Electromagnetism

Electrostatics:

Think of charge as a character of an electric particle. It can be + or - . Eg an electron has a negative charge defined by e^-

Charge is measured in Coulombs, C. The charge on an electron in coulombs is -1.6×10^{-19}C.

1.0:

Show that there are more than 10^{18} electrons in 1 Coulomb.

Coulomb's Law:

There are two types of electric charge in the universe: positive and negative. It is important to understand that like charges repel whilst unlike charges attract. The strength of this repulsion or attraction is given by Coulomb's Law

$$F = \frac{kQ_1Q_2}{r^2}$$

Q_1 is the charge on the first particle

Q_2 is the charge on the second particle

r is the distance between them

k is a constant equal to 9×10^9 Nm^2C^{-2}

Coulomb's Law tells us that the force between two charged objects is proportional to each of their charges and inversely proportional to the square of their separation. Since it's a force, it also needs a direction; to find this direction remember that like charges repel and unlike charges attract. If we have a positive charge and a negative charge, we know that they will be attracted towards each other - so that means that a negative F will denote an attractive force. If we have two like charges, F will be positive. In this case, the vector nature of F is not denoted with an absolute direction, but instead it will determine if two charges are drawn towards each other or directly repelled from each other.

1.1:

Two spheres of positive charge are placed close to each other. How do acceleration and velocity change as they move away from each other?

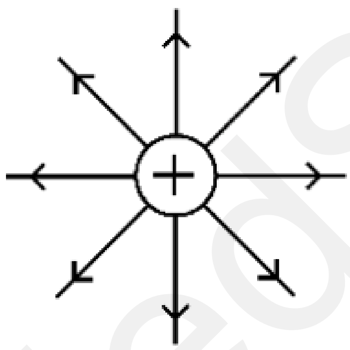
1.2:
Two charges are separated by 1 micrometre. One has a charge +2 μC and the other is an electron. Use Coulomb's Law to calculate the force between them, without using a calculator.

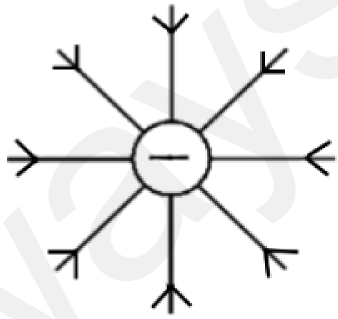
Electric Fields:
A force field is an area where a force is experienced. A charge creates an electric field. Another charge placed in that field in that field will move along an electric field line.

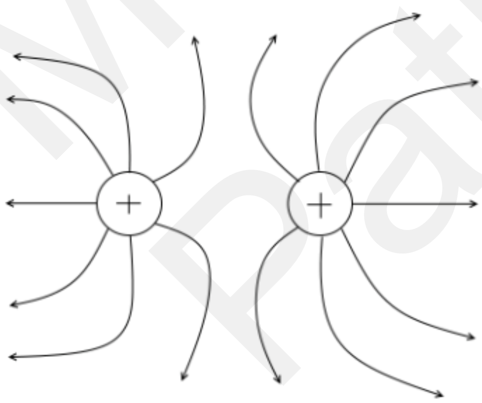
The electric field E is defined as the force per charge on a positive test charge. The 'test charge', q, is defined as one that's so weak it doesn't create its own field. As a result of this all that we're left with is the field around the second particle, Q. The electric field created by charge Q is given by:

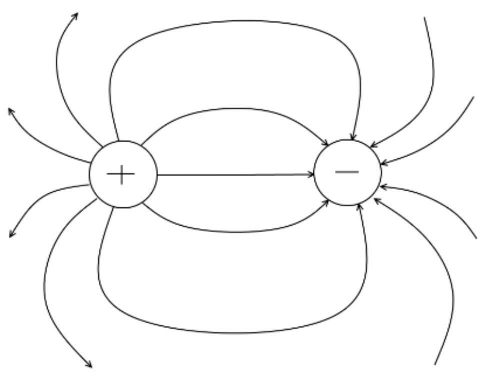
$$E = \frac{F}{q} = \frac{kQ}{r^2}$$

In other words, E= force experienced by a test char ge in an electric field









Electric Potential:
The potential energy per unit charge is the electrical potential, V, which is the amount of energy a test charge would have if it were placed at that point

$$V = \frac{kQ}{r}$$

The electric potential is a scalar. The difference in electric potential between two points is the potential difference, measured in volts. It is the work done per unit charge in moving a charge from one point to another in an electric field along any path.

