Theme 7: Magnetic Effects of Electric Current

Prior Knowledge

It is recommended that you revise the following topics before you start working on these questions.

- Magnetic Field and Field Lines - working of compasses, poles, shapes of magnets
- Electromagnetic Induction - the magnetic field around current-carrying conductors and electric currents in a conductor in the presence of a changing magnetic field
- The direction of Induced Currents, Fields and Forces - Fleming's Left And Right Hand Thumb Rules, the strength of an Electromagnet

Electromagnet

Electromagnets, at first glance, seem to be less useful than permanent magnets, because they require a constant input of energy to remain magnetised. However, the fact that electromagnets can be turned ON and OFF has been exploited in many areas, one of these is for lifting and sorting metal scraps. Also, the ability to vary the strength of the magnet proves very useful in a variety of applications.

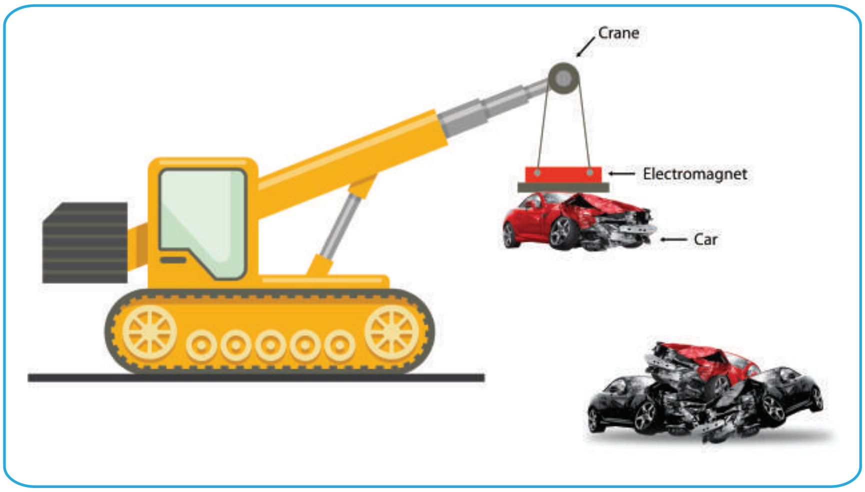


Fig. 7.1, An Electromagnetic Crane

Case Study A - Electromagnet

The magnetic behaviour of an electromagnet is the result of current flow through a wire. A current carrying wire produces circular lines of magnetic force centred at the wire (Fig. 7.2). The direction of the current is, by convention, the direction in which positive charges move. The direction of the magnetic field is from North to South.

