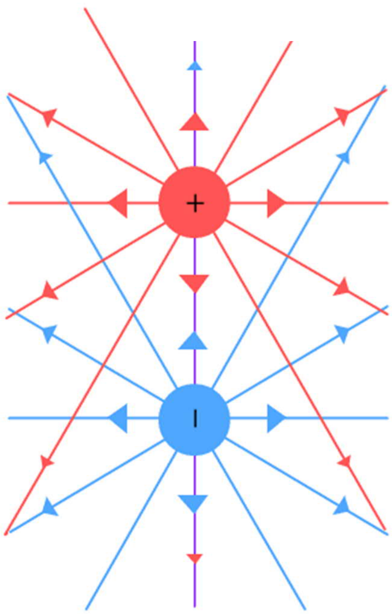


PHYSICS

2.1 Electric Field

ABSTRACT

This study notes have been developed and written to meet the scope and syllabus of all the content of the Stage 2 Physics 2020. The goal of this topic is to enable students not just to recognize concepts, but to work with them in ways that will be useful in final exam.

Muralikumar ME., CPEngg., RPEQ.,

Stage 2 Study Notes

Table of Contents

Subtopic 2.1 Electric Fields

Students are introduced to two fundamental postulates of electrostatics: Coulomb's Law and the principle of superposition. The electric field at a point in space is defined and used, with Coulomb's Law, to derive a formula for the electric field at a distance from a point charge. In this topic the charges are assumed to be in a vacuum (or, for practical purposes, air).

Students explore several important electric field distributions, including those used in a wide range of applications.

Science Understanding	Possible contexts
Electrostatically charged objects exert forces upon one another; the magnitude of these forces can be calculated using Coulomb's Law. • Solve problems involving the use of: $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$. • Using proportionality, discuss changes in the magnitude of the force on each of the charges as a result of a change in one or both of the charges and/or a change in the distance between them. • Explain that the electric forces are consistent with Newton's Third Law.	This uses the concepts of force developed in Stage 1, Subtopic 1.2: Forces and charge in Subtopic 2.1: Potential difference and electric current. Compare and contrast Coulomb's Law with Newton's Law of Universal Gravitation. Use a Van de Graaff generator to demonstrate repulsion between like charges. Explore an example of the development of complex models using evidence from many sources using the video, 'Coulomb's Law': https://youtu.be/B5LVoU_a08c
When more than two point charges are present, the force on any one of them is equal to the vector sum of the forces due to each of the other point charges. • Use vector addition in one dimension or with right-angled, isosceles, or equilateral triangles to calculate the magnitude and direction of the force on a point charge due to two other point charges.	The Principle of Superposition is a key concept in this topic and in Stage 2, Topic 3, Light and atoms. It is essential here when sketching electric field diagrams, particularly of two charges or two parallel plates.
Point charges and charged objects produce electric fields in the space that surrounds them. A charged object in an electric field experiences an electric force. The direction and number of electric field lines per unit area represent the direction and magnitude of the electric field. • Sketch the electric field lines: ◆ for an isolated positive or negative point charge and for two-point charges	Computer interactive: 'Electric Fields and Charges' from https://phet.colorado.edu/en/simulation/charges-and-fields Demonstrate electric fields using an HT (high tension) power supply or a Van de Graaff generator. Explore applications of electric fields, such as: • electrostatic loudspeakers • shark shields • capacitors.

<table>
<tr><th>Science Understanding</th><th>Possible contexts</th></tr>
<tr><td>◆ between and near the edges of two finite oppositely charged parallel plates.
A positively charged body placed in an electric field will experience a force in the direction of the field; the strength of the electric field is defined as the force per unit charge.
• Solve problems involving the use of: $\vec{E} = \vec{F}/q$.
• Using Coulomb's Law, derive the formula: $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$.
• Solve problems using: $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$, for one- or two-point charges.</td><td>Use electric field sensors to map electric fields and explore the relationship between electric field strength and distance from charged conductors.</td></tr>
<tr><td>There is no electric field inside a hollow conductor of any shape, provided that there is no charge in the cavity.
• Sketch the electric field produced by a hollow spherical charged conductor.</td><td>Assess the benefits and limitations of applications of electrostatic shielding.
Examples include:
• Faraday cages
• microwave ovens
• NMR (nuclear magnetic resonance) imaging rooms
• coaxial and USB cables
• difficulties with mobile phone reception.</td></tr>
<tr><td rowspan="2">Electric fields are strongest near sharp points on conductors. These fields may be large enough to ionise the polar and non-polar molecules in the air in the vicinity of the sharp points, resulting in charge movement away from the conductor. This is called a 'corona discharge'.
• Sketch the electric field produced by a charged pear-shaped conductor.
• Describe how the large electric field in the vicinity of sharp points may ionize the air.</td><td>Demonstrate corona discharges using a Van de Graaff generator.</td></tr>
<tr><td>Explore problems for which scientists have developed practical solutions by making use of strong electric fields. Examples include:
• photocopier (charging drum and charging/discharging paper)
• lightning rod
• electrostatic precipitator
• spark plugs.</td></tr>
</table>

1 Coulomb's Law

1.1 Coulomb's Law

The magnitude of electrostatic force between two stationary point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.

$$F \propto \frac{q_1 q_2}{r^2}$$

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} \qquad where\ \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ Nm^2C^{-2}$$

Note

- The forces are directly proportional to the product of their charges
- The forces are indirectly proportional to the square of the distance between them.
- The Coulomb's law gives only the magnitude of the electrostatic force between the charges. For the direction of the force, we need to consider the properties of like and unlike charges.
- The electrostatic forces are attractive if the charges are opposite in nature and repulsive if the charges are alike.
- The electrostatic forces are mutual forces along a straight line joining the charges. Each charge exerts a force on the other charges.

1.2 Proportionality of Coulomb's Law:

The electrostatic force is directly proportional to the product of the charges.

$F \propto q_1 q_2$

The electrostatic force is indirectly proportional to the square of the distance between the charges.

