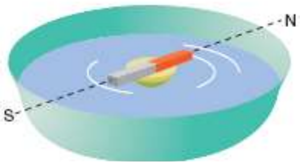
Section 3.1.3 – Magnetic Fields

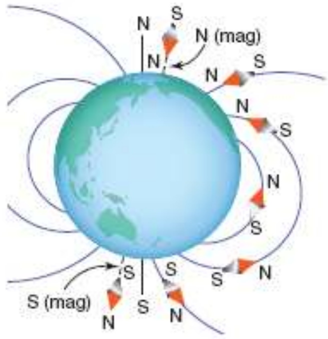
Magnetic Fields

The iron ore called **magnetite** (an oxide of iron) is part of a naturally occurring rock that the Anglo-Saxons called **lodestone** (direction stone). It was used by early navigators as a **compass**.

A suspended magnet will turn so that one end will point towards the north pole of the Earth and the other towards the south pole. Accordingly they are called:

- North seeking pole (**North pole**)
- South seeking pole (**South pole**)

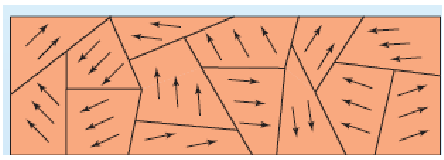




Iron (Fe), **nickel (Ni)**, **cobalt (Co)** and some of the rare earths (gadolinium, dysprosium) exhibit a unique **magnetic behavior** which is called **ferromagnetism**.

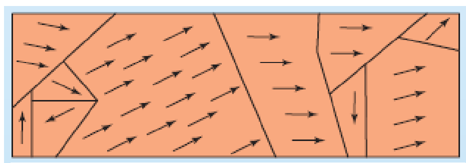
The magnetic phenomenon, which originates at the atomic level, causes **unpaired electron spins** to **line up parallel** with each other in a region called **domains.** Within the domain, the magnetic field is intense.

A normal sample of iron is **not magnetised** as the many domains are **randomly oriented** with respect to one another.



Randomly orientated domains

However, in the presence of an **external magnetic field**, say a bar magnet or solenoid, the **domains align** themselves along the magnetic field to create a unified magnetic field.



Aligned domains

There are many practical applications of ferromagnetic materials, such as the **electromagnet.**

Magnetic Forces

Please note that the forces produced by magnets are indeed **vector** in nature and follow the traditional rules of **vector addition** and **subtraction.**

You will recall that:

- Like poles repel (ie. two North or South poles)
- Opposite poles attract (ie. a North and South pole)

