9 DESCRIPTION AND PROPERTIES OF FIELDS

OBJECTIVES

At the end of this topic, students should be able to:

- identify force fields;
- state the properties of a force field;
- explain why two solid bodies of different masses released from rest at the same point simultaneously fall to the ground at the same time.

FIELDS

If a small mass is free to fall under the influence of gravity, it falls towards the centre of the earth. The earth draws the object towards itself even when there is no physical connection between them. The interaction between the mass and the earth is explained by assuming that a field exists around the earth. This field exerts a force on any mass in its domain or region within which the force acts.

There are four types of non-contact forces i.e. forces between bodies without physical link or connection between them: gravitational, electric, magnetic and nuclear forces. These forces though invisible, yet we do observe their effects on other objects which come into their domain. One thing about these forces is that they act through a distance with no physical link between them and the objects which enter into the area of their influence. To understand how these forces behave we introduce the concept of **field.**

What is a field?

We can observe the effects of force fields like gravitational force when a stone thrown up falls down.

A field is the space around a mass or a charge where a force due to the mass or the charge may be felt.

Every object (mass or charge) produces a field of forces around it; the field formed by these objects exert forces on other objects pulling them towards its centre.

Types of fields

There are two types of fields namely: the **vector field** (gravitational, electric and magnetic fields) and the **scalar field** (temperature and pressure fields). A vector field has both size or magnitude and direction, while a scalar field has only size or magnitude.

Field line and field strength

If a small mass is placed in the field produced by a bigger mass, a force acts on the smaller mass pulling it towards the bigger mass. The smaller mass moves towards the source of the field travelling along the shortest path. You can experiment this by placing a small magnet near a bigger one.

Field line or line of force is the direction a mass or charge will move if placed in the field and allowed to move.

The strength of a field is measured by the closeness of the field lines to one another or by the force it exerts on a unit mass (charge) placed in that field.

The following properties are common to all types of field.

They consist of field lines. The direction of the field line is the direction of force acting on the object placed in the field.

They have both strength and direction. The strength of a field is measured by the closeness of the lines of force.

They act through a distance and exert forces on the objects in their domain with no physical contact between them.

They obey an inverse square law i.e their effect decreases as the object moves away from the source of the force field.

Gravitational field

An invisible force field known as **gravity or gravitational force field** surrounds the earth. Gravity or gravitational force is the consequence of gravitational field surrounding the earth. Gravity pulls you back to the ground when you jump up. All masses placed in the earthâ€™s field experience a gravitational force moving them towards the centre of the earth.

Gravitational field is the space surrounding a mass where the force due to the mass can be exerted on other masses.

If a small mass is dropped close to the earthâ€™s surface, it falls towards the earth with a constant acceleration. The direction of the falling mass is the direction of gravity or gravitational field. **Gravitational field always points inwards to the mass producing it.** Figure 10.1 illustrates the gravitational field around the earth.

Gravitational field line and strength

Gravitational field is assumed constant or uniform in a location spanning few kilometres from the earthâ€™s surface. As we move hundreds of kilometres away from the earthâ€™s surface, the strength of the field decreases because the field lines spread.

Every object (mass) creates around itself a gravitational field which acts on other masses in the same field pulling them towards the centre of the source. This is Newtonâ€™s view of gravitational field. Albert Einstein explained that gravitational field is the effect produced by the distortion of space and time by large masses positioned in space. The distortion makes space to be curved around the mass. The resulting effect is that the smaller mass moving close to the bigger mass is pulled along the curved space towards the bigger mass.