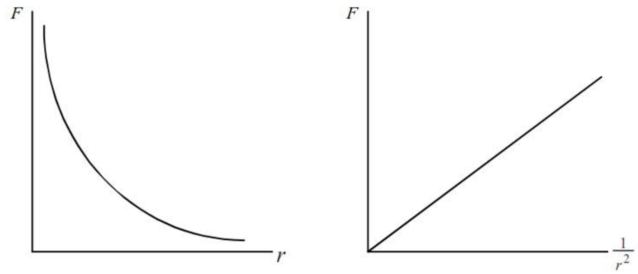
$F \propto {}^{1}/_{distance^2}$

We can use these proportionalities to discuss the changing values of a force as charge sizes and the distances between the charges change.

Note

- If q_1 is doubled then the force is doubled.
- If q_2 is doubled then the force is doubled.
- If both q_1 & q_2 are doubled then the force is 4 times as large.
- If the distance between the charges is doubled then the force is ¼ the size.

Graphically

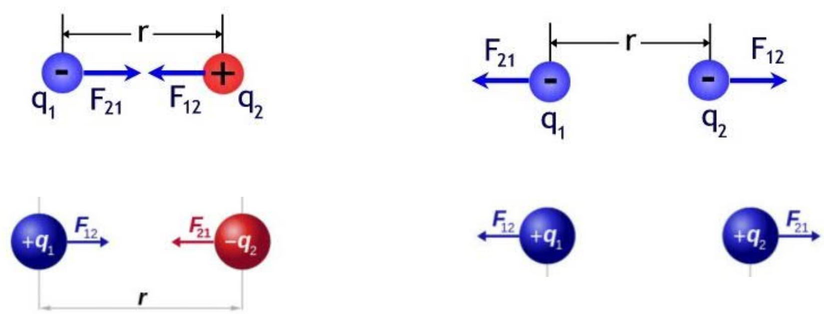


- If q_1 & q_2 are constant, then the force (F) is proportional to $1/d^2$
- The graph is a straight line through the origin.
- The slope of the graph will be given by,

$$slope = \frac{q_1 q_2}{4\pi\varepsilon_0}$$

1.3 Consistence with Newton's third Law

As per Newton's third law, the force between two electric charges is same in magnitude and opposite directions, either as attraction (or) repulsion.



However, no matter what the size of the charges, both charges experience the same force in magnitude.

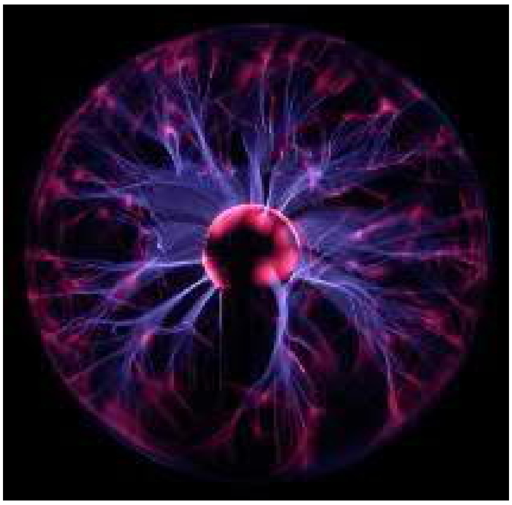
2 Coulomb's Law Vs the Law of Universal Gravitation

2.1 Similarities

- Both are inverse square laws; for gravity it is the product of two masses, and for the electric force it is the product of the two charges.
- The forces act along the line joining the centres of the masses or charges.
- The magnitude of the force is the same as the force that would be measured if all the mass or charge is concentrated at a point at the centre of the sphere. Therefore, distance in both cases is measured from the centres of the spheres.
- In both cases we are assuming that 'r' is longer than the radius of the object.

2.2 Difference

Electrostatic Force	Gravitational Force
Can be attractive or repulsive	Can only be attractive
Coulomb's constant [9.0×10^{9} Nm^2/C^2] is a very large number, implying that even small charges can result in noticeable forces.	The universal gravitational constant [6.67×10^{-11} Nm^2/kg^2] is very small, meaning that in many cases the gravitational force can be ignored.
It depends directly on the unit property (charge)	It depends directly on the unit property (mass)
The electrostatic force between the two charges depends on nature of the medium in which the two charges are kept at rest.	The gravitational force between two masses is independent of the medium. For example, if 1 kg of two masses are kept in air or inside water, the gravitational force between two masses remains the same.
If the charges are in motion, yet another force (Lorentz force) comes into play in addition to coulomb force.	The gravitational force between two point masses is the same whether two masses are at rest or in motion.
Magnitude of the force is much stronger than gravitational force.	Magnitude of the force is much weaker than electrostatic force.



PHYSICS

2.2 Motion of Charged Particles in Electric Field

ABSTRACT

This study notes have been developed and written to meet the scope and syllabus of all the content of the Stage 2 Physics 2020. The goal of this topic is to enable students not just to recognize concepts, but to work with them in ways that will be useful in final exam.

Muralikumar, ME., CPEngg., RPEQ

Stage 2 Study Notes

Table of Contents

2.2 Motion of Charged Particles in Electric Field

Students are introduced to the concept of work done by an electric field on a charged particle. The potential difference between two points in an electric field is defined and used to determine the work, and hence energy changes, of charged particles moving in uniform electric fields in a vacuum.

Students use formulae to determine the electric force and hence the resulting motion of charged particles in uniform electric fields. Students use the electric field and electric force concepts to explore the motion of ions in particle accelerators, such as a cyclotron.