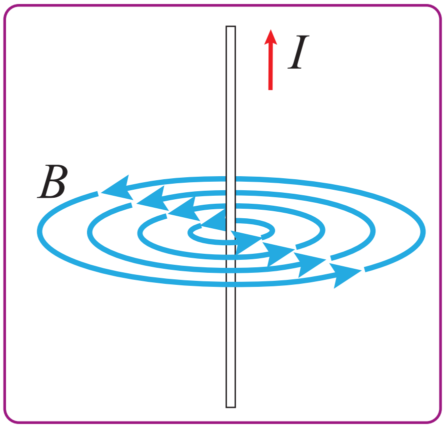


Fig.7.2, Magnetic field around a wire

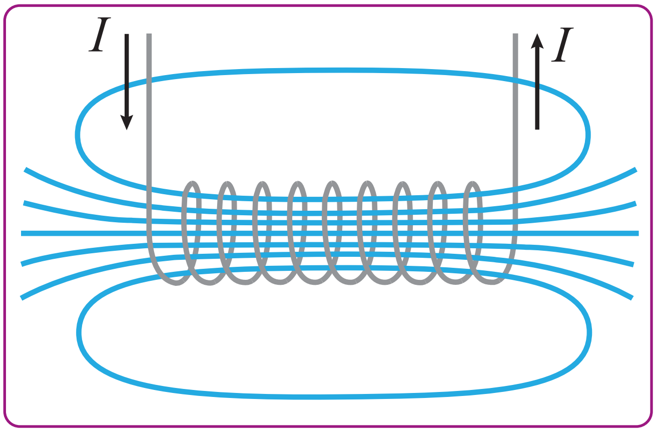
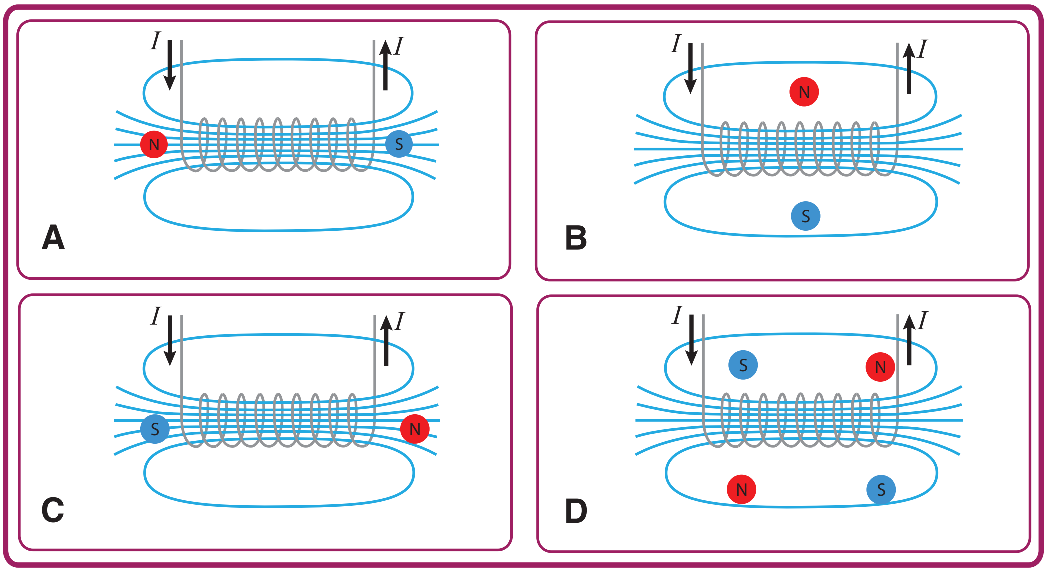


Fig.7.3, Magnetic field around a coil

Pictured in Fig. 7.3 is a similar set-up but with the wire wound into a coil which helps in adding the magnetic forces at the centre of the coil.

Question 1

Where do you think the poles of the electromagnet shown in Fig. 7.3 lie?



Answer

Question 2

What does the strength of an electromagnet depend on? The formula to calculate the strength is $B=\mu nI$ where B is the magnetic field strength; μ indicates the resistance to magnetic field offered by the material around which the coil has been wound; I is the current passed through the coil and n is the number of turns of the wire divided by the length of the coil (see Fig. 7.4). Using this information, select the strongest magnet out of the list below. Assume that same current is passed through each.

a. A high resistance wire wrapped close together in a coil
b. A low resistance wire looped close together in a coil
c. A high resistance wire neatly looped with 1 cm spacing between the turns
d. A low resistance wire neatly looped with 1 cm spacing between the turns

Answer

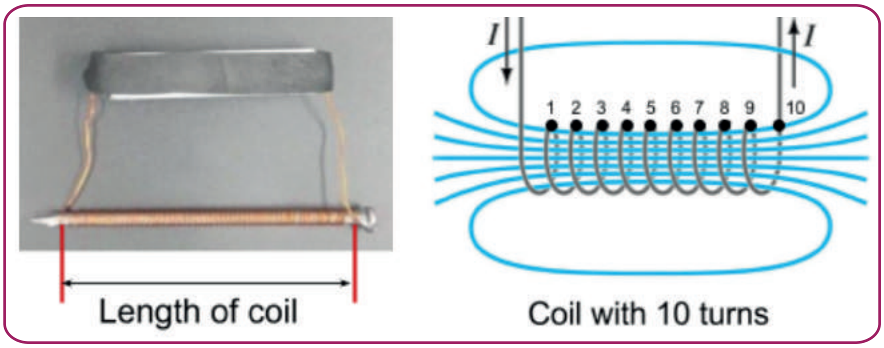


Fig.7.4, How to count number of turns and how to measure length of coil

Question 3

In questions one and two we looked at coils of wire in the open air, i.e with an air core. But for many practical applications, the wire is wrapped around a metal core (such as iron nail). This increases the strength of the resulting electromagnet even when the current and density of turns are kept the same. Keeping in mind the factors that affect coil strength, why do you think this is the case?

a. The iron nail behaves exactly like the open air.
b. The iron nail is not easily magnetised in a magnetic field.
c. The iron nail is easily magnetised in the magnetic field as compared to air.
d. The iron nail is repelled by magnetic field.

