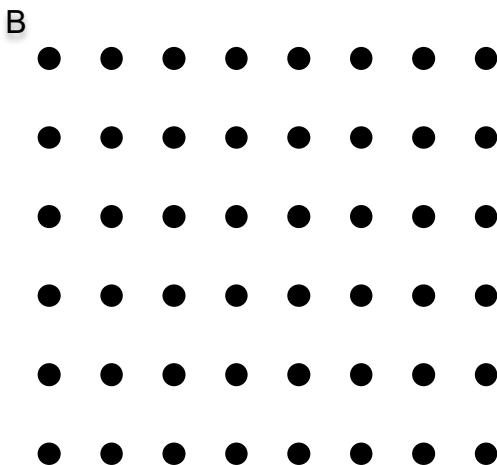


MOVING CHARGES IN A MAGNETIC FIELD

We have previously derived the formula for the force exerted on a charged particle moving in a magnetic field:

We have also derived a formula for the force required for an object to maintain a circular path:

Because the force experienced by a charged particle moving in a magnetic field will be perpendicular to the direction of velocity – it is possible to have circular motion.



Electromagnetism #2

FORCE ON CHARGED PARTICLE IN A MAGNETIC FIELD

1. A charge of +2.00 C is moving due North at $3.00 \times 10^2 \text{ ms}^{-1}$ in a magnetic field pointing to the West of flux density $5.00 \mu\text{T}$. Calculate the force the charge will experience.
[$3.00 \times 10^{-3} \text{ N}$, Up]

2. A charge of -1.80 C is moving horizontally West at 1.00 kms^{-1} between the horizontal poles of an electromagnet which produces an upwards flux density of $15.0 \times 10^{-6} \text{ T}$. Calculate the force the charge will experience.
[$2.70 \times 10^{-2} \text{ N}$, South]

3. An electron is moving East at $5.00 \times 10^3 \text{ ms}^{-1}$ inside a T.V tube and it passes through a magnetic field of $8.00 \times 10^{-5} \text{ T}$ vertically upwards. Calculate the force it will experience.
[$6.40 \times 10^{-20} \text{ N}$, North]

Electromagnetism #2

4. An electron moves due north at $1.00 \times 10^6 \text{ ms}^{-1}$ into a uniform magnetic field of $5.00 \times 10^{-2} \text{ T}$ directed vertically upwards. Calculate the magnitude of the force on the electron and determine the direction in which will it be deflected.

[$8.00 \times 10^{-15} \text{ N}$, West]

5. A positively charged carbon ion ($m = 2.00 \times 10^{-26} \text{ kg}$ and a charge of $1.60 \times 10^{-19} \text{ C}$) moves in a circular path of radius 0.200 m . A magnetic field of 0.500 T is perpendicular to the plane of the circular path. Calculate the speed of the carbon ion.

[$8.00 \times 10^5 \text{ ms}^{-1}$]

6. A charge moving north at $3.00 \times 10^2 \text{ ms}^{-1}$ enters a region in which there is a $5.00 \mu\text{T}$ field acting vertically downwards. The charge undergoes circular motion in a clockwise direction with a centripetal force of $3.00 \times 10^{-3} \text{ N}$ acting. Calculate the size of the charge and state its nature.

[-2.00 C]