Science Understanding	Possible contexts
Electric fields store electric potential energy. When a charged body moves or is moved from one point to another in an electric field and its potential energy changes, work is done on or by the field. The electric potential difference, ΔV, between two points is the work done per unit charge on a small positive test charge moved between the points, provided that all other charges remain undisturbed. The electron volt (eV) is a unit of measurement which describes the energy carried by a particle. It is the work done when an electron moves through a potential difference of 1 volt. • Solve problems involving the use of $W = q\Delta V$. • Convert energy from joules into electron volts and vice versa. The magnitude of the electric field (away from the edges) between two oppositely charged parallel plates a distance d apart, where ΔV is the potential difference between the plates, is given by the formula: $E = \frac{\Delta V}{d}$. • Solve problems involving the use of $E = \frac{\Delta V}{d}$.	This uses the concepts of force developed in Stage 1, Subtopic 1.2: Forces and energy in Stage 1, Subtopic 4.1: Energy. Use the concepts of work done and gravitational potential energy to introduce the concepts of electric potential energy and potential difference. The energy conversions relating to this concept have relevance to several other sections in the subject outline, including: • Stage 2, Subtopic 1.2: Forces and momentum: ion thrusters • Stage 2, Subtopic 3.2: Wave–particle duality: particle accelerators, X-ray production, the photoelectric effect, the Davisson–Germer experiment • Stage 2, Subtopic 3.3: The structure of the atom: production of line emission spectra. The meaning of the formula $W = q\Delta V$ should be emphasised in each context. Discuss the convenience of the different energy units (J and eV) in different circumstances.

Science Understanding	Possible contexts
The force on a charged particle moving in a uniform electric field is constant in magnitude and direction, thus producing a constant acceleration. • Derive the formula $\vec{a} = \frac{q\vec{E}}{m}$ for the acceleration of a charged particle in an electric field. • Solve problems using $\vec{a} = \frac{q\vec{E}}{m}$ and the motion formulae for the movement of charged particles parallel or antiparallel to a uniform electric field. • Describe the motion of charged particles parallel or antiparallel to a uniform electric field. In a cyclotron, the electric field in the gap between the Dees increases the speed of the charged particles. • Describe how an electric field between the Dees can transfer energy to an ion passing between them. • Describe how ions could be accelerated to high energies if they could be made to repeatedly move across an electric field. • Calculate the energy transferred to an ion each time it passes between the Dees. • Explain why the ions do not gain kinetic energy when inside the Dees.	Explore solutions to scientific problems developed using the motion of charges parallel or antiparallel to electric fields, such as: • linear accelerators • electron guns (e.g. in electron microscopes, oscilloscopes) • ion thrusters (e.g. in spacecraft propulsion) • X-ray tubes (e.g. in medicine).
When a charged particle moves at an angle to the uniform electric field the component of the velocity perpendicular to the field remains constant. • Compare the motion of a projectile in the absence of air resistance with the motion of a charged particle in a uniform electric field. • Solve problems for the motion of charged particles that enter a uniform electric field perpendicular to the field. • Solve problems for the motion of charged particles that enter a uniform electric field at an angle to the field where the displacement of the charged particle parallel to the field is zero.	Reinforce the concepts and processes introduced in Stage 2, Subtopic 1.2: Projectile motion. Investigate the motion of electrons in an electric field using Teltron tubes.

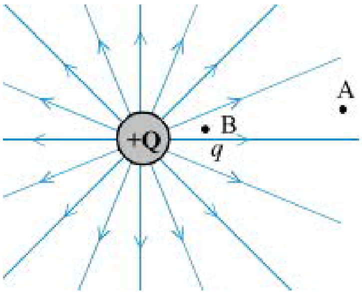
1 Electric Potential Difference

1.1 Electric Potential Energy

Consider a positive charge +Q and its associated electric field. Place a small positive charge 'q' at point B in this field. If 'q' is free to move, it will accelerate away from +Q under the influence of the coulombic repulsive force.

By the conservation of energy, it must come from the transformation of some other form of energy to kinetic energy.

Any charge placed in an electric field has an electric potential energy due to its position in the electric field – just as a mass placed in a gravitational field has gravitational potential energy due to its position in the field.



1.2 Gain or Lose of Potential Energy

In the case of motion in a gravitational field, if the mass falls it loses gravitational potential energy, and if it rises it gains gravitational potential energy.

With motion of charges in electric fields the situation is more complex – there are two different types of charge. The gain or loss of potential energy depends on the type of charge and the direction that it moves relative to the field.

- If a positive charge moves in the direction of the electric field – it accelerates freely. Therefore, it gains kinetic energy, and so it loses electric potential energy.
- If a positive charge moves opposite to the direction of the electric field – it moves against the force on it. Therefore, work must be done on it, and so it gains electric potential energy.
- If a negative charge moves in the direction of the electric field – it moves against the force on it. Therefore, work must be done on it, and so it gains electric potential energy.
- If a negative charge moves opposite to the direction of the electric field – it accelerates freely. Therefore, it gains kinetic energy, and so it loses electric potential energy.

1.3 Electric Potential Difference

The electric potential difference (ΔV) between two points in an electric field is the work done (W) per unit charge (q) in moving a positive charge between the two points, provided all other charges involved remain undisturbed.

$$\boxed{\Delta V = \frac{W}{q} = \frac{Fs}{q}}$$

$$\boxed{W = q\,\Delta V}$$

For electric potential difference, $Unit\ \mathbf{J\,C^{-1}}$, $\mathbf{1Volt = 1\,JC^{-1}}$

1.4 Electron Volt as a Unit of Energy

An electron volt (eV) is the work done when an electron moves through a potential difference of 1 volt (or)

An electron volt (eV) is the energy gained or lost by an electron in moving through a potential difference of 1 volt.

Hence if an electron moves through a potential difference of 1 Volt, the work done (and the change in potential energy) is given by

Work done $\boxed{W = \Delta PE = q\,\Delta V}$

$= 1.60 \times 10^{-19} \times 1 = 1.60 \times 10^{-19}$ J

Thus, one electron volt is the equivalent of 1.60×10^{-19} J

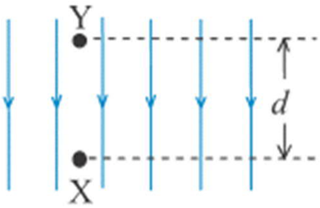
Thus $\boxed{\mathbf{1eV = 1.60 \times 10^{-19}\,J}}$

The electron volt is not a standard unit for energy. The standard unit of energy is the Joule. If energy has to be used in any formula, electron volt must be converted to Joules.