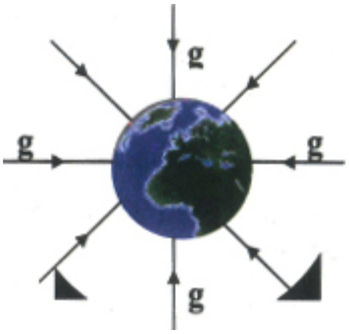


Figure 9.1 Earthâ€™s gravitational field

Acceleration due to gravity

The force of gravity pulls objects back to the earth. So we say that such objects accelerate downward. All objects, if allowed to fall under the influence of gravity alone, tend to fall at **constant acceleration.** The constant acceleration is called acceleration due to gravity. The magnitude of acceleration due to gravity is approximately $10ms^{-1}$ near the earthâ€™s surface. Ancient Greek thought that bigger masses fell faster than smaller masses. Galileo Galilei tested this idea by dropping two masses of different sizes simultaneously from the same height. He discovered that they reached the ground at the same time and concluded that all objects irrespective of their masses fall towards the earth with constant acceleration, if there is no resistance to their motion.

Isaac Newton performed the same experiment in a vacuum and found that a feather and an iron ball both reached the ground at the same time. Multi-flash photographs of two iron balls of different masses falling from the same height revealed that:

- both balls increase their speed steadily in steps.
- both balls fall towards the earth with a constant acceleration. This is illustrated in Figure 9.2.

The effect of air resistance on falling objects

If a feather and a stone are dropped simultaneously from the same height, the stone reaches the ground before the feather. This is because air resistance opposes the motion of the feather more than that of the stone. **The feather has a smaller mass and a wider surface area; its weight is small compared to the resistance of the air, therefore, the resistance of the air slows down its motion.** On the other hand, the surface area of the stone is small and the weight is far greater than the air resistance, such that the effect of air resistance is neglected. This explains why the stone reaches the ground before the feather. If they are allowed to fall in vacuum, they will reach the ground at the same time.

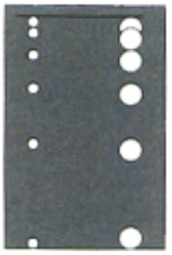


Figure 9.2 Different masses fall at the same rate to the earth

Measurement of acceleration due to gravity

Acceleration due to gravity is measured more accurately using an electric stop clock with high degree of accuracy. The clock is used to time the fall of an iron ball through a known distance (h). The electromagnet held the iron ball in position when the two-way switch is in position A. If it is turned from A to B, the electromagnet releases the iron ball and simultaneously the clock starts timing the fall. Timing of the fall stops immediately the ball hits the trap door. The collision of the ball on the trap door disconnects the clock to end the timing. The time it takes the ball to fall is measured from the stop clock. We can find acceleration due to gravity by substituting the value of h and t in the formula