Electromagnetism #2

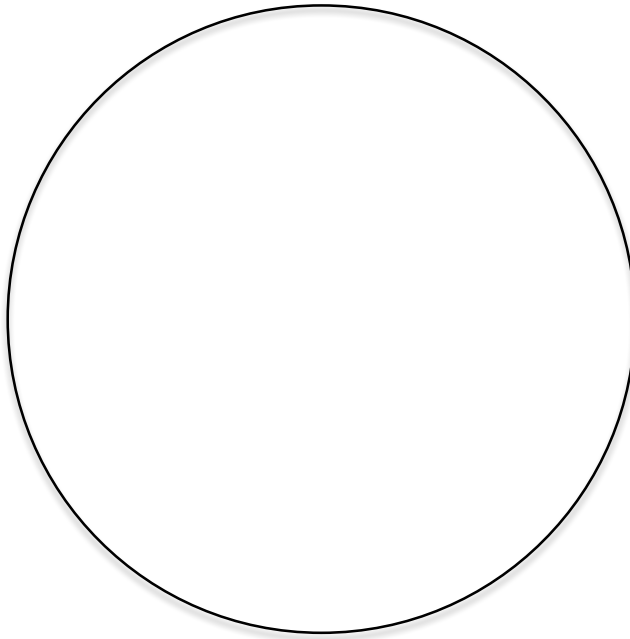
7. An electron travelling at $1.60 \times 10^4 \text{ ms}^{-1}$ enters a region in which there is a uniform magnetic field of $3.00 \times 10^{-2} \text{ T}$. Calculate the radius of curvature of the resulting path.

[$3.04 \times 10^{-6} \text{ m}$]

8. A beam of electrons moves at $4.00 \times 10^6 \text{ ms}^{-1}$ perpendicular to a magnetic field of $5.00 \times 10^{-4} \text{ T}$. Calculate:

- (a) The magnitude of the force on each electron in the beam
 - (b) The radius of the circular path of the electrons.
 - (c) The radius of a beam of alpha particles that moves into this same field with a velocity of $8.00 \times 10^2 \text{ ms}^{-1}$. The mass of an alpha particle is $6.68 \times 10^{-27} \text{ kg}$.
- [$3.20 \times 10^{-16} \text{ N}$; $4.56 \times 10^{-2} \text{ m}$; $3.34 \times 10^{-2} \text{ m}$]

THE EARTH'S MAGNETIC FIELD



Magnetic Declination –

Magnetic Inclination or Dip –



Perth (southern hemisphere)



Equator



USA (northern hemisphere)

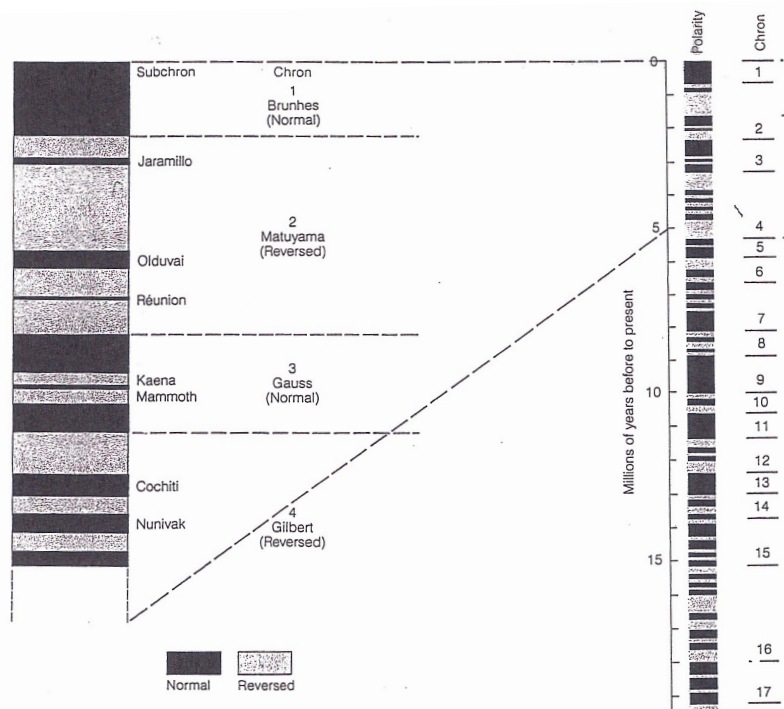
EARTH'S MAGNETIC FIELD – ORIGINS, POLE REVERSAL AND AURORAS

ORIGINS

- The magnetic field pattern of the Earth is similar to one that would be set up by a bar magnet deep within the Earth.
- But – although the Earth does have large deposits of iron ore deep beneath the surface, the high temperatures of the core (above T_{curie} of iron) prevent the iron from retaining permanent magnetism.
- Instead, the origin of the Earth's magnetic field is believed to be due to charge carrying convection currents in the Earth's outer core.
- Particles in the molten rock become charged due to friction.
- Moving charges constitute a current and there is a magnetic field associated with a current.
- There is also some evidence to suggest that the faster a planet rotates the stronger its magnetic field is.