2 Electric Field Strength ($\boldsymbol{E}$) in a Uniform Electric Field

Consider the uniform electric field between two parallel plates, d meters apart, with a potential difference of ΔV volts between them. Consider moving a small positive charge 'q' from the negative plate to positive plate.

Because it is a uniform electric field of constant strength E there is s constant force $(F = qE)$ on this charge throughout its travel. To move this charge, we must do work on it.



Work done $W = Fs.$

$W = qE\,d.\,[F = qE, s = d]$

But $W = q\,\Delta V.$

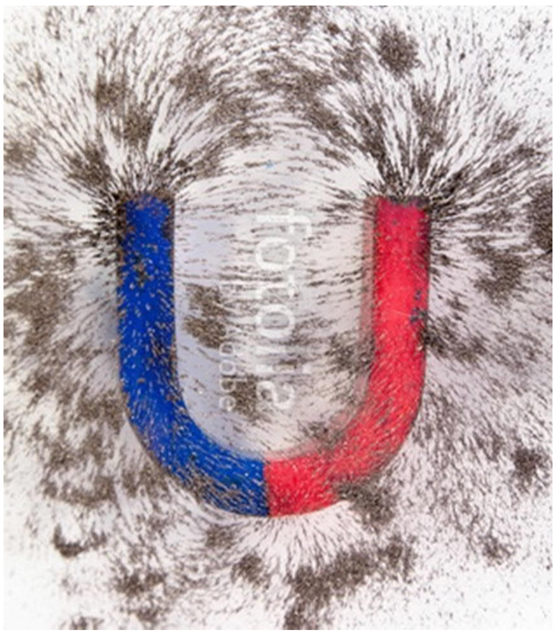
Therefore $qE\,d = q\,\Delta V.$

$$\boldsymbol{E} = \frac{\Delta \boldsymbol{V}}{\boldsymbol{d}}.$$

Thus, in a uniform electric field, the magnitude of the field strength E

- is the change of potential difference per unit distance in the direction of the field (or)
- is the rate of change of potential difference with respect to distance in the direction of the field (or)
- is equal to the potential gradient.

[Unit: $1Vm^{-1}$ = 1 NC^{-1} (Volt per metre)]



PHYSICS

2.3 Magnetic Field

ABSTRACT

This study notes have been developed and written to meet the scope and syllabus of all the content of the Stage 2 Physics 2020. The goal of this topic is to enable students not just to recognize concepts, but to work with them in ways that will be useful in final exam.

Muralikumar, ME., CPEngg.,RPEQ.,

Stage 2 Study Notes

Table of Contents

2.3 Magnetic Field

Students are introduced to the concept that a moving charge produces a magnetic field in addition to its electric field. The magnetic field strength at a point in space is defined and used. The interaction between magnetic fields and electric currents is described and used to define the strength of the magnetic field in terms of the force on current-carrying conductors.

Science Understanding	Possible contexts
Magnetic fields are associated with moving charges, such as charges in an electric current. Current-carrying conductors produce magnetic fields; these fields are utilized in solenoids. Magnetic field lines can be used to represent the magnetic field. The direction of the magnetic field depends on the direction of the moving charge that is producing the magnetic field. The magnitude of magnetic field strength, B, at any point is represented by the number of lines crossing a unit area perpendicular to the field in the vicinity of the point. • Sketch and/or interpret the magnetic field lines produced by an electric current flowing in a straight conductor, a loop, and a solenoid.	This uses the concept of electric current developed in Stage 1, Subtopic 2.1: Potential difference and electric current. Demonstrate magnetic field lines around permanent magnets, current-carrying conductors, and solenoids. Investigate electromagnets and their uses. Determine the direction of magnetic fields using a 'right-hand rule'. Investigate factors affecting magnetic field strength near a solenoid.
The magnitude of the magnetic field strength in the vicinity of a current-carrying conductor is given by $B = \frac{\mu_0}{2\pi}\frac{I}{r}$, where r is the radial distance to the conductor. • Solve problems involving the use of $B = \frac{\mu_0}{2\pi}\frac{I}{r}$,	Compare and contrast the factors affecting gravitational field strength, electric field strength, and magnetic field strength. Use sensors to measure the magnitude of the magnetic field strength at different distances from or different currents in conductors, loops, and solenoids.

1 Magnetic Fields

Moving electric charges produce magnetic fields. Since an electric current is many moving charges, a current in a wire will produce a magnetic field. If the charges stop moving, then the magnetic field will no longer exist, but the electric field will remain. Thus, there is no magnetic field if the charge is stationary.

2 Pictorial Representations

2.1 Magnetic field lines

As with gravitational and electric fields, magnetic fields also represent by field lines which are called as lines of force.

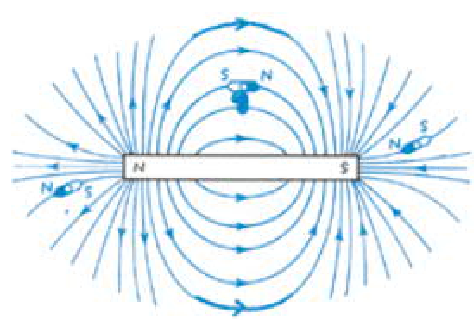
The magnetic field is a vector representation of the space and should therefore be defined in terms of magnitude and direction.

Since there can be only one resultant magnetic field at any point, field lines never cross each other.