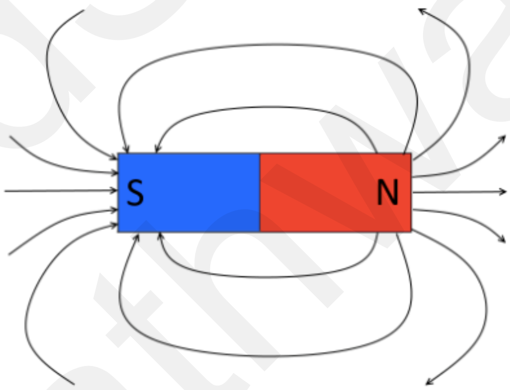
1.3:

A 0.1C charge is moved from point A to point B. The potential at point A is 100V and at point B is 80V. The path the charge takes is 2m long and the distance from A to B is 1m. What is the work done?

Hint: (voltage = Energy/ Coulomb)

Magnetism:

- Like poles repel, unlike poles attract.
- Magnetism also arises from the motion of charged particles



1) Electric charges in a Magnetic Field

When a particle with charge *q* moves through a magnetic field *B* with speed *v* it experiences a force F_B due to that magnetic field with magnitude given by

$$F_B = |q|vBSin\theta$$

θ= angle between the direction of motion of the charged particle and the magnetic field B

Right hand palm rule:

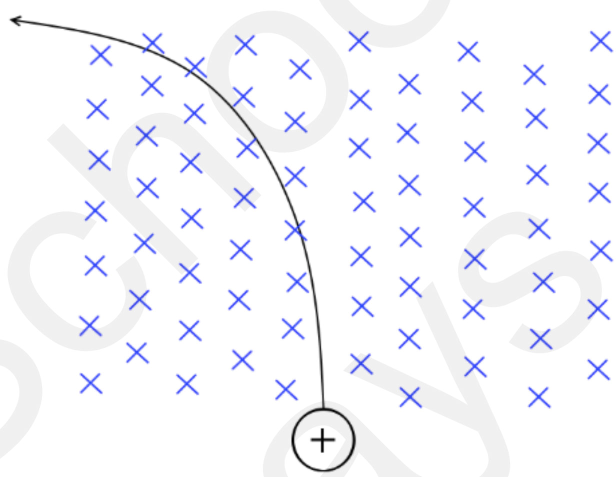
To use the right hand palm rule, hold out your palm flat. Picture vector **v** travelling in the direction of your thumb and the magnetic field vector **B** being in the direction of your fingers. The resulting force **F** will be directly out of your palm.

Note that **v** here is the direction of velocity of a *positive* charge. The force on a negative charge will always be in the opposite direction to the force acting on a positive charge.

X = Into the page
• = Away from page

A positively charged particle travelling upwards on the page encounters a field pointing into the page. Draw this situation and predict the motion of the particle.

Solution:



Particle will bend to the left.

1.4

"A proton (charge q=1.6 × 10^{-19} C) is moving at 2 × 10^5 ms^{-1} parallel to the ground. A magnetic field of 1 Tesla (T) is in the vertical direction. What is the magnetic force of the electron?"