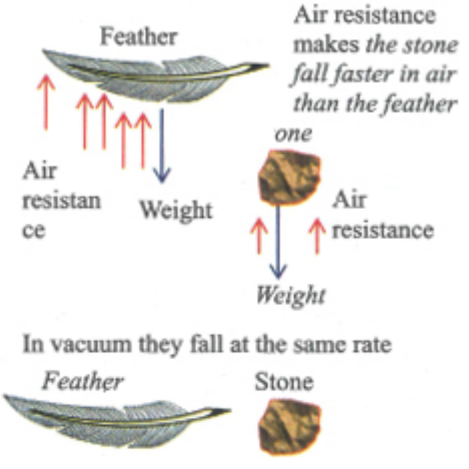


Figure 9.3 Air resistance makes the stone fall faster than the feather

$$g = \frac{2h}{t^2}$$

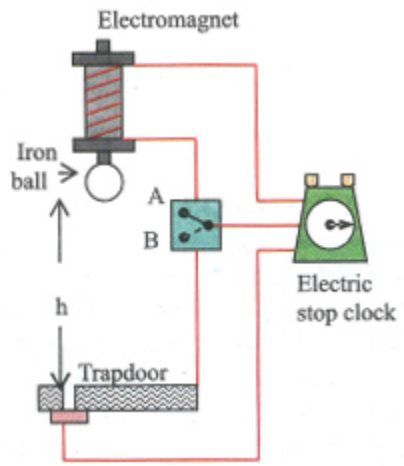


Figure 9.4 Timing the free fall of an iron ball

Summary

- Force fields act through a distance with no physical link between them and the objects, which enter into the area of their influence.
- A field is the space around a mass or a charge where a force due to the mass or the charge may be felt.
- The direction an object will move if placed in the field and allowed to move is called the field line or line of force.
- Gravitational field is the space surrounding a mass where the force due to the mass can be exerted on other masses.
- All objects, irrespective of their masses, fall to the earth with constant acceleration if there is no resistance to their motion.

Practice questions 9a

1. (a) Explain the terms: *field, field line* and *field strength*.
   (b) State **two** properties of a field.
2. (a) What is a vector field?
   (b) Distinguish between vector and scalar fields.
   (c) Give **two** examples of each field.
3. (a) What do you understand by gravitational field?
   (b) Define gravitational field strength and explain why its value is constant near the earthâ€™s surface.
4. (a) Define acceleration due to gravity.
   (b) Describe an experiment to determine the acceleration due to gravity in the laboratory.

5. (a) Describe the motion of a body falling freely under the influence of gravity alone.
(b) A newspaper page and a brick are dropped at the same time. Describe the effect of air resistance on the motion of each.
(c) What will happen if both are to fall in a vacuum?

MAGNETIC FIELD

OBJECTIVES

At the end of topic, students should be able to:

- identify magnetic force as a force field and explain magnetic field;
- plot magnetic field around a magnet using magnetic compass or iron filings;
- state the properties of a magnetic field lines;
- identify the poles of a magnet plot or magnetic field around a magnet using magnetic compass or iron filings;
- explain neutral point and identify its position between like poles.

A magnet has the ability to attract pieces of iron pins. The force a magnet exerts on iron pins acts through a distance with no contact between them. Magnetic force is a force field called **magnetic force field**.

The space around a magnet where the force of the magnet can be exerted on magnetic materials is called magnetic field.

Plotting a magnetic field

The field pattern around a bar magnet can be obtained using a magnetic compass. A magnetic compass consists of a small magnet inside a case with a glass covering.

When the compass is placed in a magnetic field, the North Pole of the magnet producing the field, repels the North Pole of the compass while the South Pole of the magnet attracts the North Pole of the compass.

Figure 9.5 Magnetic compass

The magnetic field pattern of a bar magnet is plotted as follows:

- Place a white paper over the magnet and trace the outline with a sharp pencil.
- Place a magnetic compass at one end of the magnet, the position

of the N-pole and S-pole of the compass magnet are marked with a sharp pencil.

- Move the compass to a new position where the tail or S-pole is on the dot for the previous mark for the head or N-pole of the compass.
- Repeat the process until a complete loop is formed and repeat the whole procedure. Many loops are produced round the magnet. These loops form what we call the **magnetic field**.

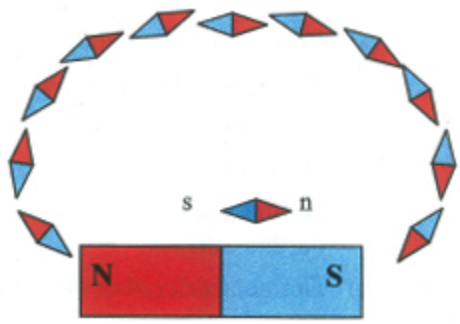


Figure 9.6 Plotting magnetic field pattern of a bar magnet using magnetic compass

The magnetic field pattern for a bar magnet is shown in Figure 9.7.

Note that the magnetic lines enter the magnet through the S-pole and leave the magnet through the N-pole.

Another way of getting the field pattern of magnets is to sprinkle iron filings on the paper placed above the magnet. The paper is tapped gently until the filings lined up to show the pattern of the magnetic field.