2.2 Direction of the Magnetic Field

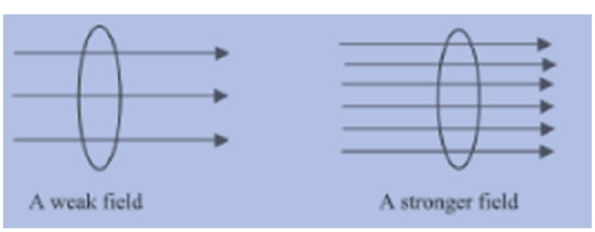
The direction of a magnetic field is defined as the direction in which the north pole of a small compass needle points when placed in the magnetic field.

If a field line is curved at any point, the direction of the field at that point is in the direction of the tangent to the curved line at that point.



2.3 Magnitude of the Magnetic Field

The magnitude of the magnetic field at any point is represented by the number of field lines crossing a unit area perpendicular to the direction of the magnetic field. Thus, a strong magnetic field represents by drawing more field lines per unit area and a weaker magnetic field by drawing comparatively less field lines per unit area.



3 Some Specific Magnetic Fields

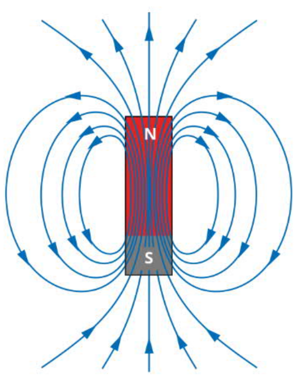
3.1 Field of a Bar Magnet

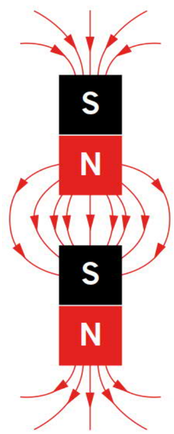
In a Bar magnet, the direction of the magnetic field is from the North Pole of the magnet to South Pole of magnet.

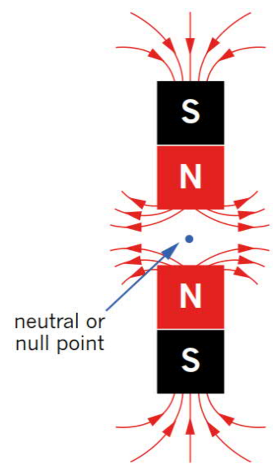
The direction of the field at any point is in a direction that is at a tangent to the field line at that point.

The magnitude of the field at any point is represented by the number of field lines crossing a unit area, perpendicular to the field. The closer together the lines of force, the stronger the magnetic field, and the further apart the lines of force, the weaker the field. This is the same as with all other fields, namely gravitational and electric.

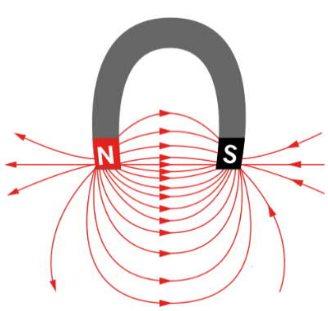
When two magnets are placed close together, two situations may arise. If the poles are unlike, then attraction will occur between them and a magnetic field will be created that extends between the two poles. On the other hand, if like poles are very near each other, repulsion will occur. In this situation, there will be a neutral point between the two poles where there is no magnetic field.







Different shaped magnets produce different shaped fields. The diagram shows the magnetic field plotted for a horseshoe magnet.



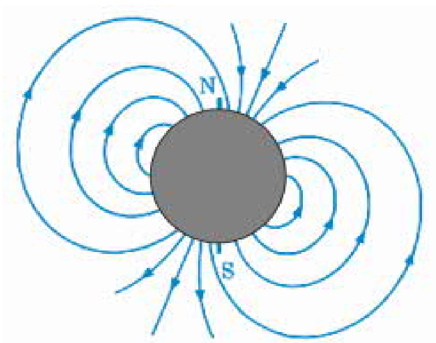
3.2 Earth's Magnetic Field

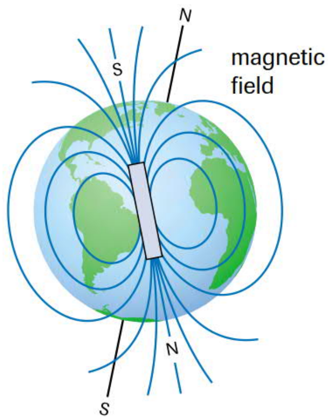
In the Earth's magnetic field, it is noted that this field is directed from the South Pole to the North Pole of the Earth, which seems wrong.

But remember that the direction of a magnetic field at any point is the direction of the force on the North Pole of a compass needle placed at that point. If we look at a compass needle near the surface of the Earth, it points towards the North Pole of the Earth.

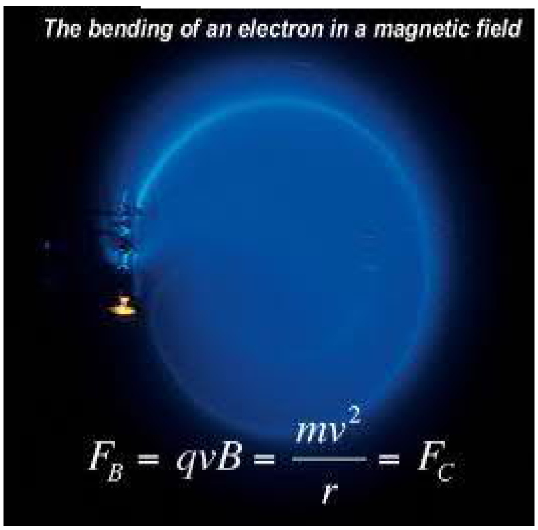
The North Pole of a compass needle and the North Pole of the Earth are two different things. The North Pole of a compass needle is that pole which points to the North Pole of the Earth. Thus, the North Pole of the Earth is attracting the North Pole of the compass needle; therefore, it is effectively the South pole of the Earth's magnetic field.

Earth's magnetic field resembled the field of a large bar magnet, inclined at a slight angle to Earth's axis, with its S-pole in the northern hemisphere.