Step 1: Apply the right hand palm rule

Step 2: apply the correct formula

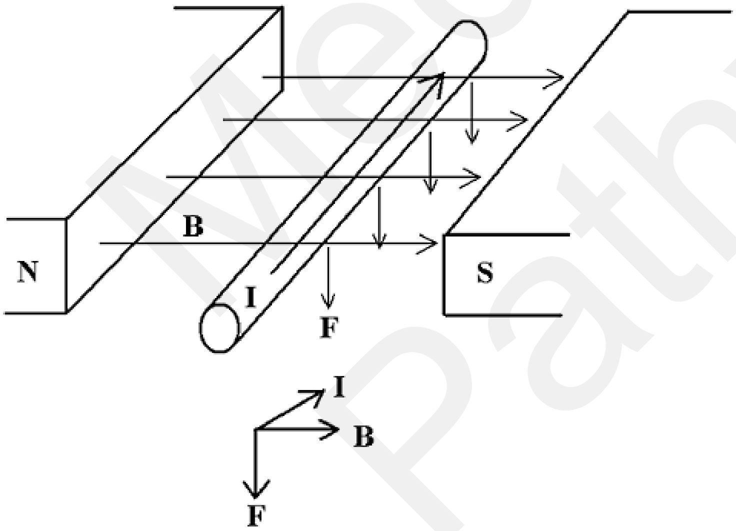
Step 3: What are the units and direction

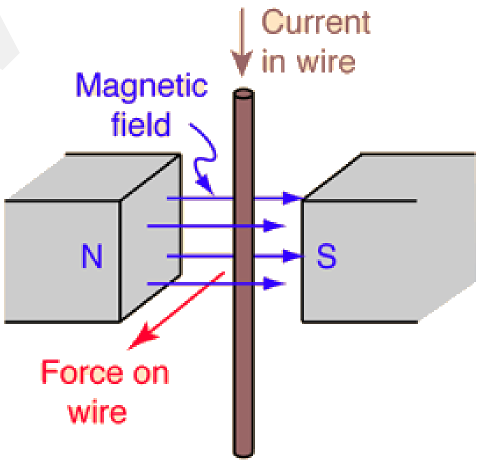
2) A current carrying wire in a magnetic field:
Electrical Current is juts a flow of electron, and so a current-carrying wire in a magnetic field also experiences a force on it.
I = current (A)
l = length (m)
θ = angle between current direction and the magnetic field B

Similarly, a wire carrying a current will experience a force when it passes through a magnetic field. The equation for this is given by

$$F = IlBsin\theta$$

where I is the current, and l is length of the wire within the magnetic field. Just as in the case of the force of charged particle in a magnetic field, we can calculate the direction of the force using the right hand palm, right hand curl or left hand gun rule - just substitute the current direction *I* for the velocity, **v**.



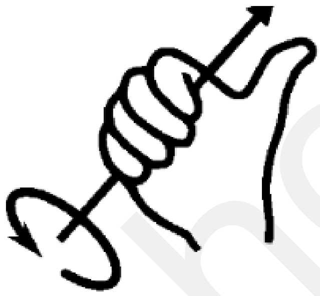


Current Carrying Wires

Current carrying wires create their own magnetic fields. The field strength is inversely proportional to the distance from the wire.

$$B = \frac{\mu_0 I}{2\pi r}$$

where μ_0 is the permeability of free space – just a constant (1.26×10^{-6} m·kg·s^{-2}·A^{-2}) . The magnetic field lines are circles whose centres are on the wire. The direction of the field is given by the right hand grip rule.



To use the right hand grip rule, point your thumb in the direction of **positive** current flow and wrap your fingers around like you're gripping an arrow as shown in the diagram.

Faraday's Law – Current is induced in a conductor when the magnetic environment around that conductor changes. A changing magnetic field induces a current. Similarly a changing electrical field induces magnetism (a magnetic field).

1.5:

"A wire carries a current of 10 Amps (A). What is the strength and direction of the magnetic field around it at a distance of 1 millimetre?"

1) Right hand grip rule

2) Apply the formula

1. 6

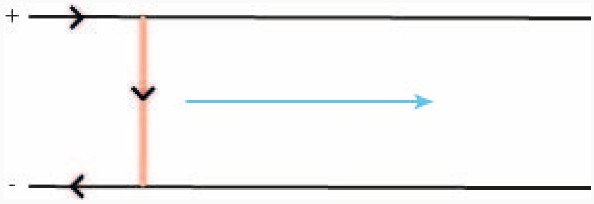
Challenge Question:

Consider two current carrying wires next to each other. If the currents run in the same direction do the wires attract or repel each other? What about if the currents run in the opposite direction?