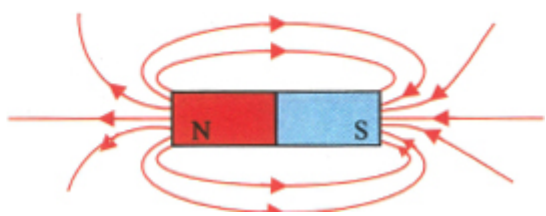


Figure 9.7 Magnetic field pattern of a bar magnet

Magnetic field line

If a free N-pole is placed near the N-pole of a magnet, they will repel each other. The free N-pole will move away from the N-pole of the magnet towards the S-pole.

The direction of the force moving the free N-pole away from the N-pole of the magnet at any point is called the magnetic field line.

Magnetic field line is also called **magnetic line of force** or magnetic line of flux. Each curved line in Figure 9.7 represents a magnetic field line or line of force.

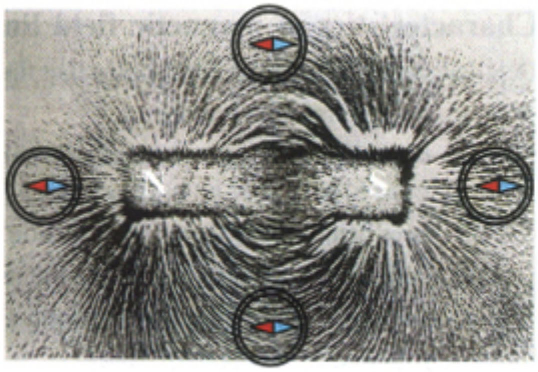


Figure 9.8 Pattern of magnetic field from iron filings

Magnetic flux (Ã˜) and magnetic flux density (B)

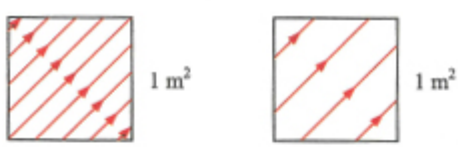
Magnetic flux (Î¦) is total number of magnetic field lines moving out from the N-pole of a magnet or entering the S-pole of the same magnet.

The unit of magnetic flux is Weber (wb). The magnetic flux density (B) is the total number of magnetic field lines per unit area.

$$B = \frac{\Phi}{A}$$

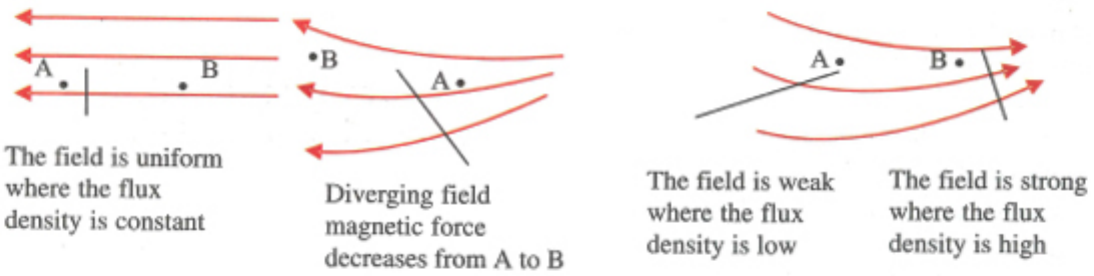
Î² = magnetic flux density,
Î¦ = magnetic flux and
A = area covered by the magnetic flux.

The unit of magnetic flux density is Weber per square metre (wbm^{-2}) or Tesla (T). *Magnetic flux density measures the strength of the magnetic field at a given point*. Where it is high, the magnetic field is strong and close to each other. For a bar magnet, the magnetic flux density (B) is greatest near the N-pole and S-pole. Note that the magnetising force is greatest at the poles. **A magnet with strong field has more field lines than a magnet with a weak field.**



Magnetic field lines are more per unit area for strong fields

Magnetic field lines are more per unit area for strong fields



A converging magnetic field implies an increasing magnetic field, the field decreases if the magnetic field diverges or spreads towards a point. When the field lines are uniform, the magnetic force is constant.