Also note that the field lines are not emanating from the South Pole and not finishing at the North Pole but are displaced somewhat. This is because the locations of the Earth's Geographic North and South Poles are not the same as the locations of the Magnetic North and South Poles.



PHYSICS

2.4 Motion of Charged Particles in Magnetic Field

ABSTRACT

This study notes have been developed and written to meet the scope and syllabus of all the content of the Stage 2 Physics 2020. The goal of this topic is to enable students not just to recognize concepts, but to work with them in ways that will be useful in final exam.

Muralikumar, ME., CPEngg., RPEQ.,

Stage 2 Study Notes

Table of Contents

2.4 Motion of Charged Particles in Magnetic Field

The interaction of current-carrying conductors and magnetic fields is extended to the interaction of moving charged particles and uniform magnetic fields. Students investigate applications of the magnetic force on a current-carrying conductor.

Students explore the velocity dependence of the magnetic force on a moving charged particle, comparing this with the electric force. They discuss the circular path of charged particles moving at right angles to a uniform magnetic field, and apply their understanding to the deflection of ions in applications such as a cyclotron.

Science Understanding	Possible contexts
Magnets, magnetic materials, moving charges, and current-carrying conductors experience a force in a magnetic field. The force on a current element that is parallel or antiparallel to a magnetic field is zero. The magnetic force depends on both the magnitude and the direction of the velocity of the particle. The direction of the force on a current-carrying conductor or an individual charged particle moving at any angle θ to a uniform magnetic field depends on the direction of the magnetic field and the direction of charge movement. • Determine the direction of one of: ◆ force ◆ magnetic field ◆ charge movement given the direction of the other two. • Solve problems involving the use of $F = IlB\sin\theta$ for a current-carrying conductor and $F = qvB\sin\theta$ for a moving charged particle. A charged particle moving at right angles to a uniform magnetic field experiences a force of constant magnitude at right angles to the velocity. The force changes the direction but not the speed of the charged particle and hence it moves with uniform circular motion. • Explain how the velocity dependence of the magnetic force on a charged particle causes the particle to move with uniform circular motion when it enters a uniform magnetic field at right angles.	This uses the concept of force developed in Stage 1, Subtopic 1.2: Forces and the concept of circular motion in Stage 2, Subtopic 1.3: Circular motion and gravitation. Demonstrate the production of sound in loudspeakers. Use a current balance to determine the force on current-carrying conductors due to an external magnetic field. Investigate the motion of charges using Teltron tube or fine-beam apparatus. Use Teltron tubes to measure the charge-to-mass ratio of electrons. Evaluate the economic, social, and environmental impacts of some applications of charges moving within magnetic fields, such as: • moving-coil loudspeaker • synchrotron • mass spectrometer • electric motors • use of magnetic fields in electron microscopes. • maglev trains.
• Derive $r = \frac{mv}{qB}$ for the radius r of the circular path of an ion of charge q and mass m that is moving with speed v at right angles to a uniform magnetic field of magnitude B. • Solve problems involving the use of $r = \frac{mv}{qB}$.	

Science Understanding	Possible contexts
Cyclotrons are used to accelerate ions to high speed. The high-speed ions are collided with other nuclei to produce radioisotopes that can be used in medicine and industry. • Discuss the importance of being able to generate radioisotopes in a timely manner near the location they are required.	Discuss the advantages and disadvantages of generating radioisotopes in a cyclotron compared to a nuclear reactor. Make recommendations for particular contexts. Debate the need for both cyclotrons and nuclear reactors in the production of radioisotopes, including the relationship between public debate and science. Discuss the importance of the cyclotron in the South Australian Health and Medical Research Institute (SAHMRI) facility. Investigate medical uses and disadvantages of radioisotopes for diagnostic and therapeutic purposes (e.g. PET scanners, boron neutron capture therapy). Investigate benefits and limitations of using radioisotopes in industry (e.g. in quality assurance processes). Discuss the safe storage and disposal of radioactive materials.
The magnetic field within the dees of a cyclotron causes the charged particles to travel in a circular path, so that they repeatedly pass through the electric field. • Describe the nature and direction of the magnetic field needed to deflect ions into a circular path in the dees of a cyclotron. • Derive the formula $T = \frac{2\pi m}{qB}$ for the period T of the circular motion of an ion, and hence show that the period is independent of the speed of the ion. • Derive the formula $E_K = \frac{q^2B^2r^2}{2m}$ for the kinetic energy E_K of the ions emerging at radius r from a cyclotron.	Study the production and use of radioisotopes, for medical or industrial use. Explore the limitation on the energy of a charged particle emerging from a cyclotron due to relativistic effects.
• Use the formula $E_K = \frac{q^2B^2r^2}{2m}$ to show that E_K is independent of the potential difference across the dees and, for given ions, depends only on the magnetic field and the radius of the cyclotron. • Solve problems involving the use of $T = \frac{2\pi m}{qB}$ and $E_K = \frac{q^2B^2r^2}{2m}$	

1. Force on a Charged Particle in a Magnetic Field

1.1 Factors affecting the Magnetic Force $\boldsymbol{F}$

When a charged particle is in a magnetic field, it is found that the force on the charged particle depends on the following factors

- The state of motion of the particle.
- The magnitude and direction of the velocity of the moving charged particle.
- The magnitude and sign of the charge on the charged particle.
- The magnetic field strength.

There is no interaction between a magnetic field and a stationary charged particle. Moving charged particles, on the other hand, have a magnetic field associated with them, and an interaction between this magnetic field and an external magnetic field can create a force on the moving charged particle.

The force on a charged particle moving in a magnetic field is velocity dependent. The magnitude and direction of this force depend on the magnitude and direction of the velocity of the charged particle.