1.7

A railgun uses a combination of powerful magnetic fields and electric currents to launch objects at incredibly high speeds.

The barrel of the railgun consists of two rails joined by a sliding armature that can carry a current. Projectiles are loaded into the armature, shown in red, and flung in the direction of the blue arrow when fired. A 7.5×10^3 A current is moving through the rails in the direction of the black arrows.



1. What magnetic field is required to provide the 3.0 m armature with 2.3×10^6 N of force? Assume the magnetic field is completely perpendicular to the current. The equation $F = IlB \sin\theta$ may help.

A. 102 T into the page

B. 102 T out of the page

C. 98 T into the page

D. 98 T out of the page

2. Aside from the force used to launch the projectile, there are other forces present. Which of the below is true?

A. There is a force pushing the armature into the page

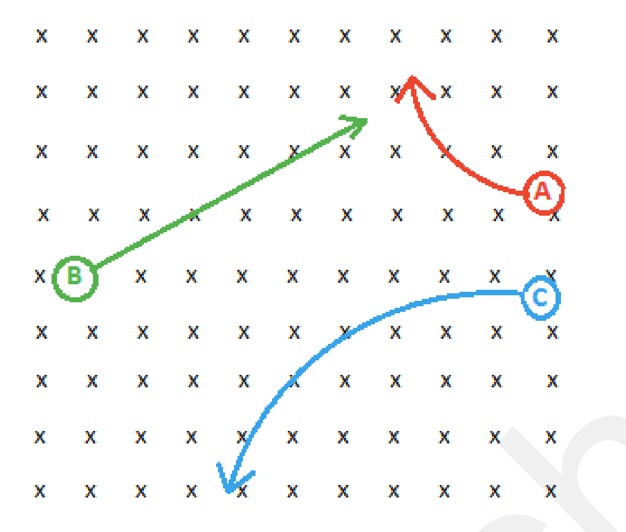
B. There is a force pushing the armature out of the page

C. There is a force pushing the rails together

D. There is a force pushing the rails apart

1.8:

The trajectories of three particles A, B and C as they enter a uniform magnetic field are shown in the diagram. Given that the magnetic field strength is $50\mu T$ into the page, answer the following questions.



The following equation may be helpful.

$$F_B = Bvq$$

where F_B = force exerted on particle (N), B = magnetic field strength (T), v = velocity of particle (ms^{-1}), q = charge on particle (C)

1. Particle A is most likely

A. positively charged

B. negatively charged

C. uncharged

D. can be either positively or negatively charged

2. Select the correct statement that describes particle A.

A. Particle A is lighter than particle C

B. Particle A is slower than particle C

C. Particle A is both lighter and slower than particle C

D. Answers A, B and C are not necessarily true.

3. If the magnitude of particle C's charge is $0.005\ C$ and its velocity is $2.5 \times 10^5\ m.s^{-1}$, calculate the force exerted on the particle by the magnetic field.