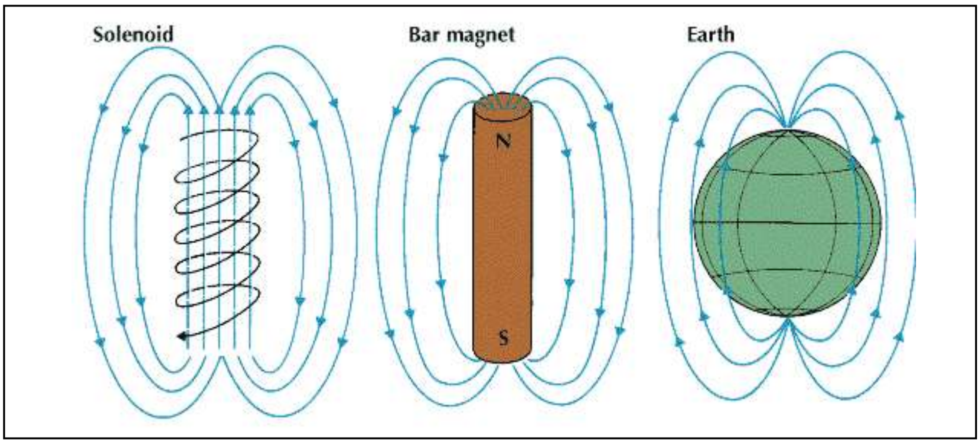
Magnetic Fields

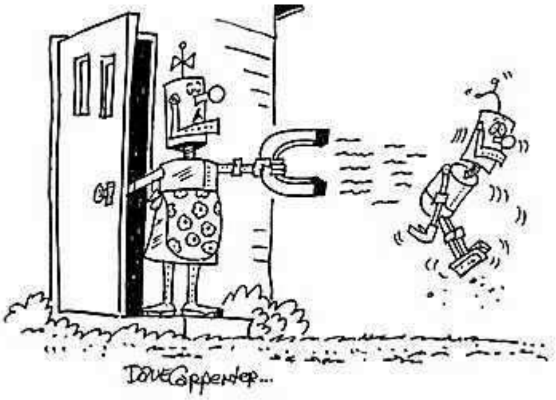
"A magnetic field describes the property of the space around a magnet that causes an object in that space to experience a force due only to the presence of the magnet."

Field lines drawn around magnets are a visual aid, used to describe the features of a magnetic field. When drawing field lines, one must obey the following rules:

1. Each field line must leave the North pole, enter the South pole and return to the North pole through the magnet in a continuous loop.
2. Field lines may not intersect
3. The direction of the magnetic at a point is along the tangent to the field line.
4. The closeness of the field lines represents the strength of the magnetic filed
5. Field lines are always directed from the North pole to the South pole

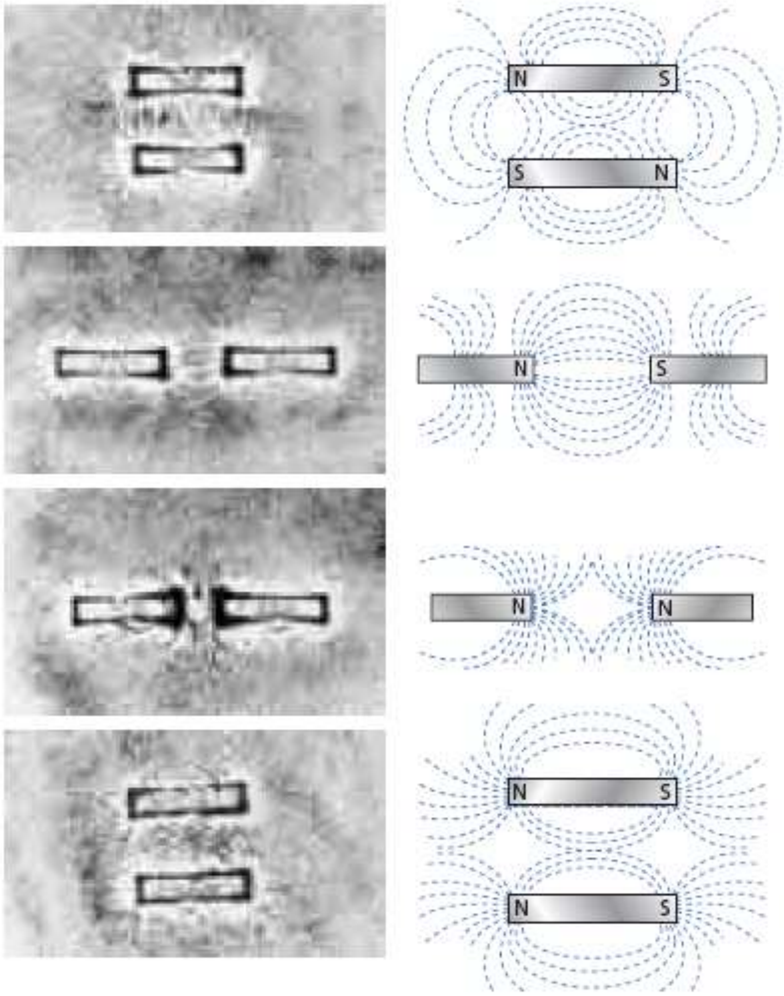
NB: **Magnetic field strength (B)** is measured in **Tesla (T).**