Answer

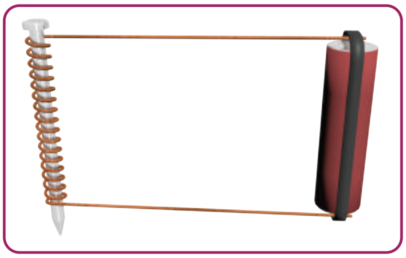


Fig.7.5, An Iron Nail Electromagnet

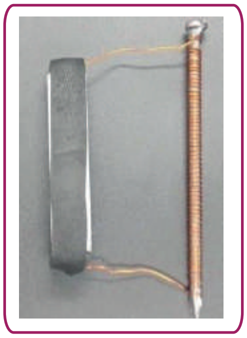


Fig.7.6, Hands on - Finished Electromagnet

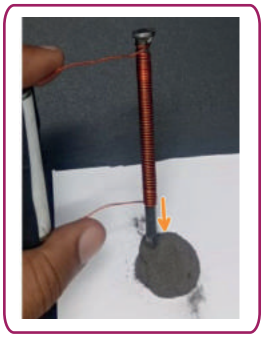


Fig.7.7, Dipping into Iron Filings

Fig.7.8, Attracted Fillings

Case Study B - DC Motor

In a DC motor, the electromagnetic effects produce rotation. To understand how DC motors work let us build a model using ring magnets, a coil through which current is passed and an AA battery. Later in this section we will also explore other types of motors.

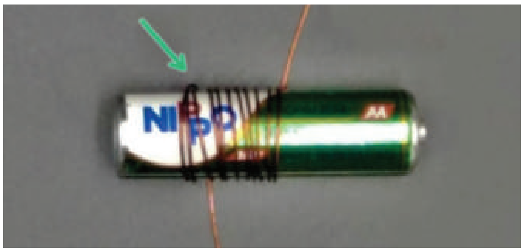


Fig.7.9, Take 60 cm of insulated (enamelled) copper wire and wind it around an AA battery. Then carefully remove the coil from the cell.

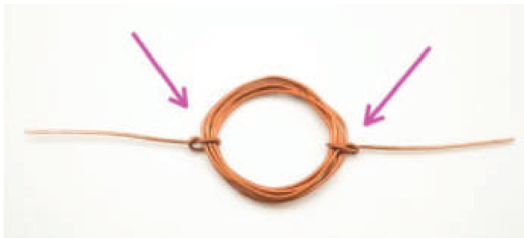


Fig.7.10, Tie knots on both ends to secure the coil. Make sure the loose ends are exactly diametrically opposite, i.e 9 o'clock and 3 o'clock.

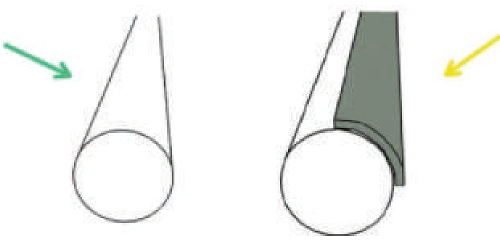


Fig.7.11, Use a paper cutter and scrape the insulation from one entire coil lead, i.e. the lead is scrapped entirely. The other lead should be scraped on three-quarters of the circumference, but much like the first lead, along its entire length, i.e. the lead is scraped on three sides.

Fig.7.12, Place the cell inside the cut cycle tube (wide rubber band).

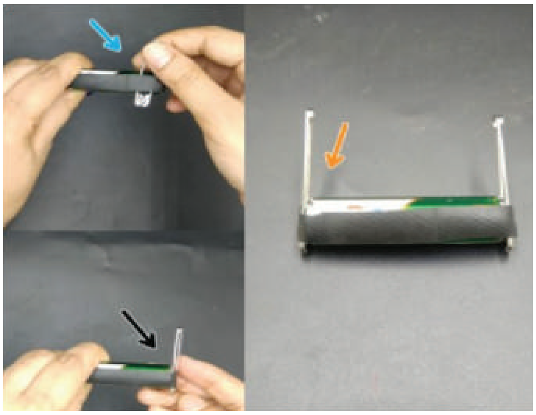


Fig.7.13, Insert the pin in between the cycle tube and cell. Place the safety pins perpendicular to the cell so that the head of each safety pin touches one terminal of the cell.