A. $6.25 \times 10^{-2}\ N$

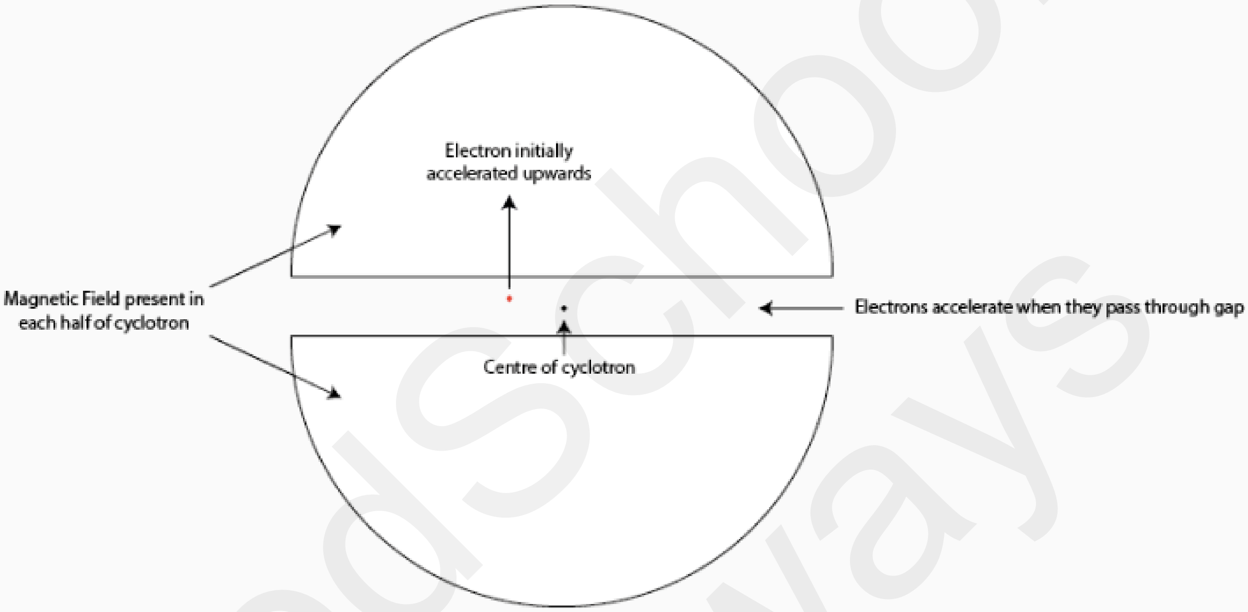
B. $1.25 \times 10^{-1}\ N$

C. $6.25 \times 10^4\ N$

D. $1.25 \times 10^5\ N$

1.9:

One of the earliest types of particle accelerators which is still used today is called a cyclotron. It is shown below.



Electrons are injected left of the cyclotron's centre, where there is a gap. In this gap, there is an alternating electric field that accelerates electrons each time they pass through the gap.

The magnetic fields in each half of the cyclotron are of equal direction and magnitude at any point in time.

1. If the electrons are initially moving upwards, which way does the magnetic field need to point to direct electrons in a clockwise circle around the centre of the cyclotron?

A. Into the page

B. Out of the page

C. To the left

D. To the right

2. The radius of a charged particle's centripetal motion in a magnetic field is given by $r = \frac{mv}{qB}$ Where m, v and q are the mass, velocity and charge of the particle respectively. B is the magnetic field perpendicular to the particle's motion while r is the radius of that motion. As stated above, each time an electron crosses the gap, the electrons accelerate. If the electrons are to follow a clockwise spiral of increasing radius, what must be required of the magnetic field?

A. The magnetic field has to alternate direction each time the electron crosses the gap

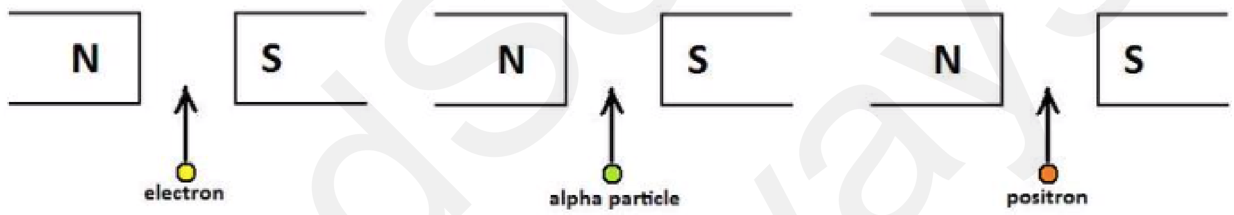
B. The magnetic field has to increase in magnitude each time the electron crosses the gap

C. The magnetic field must not decrease in magnitude each time the electron crosses the gap

D. The magnetic field has to alternate direction and increase in magnitude each the electron crosses the gap

2.0:

A scientist fires an electron, an alpha particle and a positron at the same velocity in between two magnets as shown below.