Characteristics of magnetic field lines

Detailed study of magnetic flux shows that the magnetic field lines:

i. do not cross each other;
ii. begin at the N-pole and end at S-pole outside the magnet. Inside the magnet, they run from S-pole to N-pole (they form a close loop);
iii. they behave as if they are in tension. They always shorten their length;
iv. concentrate at the poles where the magnetic force is greatest;
v. are closer where the field is strong and are far apart for a weak field.

MAGNETIC FIELD PATTERN

a) For two unlike poles

Two unlike poles (N-pole and S-pole) of a magnet attract. The field lines between the two poles are many, therefore, the field is very strong.

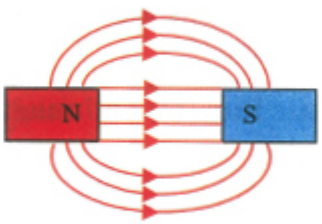


Figure 9.9 Field pattern for two unlike poles

b) For two like poles

Two like poles of a magnet repel each other. The field pattern for two N-poles of a magnet is shown in Figure 10.10.

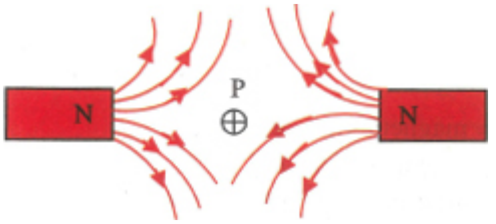


Figure 9.10 Field pattern for two like poles

The field lines repel each other so they never cross. At the point P, midway between the poles the resultant magnetic field is zero. An iron nail placed at P will not be attracted by any of the poles; the point P is called a **neutral point.**

A neutral point is a point where the resultant magnetic field or magnetic flux density is zero.

A neutral point occurs in a magnetic field when the field lines are moving in the opposite directions.

Magnetic field pattern produced by two bar magnets placed side by side is represented in Figure 10.11.

c) For two bar magnets placed side by side with unlike adjacent poles facing each other

The neutral point P is formed on the sides of the magnets. The magnetic field is strong at the ends because the unlike poles attract each other.

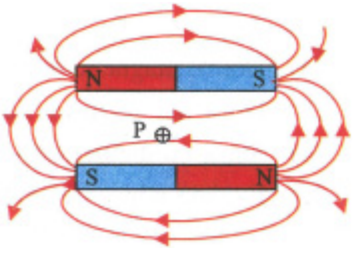


Figure 9.11 Unlike adjacent poles

d) For two magnets placed side by side with like poles facing each other

The neutral point is formed at the ends of the adjacent like poles. The magnetic force is weak near the neutral points because like poles repel.

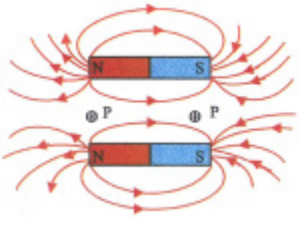


Figure 9.12 Like adjacent poles

Horseshoe magnets

Horseshoe magnets have very strong magnetic field between its poles because of high magnetic flux density between the poles. The lines of flux or magnetic field forms a complete loop which minimizes the leakage of magnetic flux.

Summary

- The space around a magnet where the force of the magnet can be exerted on magnetic materials is called magnetic field.
- The direction of the force moving the free N-pole away from the N-pole of the magnet at any point is called the magnetic field line.
- Magnetic flux (Ã˜) is total number of magnetic field lines moving out from the N-pole of a magnet or entering the S-pole of the same magnet.
- For a bar magnet, the magnetic flux density (B) is greatest at the N-pole and S-pole. The magnetising force is therefore greatest at the poles.
- A neutral point is a point where the resultant magnetic field or magnetic flux density is zero.