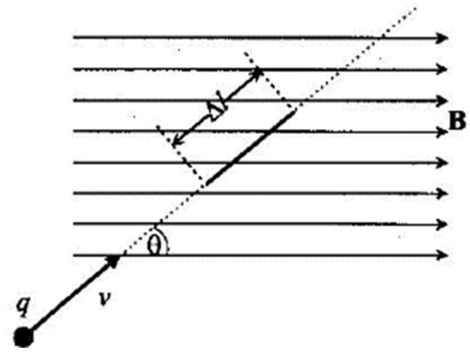
- Electric fields exert the same force on a charged particle, whether it is stationary or moving.
- Magnetic fields only exert forces on moving charged particles.

1.2 Force on a Charged Particle Moving in a Magnetic Fields

Consider a charged particle with charge q, moving with a speed v at an angle θ to a magnetic field of strength of B.

If we consider the moving charged particle as electric current, then the magnetic force is

$$\boldsymbol{F} = \mathbf{I}\Delta\boldsymbol{l}\,\boldsymbol{B}\,\boldsymbol{sin\theta}$$



The magnitude of current is defined as the rate of flow of the electric charge i.e. $I = \Delta q/\Delta t$. Considering this moving particle for t seconds, then

$$I_{average} = \frac{q}{t}$$

But in this time of t seconds the charge has moved a distance of vt meters, which equal to the length of the current element Δl

$$\Delta l = vt$$

Hence the Force on the moving charged particle can be written as

$$F = \frac{q}{t} vt\ B\ sin\theta$$

$$\boldsymbol{F = q\ v\ B\ sin\theta}$$

Note

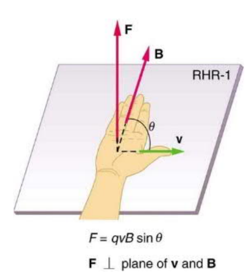
- The term $\boldsymbol{v\ sin\theta}$ is velocity component of the particle perpendicular to the field.
- If the charged particle is stationary, there is no magnetic force on it. As ($v = 0$).
- If the charged particle is moving parallel or anti-parallel to a magnetic field, there is no magnetic force on it. As ($\theta = 0^\circ\ or\ 180^\circ,\ hence\ \ sin\,\theta = 0$)
- The force on a charged particle moving in a magnetic field will be maximum when the charged particle is moving at right angles to the field. As ($\theta = 90^\circ\ or\ 270^\circ, hence\ \ sin\,\theta = 1$). In this case the force will be $\boldsymbol{F = qvB}$
- The magnitude of the force is velocity-dependent. For any charged particle moving in a given magnetic field – the grater the speed, the greater the force.

1.3 Direction of the Magnetic Force

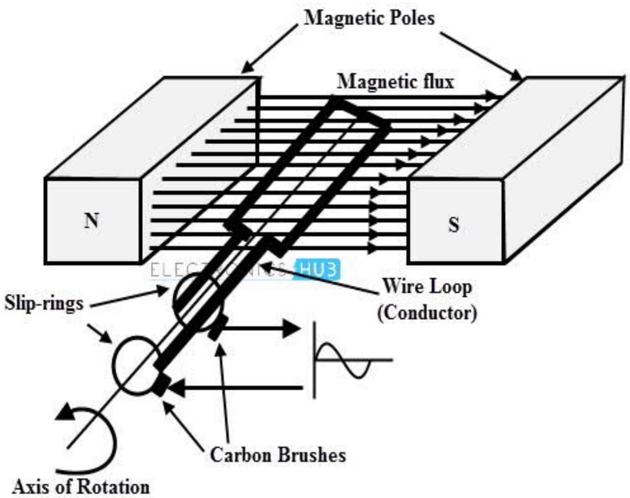
The right hand rule is used to determine the direction of the magnetic force on a positive charge.

- When considering the motion of a charged particle in a magnetic field, the relevant vectors are the magnetic field B, the velocity of the particle v, and the magnetic force exerted on the particle F. These vectors are all perpendicular to each other.
- The right hand rule states that, to find the direction of the magnetic force on a positive moving charge, the thumb of the right hand point in the direction of v, the fingers in the direction of B, and the force (F) is directed perpendicular to the right hand palm.
- The direction of the force F on a negative charge is in the opposite sense to that above (so pointed away from the back of your hand).

$ie\ \boldsymbol{F} \perp \boldsymbol{v} \perp \boldsymbol{B}$. i.e. All three are mutually perpendicular each other.



RS Coaching



PHYSICS

2.5 Electromagnetic Induction

ABSTRACT

This study notes have been developed and written to meet the scope and syllabus of all the content of the Stage 2 Physics 2020. The goal of this topic is to enable students not just to recognize concepts, but to work with them in ways that will be useful in final exam.

Muralikumar, ME., CPEngg., RPEQ.,

Stage 2 Study Notes

Table of Contents

2.5 Electromagnetic Induction

Students are introduced to the concepts of magnetic flux and induced electromotive force. They use Faraday's Law and Lenz's Law to investigate and explain a range of applications, such as electrical generators, induction stoves, and transformers.

Science Understanding	Possible contexts
Magnetic flux (Φ) is defined as the product of magnetic field strength (B) and the area perpendicular to the magnetic field ($A_\perp$). Hence: $\Phi = BA_\perp$. • Solve problems involving the use of $\Phi = BA_\perp$.	This uses the concept of electric current developed in Stage 1, Subtopic 2.1: Potential difference and electric current.
Electromagnetic induction is the process in which a changing magnetic flux induces a potential difference in a conductor. The induced potential difference is referred to as an electromotive force (emf). The changing magnetic flux is due to relative movement of the conductor or variation of the magnetic field strength. Faraday's Law states that the induced emf is equal to the rate of change of the magnetic flux. Lenz's Law states that the induced emf creates a current in a direction that opposes the change in magnetic flux producing the emf. Hence: $emf = \frac{\Delta\Phi}{\Delta t}$. For n conducting loops the induced emf is given by $emf = \frac{n\Delta\Phi}{\Delta t}$. • Solve problems involving the induction of an emf in a straight conductor. • Solve problems involving the induction of an emf in n conducting loops. • Use Lenz's Law to determine the direction of the current produced by the induced emf. • Explain Lenz's Law in terms of conservation of energy. • Explain the production of eddy currents in terms of Lenz's Law.	Computer interactives: • 'Faraday's Law' from https://phet.colorado.edu/en/simulation/faradays-law • 'Faraday's Electromagnetic Lab' from https://phet.colorado.edu/en/simulation/faraday. Demonstrate an induction coil and floating ring, Ruhmkorff coil and spark, and/or magnet falling through a copper pipe. Investigate induced emf and currents using data loggers. Investigate the output of a hand-turned generator. Compare the structure and function of a generator to an electric motor. Explore the benefits and limitations of applications of electromagnetic induction, such as: • reading data from computer hard drives • induction cooktops • electromagnetic (eddy-current) braking • maglev trains • security systems • vehicle detection at traffic lights • metal detectors • minesweepers.