POLARITY REVERSAL

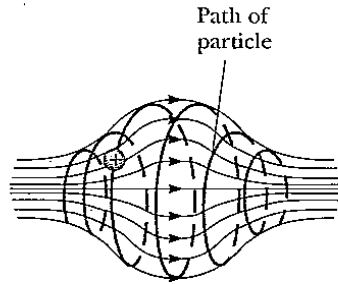
- The direction of the Earth's magnetic field has reversed direction several times during the last million years.



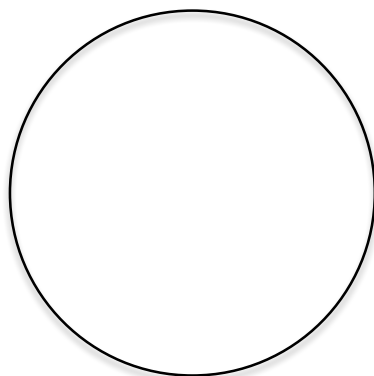
- Over a 1000 – 5000 year period the Earth's magnetic field slowly dies to low intensity and the magnetic poles move erratically and fluctuate, before building up again in the opposite direction.
- This is evidenced by geological records of basalt (a rock that contains iron).
- As lava (from the outer core) erupts onto the ocean floor and cools down, it passes through its Curie Point (500°C) leaving a permanent record of the Earth's magnetisation when it cooled.
- The rocks can be dated by alternative means to determine a timeline for these reversals.

AURORAS

- When charged particles move in a non-uniform magnetic field – the motion is quite complex.
- For a field that is strong at the ends and weak in the middle (similar to the Earth’s magnetic field), particles spiral around the field lines and oscillate back and forth between the end points. This is sometimes termed a ‘magnetic bottle’.



- Cosmic rays (also known as solar winds) carry charged particles towards the Earth. Most of these charged particles are deflected back into space by the Earth’s magnetic field, some, however, become trapped in regions called the Van Allen radiation belts.
- These particles – mostly electrons and protons – spiral around the Earth’s magnetic field lines from pole to pole within these belts.
- When these particles reach the poles they can collide with atoms in the atmosphere causing the atoms to emit visible light, producing the Aurora Australis and Aurora Borealis.
- The auroras tend to occur in the polar regions because it is here that the Van Allen Belts are closest to the atmosphere.
- The trapping of the particles is due to the non-uniformity of the Earth’s magnetic field.



Electromagnetism #2

EARTH'S MAGNETIC FIELD – DIP QUESTIONS EXAMPLES

Assume the Earth's magnetic field in Perth is 5.50×10^{-5} T at 66.0° to the horizontal.

Assume that the magnetic field at the equator is 5.50×10^{-5} T and is horizontal.

Assume that the magnetic field at the poles is 6.00×10^{-5} T and is vertical.

1. Calculate the force on a 15.0 m length of overhead cable, carrying a current of 2.50×10^2 A in a South \rightarrow North direction, due to the earth's magnetic field in Perth.

Electromagnetism #2

2. Calculate the force on a 20.0 m length of overhead cable, carrying a current of 2.50×10^2 A in West \rightarrow East direction, due to the earth's magnetic field in Perth?

Electromagnetism #2

3. In the central United States the magnetic flux density is measured to be $4.00 \times 10^{-5} \text{ T}$ at an angle of 70.0° to the ground. If a proton travels East to West in this field at a speed of $6.00 \times 10^7 \text{ ms}^{-1}$, calculate the force it would experience.

[$3.84 \times 10^{-16} \text{ N}$ 19.9° down in a Southerly direction]