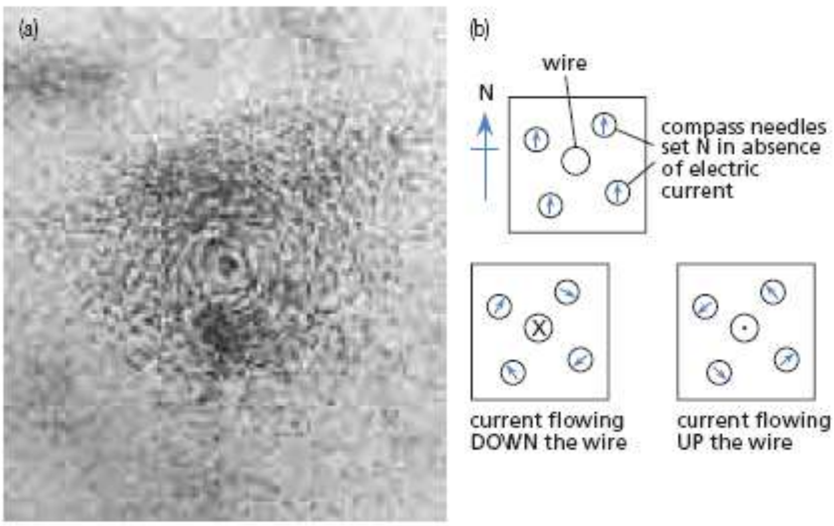


"GET BACK IN HERE AND FINISH YOUR LUNCH."

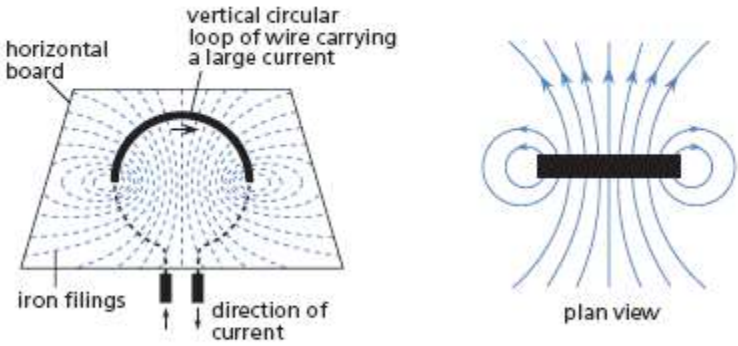
Magnetic field around a bar magnet



Magnetic field around a current carrying wire

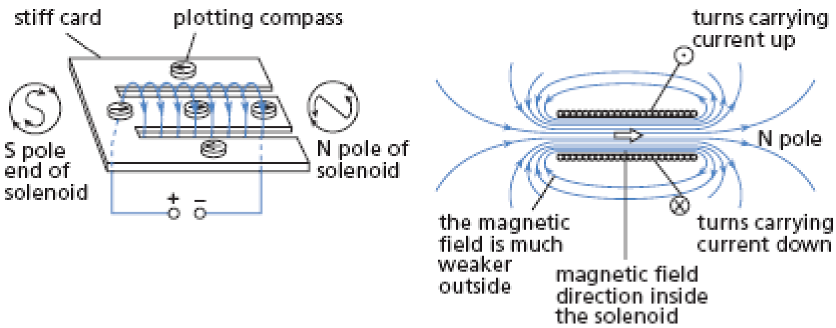


Magnetic field around a current carrying loop



7 The magnetic field pattern due to a single loop of wire.

Magnetic field around a solenoid



The magnetic field pattern due to a number of loops of wire (a solenoid).

Electromagnetism

Before Hans Christian Oersted's discovery in 1820, it was thought that electricity and magnetism were two separate a scientific phenomenon. He discovered that:

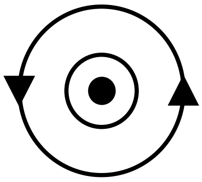
"A compass needle deflects from magnetic north when an electric current is switched on or off in a nearby wire".

In summary, Oersted stated that:

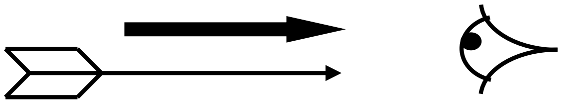
- A current carrying wire produces a magnetic field
- A moving electric charge produces a magnetic field
- The direction of the field depends upon the direction of the current

Diagrammatic Notation

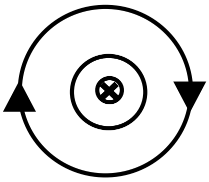
When constructing a "bird's eye" or cross-sectional diagram of a current carrying wire and associated magnetic field, use the following notation:



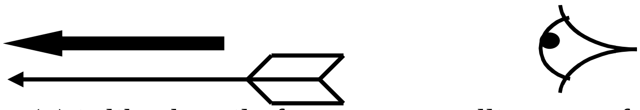
Current coming out of the page produces an anticlockwise magnetic field.