1. What is the direction of the force on the electron?

A. left

B. right

C. into the page

D. out of the page

2. Choose the correct statement that describes the direction of the force on the alpha particle and the positron.

A. The direction of the force exerted by the magnetic field on the alpha particle and positron is the same.

B. The force exerted by the magnetic field on the alpha particle and positron are in opposite directions.

C. No force is exerted on the alpha particle because it is a neutrally charged particle while force is exerted on the positron because it is a charged particle.

D. No force is exerted on the positron because it is a neutrally charged particle while force is exerted on the alpha particle because it is a charged particle.

3. Rank the magnitude of the force exerted on the three particles, where:

The force F_B exerted by a magnetic field on a charged particle is given by the equation:
$F_B = Bvq$
F_e is the force acting on the electron
F_{positron} is the force acting on positro
F_α is the force acting on alpha particle

A. $F_e = F_{\text{positron}} > F_\alpha$

B. $F_\alpha > F_e = F_{\text{positron}}$

C. $F_\alpha > F_e > F_{\text{positron}}$

D. $F_{\text{positron}} > F_e = F_\alpha$

4. Given that the magnetic force exerted on a charged particle causes the particle to follow a circular trajectory or radius $r = \frac{mv}{Bq}$ Choose the correct statement that describes the circular trajectory of the particles. An electron and a positron have the same mass.

A. The radius of the alpha particle's circular trajectory will be two times greater than that of the positron.

B. The radius of the alpha particle's circular trajectory will be half that of the positron.

C. The radius of the alpha particle's circular trajectory will be the identical to that of the positron.

D. The radius of the alpha particle's circular trajectory will be more than two times greater than that of the positron.

2.1:

Very low frequency (VLF) metal detectors operate by the principal of electromagnetic induction. A primary coil, or induction coil, produces an oscillating magnetic field. A current will be induced in any metallic objects near the induction coil, resulting the production of an opposing magnetic field. The induced magnetic field then generates a current in a secondary (detection) coil, which is then processed into a signal.

Metal detectors are only capable of detecting target objects within a short range as magnetic flux density (the magnetic field strength) from this type of coil is inversely proportional to the cube of distance from the coil $\left(B \propto \frac{1}{R^3}\right)$.

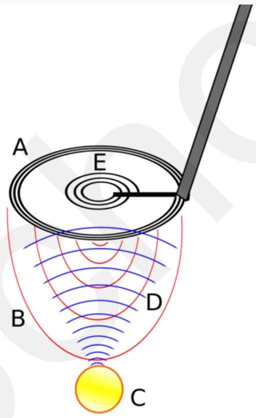


Figure 1: diagram of a VLF metal detector showing A) the inductor coil, B) the magnetic field produced by the induction coil, C) The metallic target, D) The induced magnetic field of the target and E) the detector coil.

Note: this relationship between magnetic flux density and distance is only valid when s is much greater than the radius of the coil. Assume that this condition is met for the following questions.

1. The eddy current induced in the target material (and thus the induced magnetic field) is dependant on the magnetic flux density from the induction coil. If the metal detector is moved from 1m to 2m from the target, what happens to the magnetic flux density experienced by the target?

A. It reduces to half of its initial value.

B. It reduces to one quarter of its initial value.

C. It reduces to one sixth of its initial value.

D. it reduces to one eighth of its initial value.

2. In metal detectors, the induction coil produces an oscillating magnetic field. Which of the following answers best explains the reason for using an oscillating induction coil rather than generating a constant magnetic field?

A. Constantly sending current through the coil would increase power consumption. The coil alternates to improve efficiency.

B. The oscillation of the induction coil matches the resonant frequency of most metals.

C. Current is only induced in the target metal when the magnetic field around it changes. The induction coil oscillates so that the target constantly produces a signal.

D. The detector coil can only detect a metal when the polarity of that metal opposes that of the induction coil. The induction coil oscillates to detect targets with magnetic fields in both directions.