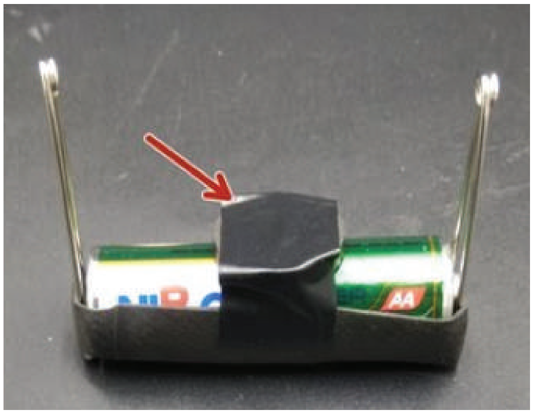


Fig.7.14, Place two ring magnets on the surface of the cell, in between the two safety pins. If necessary, use tape to secure the magnets.

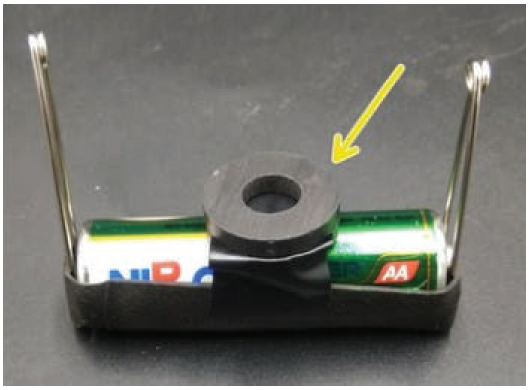


Fig.7.15, Add another magnet.

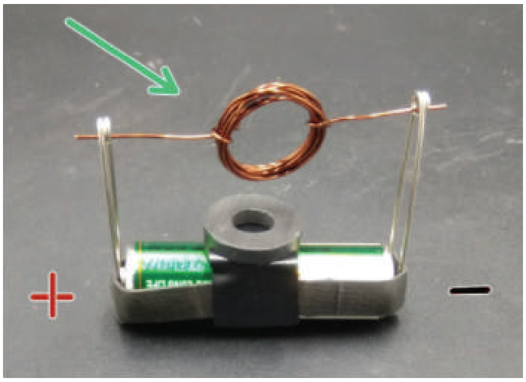


Fig.7.16, Insert the ends of the coil through the "hinge" ends of the safety pins so that the coil aligns directly above the magnets. The coil should spin once you give it a small impetus (push).

Question 4

In which direction will the point P on the coil (refer Fig. 7.17) experience a force?

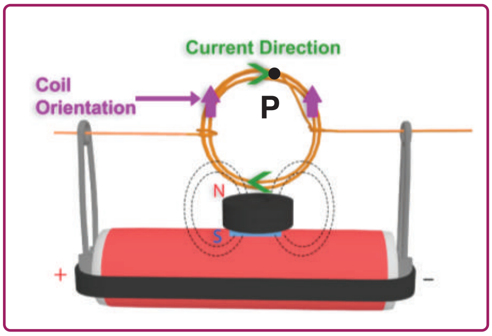


Fig.7.17, Model of a Simple DC Motor

Note that the number of turns in the coil shown in Fig. 7.17 is reduced for clarity. The real coil would have 6-8 turns like shown in the build section.

a. Outside the paper
b. Into the paper
c. Towards the positive terminal of the battery
d. Towards the negative terminal of the battery

Answer

Question 5

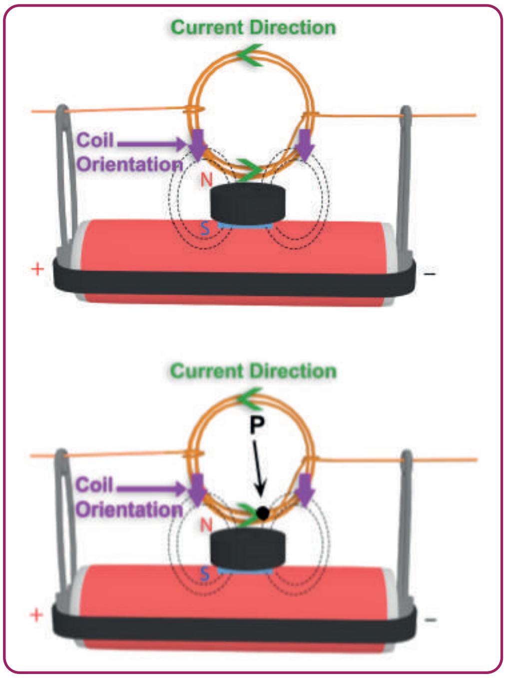


Fig.7.18, Model of a Simple DC Motor (during other half of its rotation)