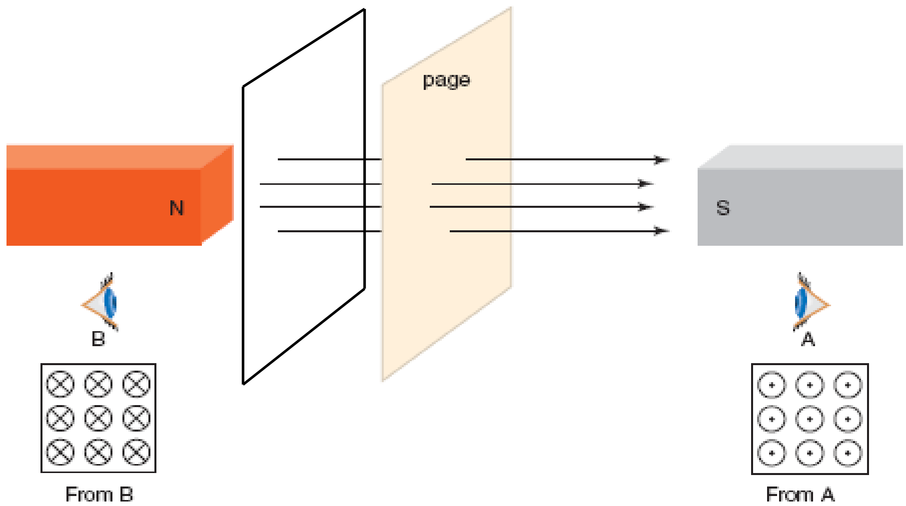
The dot (●) is like the head of an arrow heading towards you.



Current going into the page produces a clockwise magnetic field.

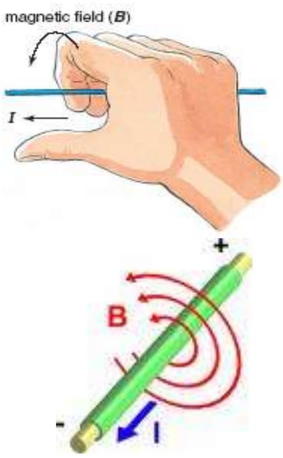


The cross (**×**) is like the tail of an arrow travelling away from you.



Electromagnetic "Hand Rules"

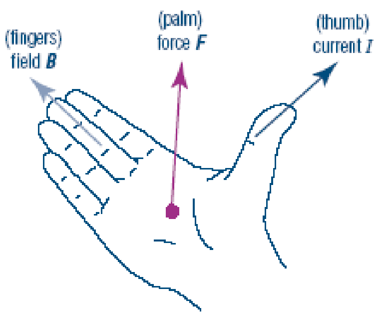
A. Right Hand "Grip" Rule
(Determines the magnetic field from the direction of current in the wire)



Use your right hand to grip the wire.

1. Point your **thumb** in the direction of **current (I)**
2. The direction your **fingers curl** indicates the direction of the **magnetic field (B)** from N→ S.

B. Right Hand "Slap" Rule
(Determines the direction of wire movement when current carrying wire is placed in a magnetic field)



Position your right hand within the magnetic field and next to the wire

1. Point your **fingers** in the direction of **the magnetic field (B)**
2. Point your **thumb** in the direction of **current (I)**
3. The direction of your open palm indicates the direction of the force of the **magnetic field** upon the current carrying wire.