Practice questions 9b

1. (a) Explain the terms: *magnetic field, magnetic flux and magnetic flux density*.
   (b) Sketch the magnetic field pattern of a bar magnet and indicate on it the places of high and low flux density.
2. (a) Define the *magnetic field* and *magnetic field line;*
   (b) Describe how to obtain the magnetic field pattern of a bar magnet.
   (c) Use magnetic field lines to explain why some magnets are weak while others are strong.
3. (a) What do you understand by magnetic field lines?
   (b) State four characteristics of a magnetic field line.
4. (a) Define magnetic field and neutral point;
   (b) Draw the magnetic field pattern for two S-poles of a magnet.
   (c) Show on the field where a neutral point may be found.
   (d) Explain why a neutral point may not exist between two unlike poles of a magnet.

ELECTRIC FIELD

OBJECTIVES

At the end of the lesson, students should be able to:

- explain the concept of electric field;
- sketch the electric field pattern for point charges, two like charges and two unlike charges.

Run a plastic comb through your dry hair or rub a plastic pen on your sleeve. The elastic comb or the plastic pen has become a charged body. A charged body is surrounded by a force field called electric field. The force field around the charge makes it to attract or repel other charged bodies.

The region around a charged body where electric force is exerted on other charged bodies is called electric field.

Electric field line

Electric field line is also called electric line of force or electric line of flux. The electric field around any charged body is made up of many lines of force.

An electric field line is the path traced by a small positive test charge as it moves in an electric field.

Electric field pattern

(a) Electric field pattern of an isolated positive and negative charge

The field pattern of an isolated positive charge is shown in Figure 9.13. Each field line is radial to the surface of the charge and is pointing away from the charge. For isolated negative charge shown in Figure 9.14, the electric filed lines move inwards towards the charge and is radial to the surface of the charge.

A positive test charge released in the field of a positive charge will move away from the charge. The direction of the positive test charge in the field is the direction of the field line. For a negative charge, the positive test charge will move towards the charge.

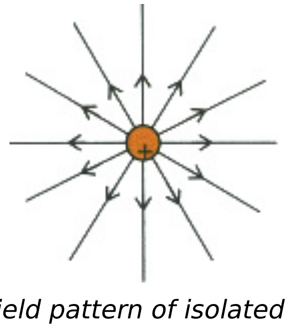


Figure 9.13 Field pattern of isolated positive charge

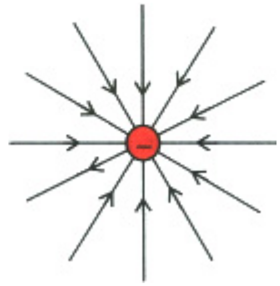


Figure 9.14 Field pattern of isolated negative charge

(b) Electric field pattern between two charges

When two charges are brought close to each other, like charges repel while unlike charges attract. The electric field patterns are as shown in figures 9.16 and 9.17.

For unlike charges, the field lines move away from the positive charge towards the negative charge. The field is strong between the charges therefore, they attract. The field between two like charges push away from each other making the charges to repel each other. Midway between the charges the resultant electric field is zero; the point where the electric field is zero is called a neutral point, marked