Science Understanding	Possible contexts
Generators use a fixed magnet to generate emfs in rotating conducting loops for electricity production. • Identify the main components of a generator. • Explain how generators can be used to produce electric current. Transformers allow generated voltage to be either increased or decreased before it is used. A transformer consists of a primary coil (with n_p turns) with a potential difference V_p and a secondary coil (with n_s turns) with a potential difference V_s. The relationship between the potential differences is given by the formula: $\frac{V_p}{V_s} = \frac{n_p}{n_s}$. • Describe the purpose of transformers in electrical circuits. • Compare step-up and step-down transformers. • Explain, in terms of the potentially large energy losses that occur as energy is fed through transmission lines from the generator to the consumer, the high voltage used in transmission. • Solve problems involving the use of: $\frac{V_p}{V_s} = \frac{n_p}{n_s}$.	Assess the economic, social, and environmental impacts of power generation by: • mechanically powered torches • domestic and industrial electricity power stations • alternators in vehicles. Analyse changes that have resulted from the use of transformers in contexts such as: • step-up and step-down transformers in electrical power transmission • step-down transformers in home appliances • induction coils in vehicles.

1 Introduction

Electricity and Magnetism were considered separate and unrelated phenomena for a long time. In the early decades of the nineteenth century it was found that moving electric charges produce Magnetic fields.

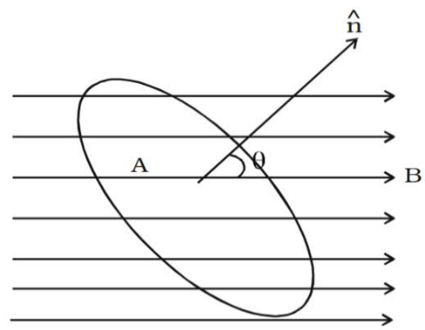
This naturally raises the questions like: Is the converse effect possible? Can moving magnets produce electric currents? Does the nature permit such a relation between electricity and magnetism? The answer is resounding yes!

Michael Faraday of England and Joseph Henry of USA demonstrated the reverse effect. They explained the possibility of producing emf across the ends of a conductor when the magnetic flux linked with the conductor changes. This was termed as electromagnetic induction. The discovery of this phenomenon brought about a revolution in the field of power generation.

2 Magnetic Flux

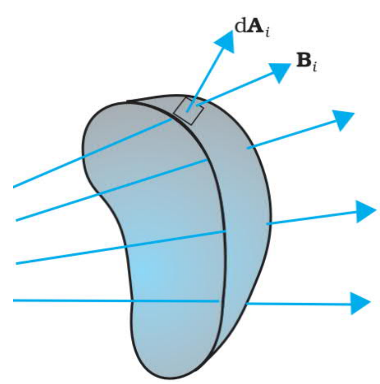
The magnetic flux (ϕ) linked with a surface held in a magnetic field (B) is defined as the number of magnetic lines of force crossing a closed area (A). If θ is the angle between the direction of the field and normal to the area, then

$$\phi = \vec{B}.\vec{A} = BA\cos\theta$$



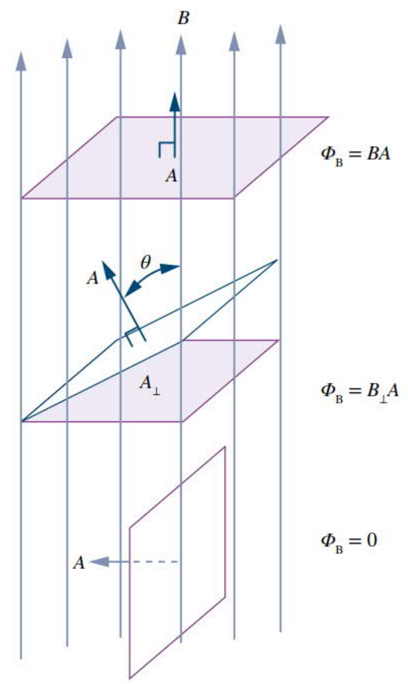
If the magnetic field has different magnitudes and directions at various parts of a surface as shown in Figure, then the magnetic flux through the surface is given by

$$\phi = B_1\,dA_1 + B_2\,dA_2 + \cdots\ldots \sum B_i\,dA_i$$



Note

- The magnetic flux (ϕ) is a measure of the number of magnetic field lines passing through an area
- the SI unit of the magnetic flux (ϕ) is the Weber (Wb) or tesla-meter (Tm^2)
- Magnetic flux is a scalar quantity.



2.1 Induced emf and current – Electromagnetic induction.

Whenever there is a change in the magnetic flux linked with a closed circuit an emf is produced. This emf is known as the induced emf and the current that flows in the closed circuit is called induced current. The phenomenon of producing an induced emf due to the changes in the magnetic flux associated with a closed circuit is known as electromagnetic induction.

2.2 Faraday Experiments

Faraday discovered the electromagnetic induction by conducting several experiments.

This figure consists of a cylindrical coil C made up of several turns of insulated copper wire connected in series to a sensitive galvanometer G. A strong bar magnet NS with its north pole pointing towards the coil is moved up and down. The following inferences were made by Faraday.