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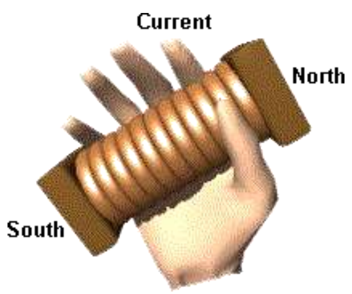
C. Right Hand "Solenoid" Rule
(Determines the North pole of a solenoid from the direction of current in the solenoid)

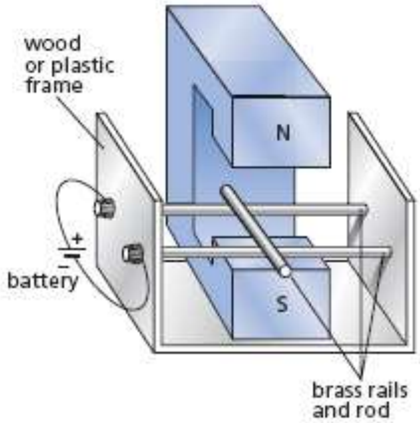


Use your right hand to grip the coil

1. Your **fingers wrap** around the coil in the direction of **current (I)**
2. Your **thumb** indicates the direction of the **North pole** of the magnetic field.

Example 1

Consider the diagram below. In which direction would the brass rod move?



Using the **Right Hand Slap Rule**, you can predict that the brass rod would move to the **right!**

- current runs from the positive rail to the negative rail ie. out of the page (thumb direction)
- magnetic field is directed from North to South ie. down the page (finger direction)
- force on the current carrying wire is shown by the direction of your palm (to the right)

Magnitude of Force upon Current Carrying Wire

The R.H. Slap rule is used to determine the direction of the force generated upon a wire when positioned perpendicular to a magnetic field. The following equation is used to determine the magnitude of the force generated:

$$F=BIl$$

Where F = Force (N)
B = Magnetic field strength (T)
I = Current (A)
l = Length (m)

Example 2

A straight wire of length 25 cm, carrying a current of 40 mA, is placed in a magnetic field ofstrength 0.5 T. calculate the force exerted upon the wire.

l = 0.25 m
$I = 40 \times 10^{-3}$ A
B = 0.5 T
F = ?

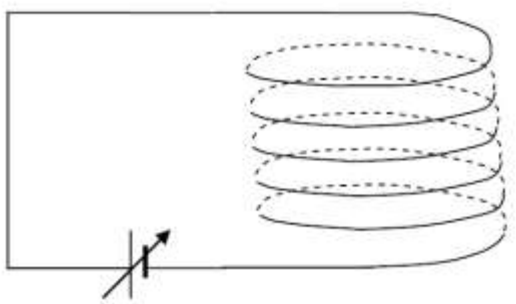
F = BIl
$F = 0.5 \times 40 \times 10^{-3} \times 0.25$
= **<u>0.005 N (5 mN)</u>**

"Henderson's got to go. His magnetic personality's not only disrupting the office, it's erasing all our software."

Exam Style Questions

Use the following information to answer Questions 1 and 2.

A solenoid, which is a coil of wire, is connected to a variable DC power supply, as shown in Figure 1.



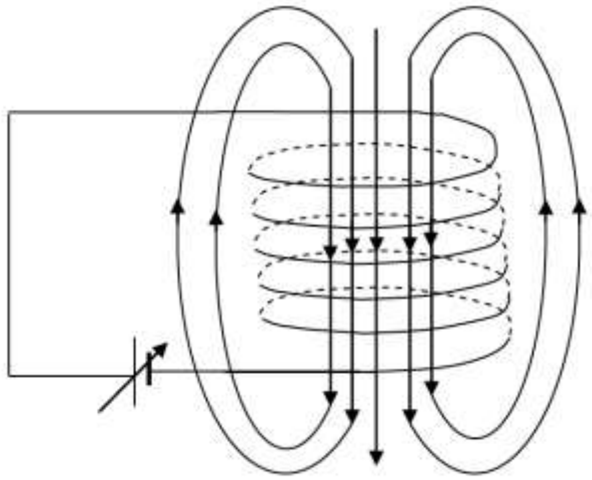


Figure 1

Question 1
Complete the diagram by sketching five magnetic field lines, with appropriate arrows, which illustrate the magnetic field inside and around the coils. Create your sketch over the diagram shown above.

- 2 marks for appropriate complete lines with arrows from north to south poles.
- Take 1 mark off if lines are crossing or touching.