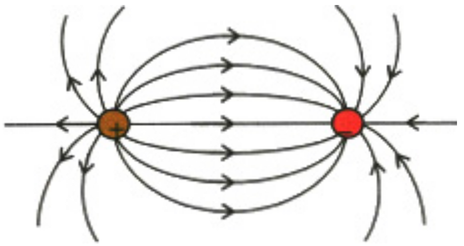


Figure 9.15 Field pattern of unlike charges

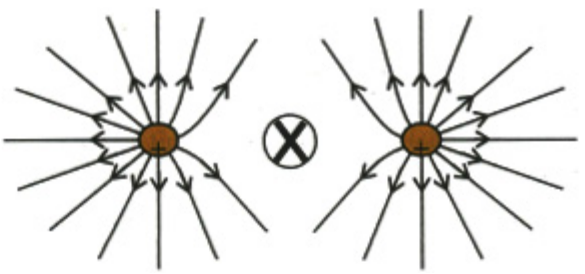


Figure 9.16a Field pattern for two positive charges

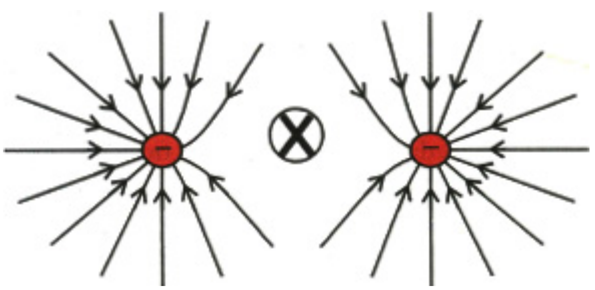


Figure 9.16b Field pattern for two negative charges

(c) Electric field pattern between two parallel plates

The electric field between two parallel plates is uniform. The force acting on a unit positive test charge is constant. The field pattern is as shown in Figure 9.17.

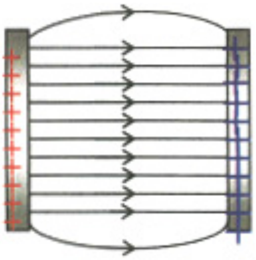
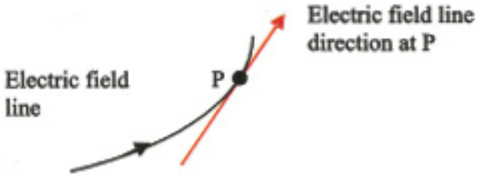


Figure 9.17 Electric field patterns of two parallel plates

Direction and strength of electric field

Electric field is a vector quantity and has both magnitude and direction. *The direction of an electric field line at any point in the field is the direction a unit positive test charge will move if it is placed in that field*. If the field line is curved, the direction of the field at any point along the curve is the tangent to the curve at that point.



The strength of the electric field is measured by the closeness of the electric field lines or by the force a unit charge experiences in the field. Where the lines are close, the field is strong at that region. The field is weak in a region where the lines are far from each other and constant where the field lines are parallel.

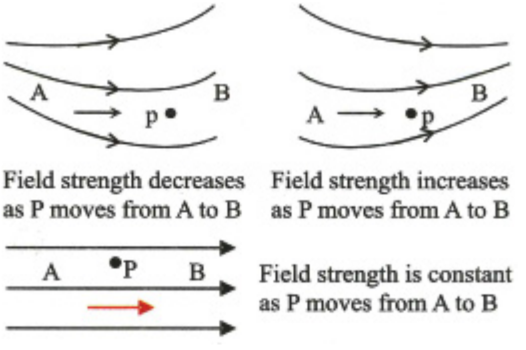


Figure 9.18 Electric field strength varies depending on the nature of the field

Summary

- Electric field is the region around a charged body where electric force is exerted on other charged bodies.
- An electric field line is the path traced by a small positive test charge as it moves in an electric field.

- The electric field line is radial to surface of the charged body and points away from the charge for a positive charge and inwards towards the charge for a negative charge.
- The direction of an electric field line at any point in the field is the direction a unit positive test charge will move if it is placed in that field.
- The strength of the electric field is measured by the closeness of the electric field lines at any point in the field.