Question 2
Describe what changes will occur to the density of the magnetic field lines when a bar made of iron is placed inside the solenoid and the voltage of the battery is increased.

The increased voltage will cause an increase in current. The magnetic field lines will become closer together as the strength of the field increases owing to the bar and the increased voltage.

- 1 mark for stating an increase in current will occur.
- 1 mark for stating the field lines will become denser.

Use the following information to answer Questions 3 and 4.

The following apparatus in Figure 2 shows a metal rod placed between two magnets. The pole pieces of the magnet are 20 cm long and 5 cm high and the uniform magnetic field between them is 3 mT. A current of 1.2 A flows in the rod from P to Q and a force is experienced by the rod pushing it in one of the directions A, B, C or D.

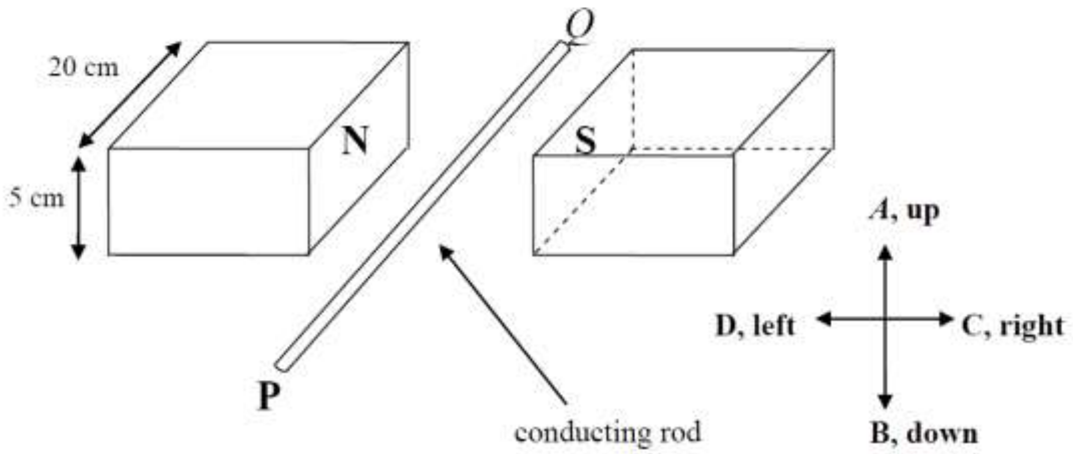


Figure 2

Question 3
Estimate the magnitude and direction of the force on the rod, the direction being stated as A, B, C or D.

Magnitude of force, F=BIl = 0.003 x 1.2 x 0.2 = 0.72N.
Direction of force is B.

- 1 mark for substituting values correctly into formula.
- 1 mark for correct magnitude of force.
- 1 mark for correct direction.

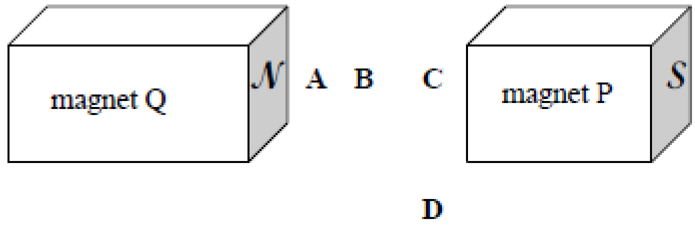
Question 4
Explain the primary cause of the force experienced by the rod. In your explanation you must refer to the magnetic field generated by the current.

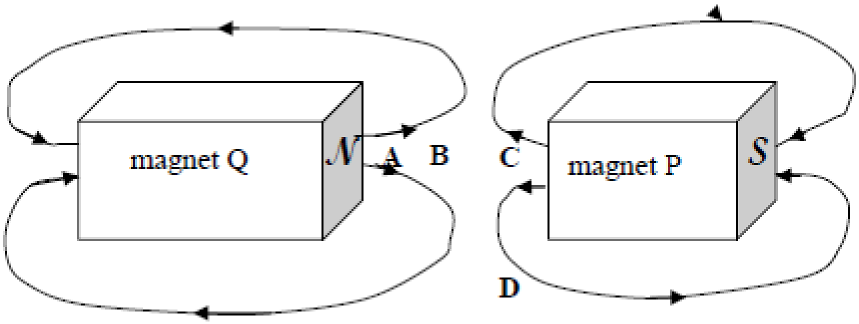
Owing to the moving charges of the current in the conducting rod, a magnetic field is generated in accordance with the right-hand grip rule. This magnetic field then superimposes onto the external magnetic field, resulting in a net magnetic field that has a varying intensity. The conductor then experiences a force in the direction of the weaker region of the field and the direction is given by the right-hand slap rule.