Practice questions 9c

1. (a) What is meant by an electric field?
   (b) Draw the field lines between two parallel metal plates; one is positively charged and the other is negatively charged.
   (c) If an electron is released midway between the plates:
      (i) state with reason the direction it will move;
      (ii) explain why the force on the electron should be constant.
2. (a) Define *electric field* and *electric field strength*.
   (b) Describe how the strength of an electric field varies from place to place for a *convergent field* and a *parallel field*.
   (c) Sketch the electric field:
      (i) around a positively charged spherical conductor;
      (ii) between two positively charged spherical conductors;
      (iii) between a positively charged and a negatively charged spherical conductor.
3. (a) Define the following terms:
      (i) electric field and electric field lines;
      (ii) electric field strength.
   (b) How can you determine the direction of an electric field at a point along a curved field line?

Past questions

1. Which of the following statements about the force field is correct?
   A. Electrostatic, gravitational and magnetic forces are always attractive.
   B. Electric, gravitational and magnetic always obey inverse square laws.
   C. Field lines are real but their corresponding fields are imaginary.
   D. Field lines and their corresponding fields are both real.

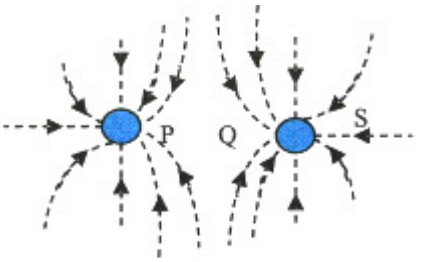
WASSCE

2. Which of the following features of an electrostatic line of force is **not** correct?

A. It is the imaginary line which a positive charge would describe if it is free to move.
B. The tangent drawn at any point on a curved line of force shows the direction of the electric field intensity at that point.
C. It is sometimes curved.
D. It can cross another line of force in a region of intense electric field.

WASSCE

3.



The diagram above shows the resultant electric field pattern due to two electric point charges P and S, which of the statements is correct?

A. P is negatively charged while S is positively charged.
B. P is positively charged while S is negatively charged.
C. Both P and S are positively charged.
D. Both P and S are negatively charged.

WASSCE

4. Lines of force
I begin and end on equal and opposite electric charges.
II are in state of tension which cause them to be shorten.
III attract one another.
Which of the statement(s) is / are correct?
A. I only
B. II only
C. III only
D. I and II only
E. II and III only

NECO

5. The space surrounding a magnet in which the magnetic force is exerted is
A. magnetic field.
B. magnetic flux.
C. magnetic point.
D. magnetic pole.
E. magnetic strength.

NECO

6. Which of the following statements about the magnetic lines of force is **not** correct?
   A. A magnetic line of force is an imaginary line which the north pole of a magnet would describe if it is to move.
   B. Magnetic lines of force do not cross one other.
   C. The presence of magnetic lines of force in a region indicates the presence of magnetic field.
   D. Magnetic lines of force are closely packed together at neutral points.

WASSCE

7. Magnetic flux density is defined as the
   A. total number of magnetic lines of force surrounding a magnet.
   B. number of magnetic lines of force per unit area normal to the magnetic field.
   C. strength of the magnetic field surrounding a current-carrying conductor.
   D. magnetic force exerted on a unit magnetic pole.

WASSCE

8. The direction of the magnetic field at a point in the vicinity of a bar magnet is
   A. along the line joining the point to a neutral point.
   B. always away from the south pole of a magnet.
   C. opposite the direction of the resultant field at that point.
   D. always towards the north pole of the magnet.
   E. the direction towards which the north pole of a compass needle would point.

WASSCE

9.

In the diagram above m_1 and m_2 represent two bar magnets. The lines of force show that the ends X and Y are respectively
   A. south and north poles.
   B. north and south poles.
   C. south and south poles.
   D. north and north poles.

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10. Which of the following forces does not generate a force-field?

A. Electrostatic forces between charged particles.
B. Gravitational force of a planet on an object.
C. Mutual force between the poles of two bar magnets.
D. Frictional force between two bodies.

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11 (i) Explain what is meant by *acceleration of free fall due to gravity, g*.

(ii) State **TWO** reasons why g varies on the surface of earth.

NECO

12. Define *gravitational field intensity*.

WASSCE J