- 1 mark for discussing that creation of the magnetic field is due to moving charges.
- 1 mark for relating two magnetic fields to resultant force.

The following information relates to Questions 5 and 6.

Two permanent magnets of different magnetic field strengths are placed as shown in the below figure. Magnet Q has about double the magnetic field strength as that of magnet P.





Question 5
Complete the diagram by sketching four magnetic field lines, with appropriate arrows, that would illustrate the magnetic field between and around the two magnets.

Mark allocation
- 1 mark for appropriate complete lines with arrows from north to south poles.
- 1 mark for showing a greater line density for the stronger magnet or a stronger field.
- Take 1 mark off if lines are crossing or touching.

Question 6
Which one of the locations A, B, C or D would have the **lowest** magnetic field strength?

Worked solution
The stronger magnet has a higher flux density and would result in the point of lowest field strength closer to the weaker magnet. Hence, correct answer is C.

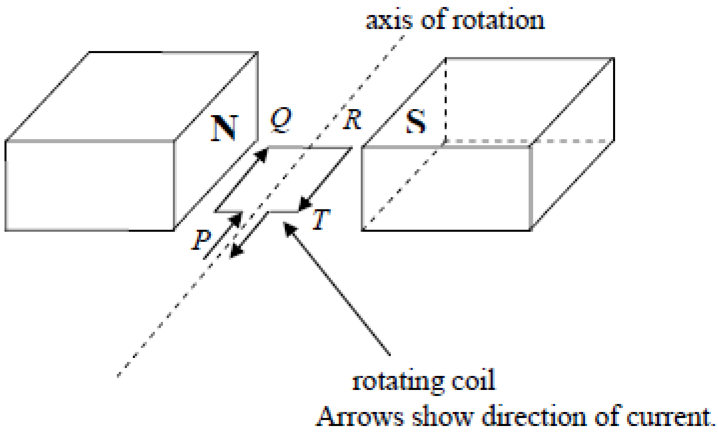
C

Mark allocation
- 2 marks for correct answer.
- No part marks.

Tips
- *Magnetic field lines do not touch or cross.*
- *Magnetic field lines are complete loops from north to south poles. Arrows indicating this direction must be shown.*

Use the following information to answer Questions 7 – 9.

A square coil, *PQRT*, with sides 20.0 cm and consisting of 100 turns is rotated in the field of a uniform permanent magnet of field strength 30 mT, as shown in the figure below, so as to operate as a DC motor. The current through the arm *PQ* is measured as 2.0 A.



Question 7
With reference to the external magnetic field and the effect of current in the coil, explain **why** there is a force on the arm *PQ* in the position shown.

Worked solution
When current passes through the conductor *PQ*, a magnetic field will be generated around the conducting wire, which will add vectorially with the external field, forming a net magnetic field. The conductor will experience a force in the direction of the net magnetic field.

Mark allocation
- 1 mark for describing the addition of self and external field.
- 1 mark for drawing the correct conclusion about generation of force.
- Give only 1 mark if $F = nBIl$ is used without further explanation.

Question 8
In the position shown, what is the magnitude of net force on the arms *PQ* and *QR*?

	Side PQ	Side QR
Magnitude of force	1.2 N	0 N

Worked solution
Using the right-hand rule, force on *PQ* is down and has a magnitude of
$F = BIl = 0.03 \times 2 \times 0.2 = 1.2$ N
Force on *QR* = 0 N.

Mark allocation
- 1 mark for correct magnitude of force on *PQ*.
- 1 mark for correct magnitude of force on *QR*.