After half rotation, in which direction will the point P on the coil (refer Fig. 7.18) experience a force?

a. Outside the paper
b. Into the paper
c. Towards the positive battery terminal
d. Towards the negative battery terminal

Answer

Question 6

What do you think would happen if the current to the coil is interrupted when it reaches the stage shown in Fig. 7.18? This could happen because of the partial insulation left on one coil end.

a. The coil will stop
b. The coil will continue moving and finish the rotation because of its momentum
c. The coil will stop and change direction
d. This couldn't happen because the safety pins are good conductors of electricity

Answer

Question 7

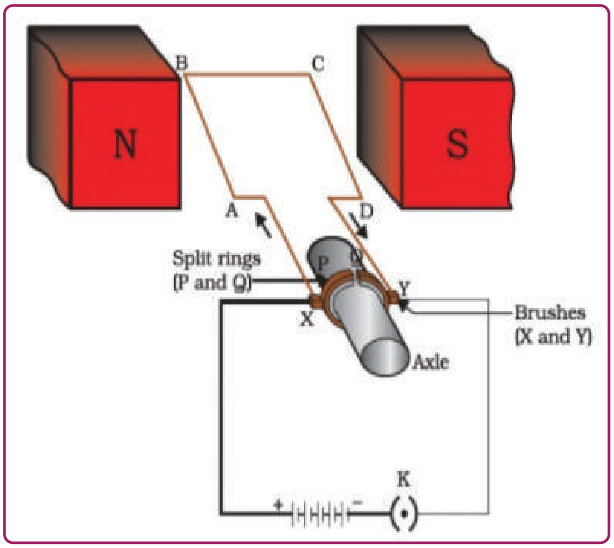


Fig.7.19, Parts of a DC Motor

What is the key difference between the motor made with the AA battery (Fig. 7.9 to Fig. 7.16) and the motor depicted in Fig. 7.19?

a. Magnets on either side of the coil, the AA battery motor would not work with magnets on either side of the coil.
b. One can change the direction of this motor while that's not possible with the AA battery version.
c. The split ring commutator, which allows current to flow through the coil throughout its rotation.
d. All of the above.

Answer

Question 8

A homopolar motor is an interesting experiment to do, one end of a battery is connected to a small yet powerful neodymium magnet, on the other end, a copper wire is shaped in such a way that it balances on the top terminal and is free to rotate. The other ends of the copper rotor are touching the magnet. The rotor begins to turn, perhaps with some gentle nudging. What can one say about the type of magnet required for this motor to work?

The magnet should have a ______________ surface.

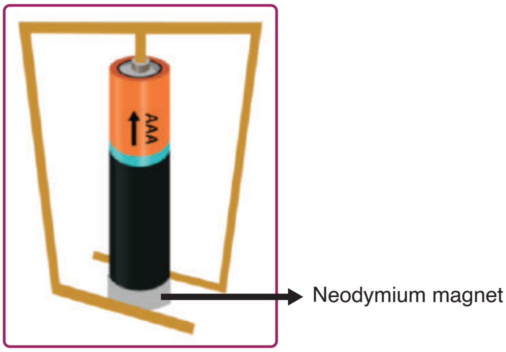


Fig.7.20, A model of a Homopolar* Motor

a. rough and non-conducting

b. rough and conducting

c. smooth and non-conducting

d. smooth and conducting

Answer

*The name homopolar indicates that the electrical polarity of the conductor and the ma netic field poles do not change (i.e., that it does not require commutation like a DC motor).

Case Study C - Railguns

With the ability for magnetic fields to move electrified conductors being well known by this time, people in the early 1900s wondered if this could be utilised as a weapon. This led to the design of a railgun which is mostly an experimental weapon that uses an electric current to launch an electrically conductive metal projectile. A railgun would have a pair of conductive rails or tracks acting as a barrel, with the bullet (often called the projectile) being another piece of conductive metal placed between the rails.

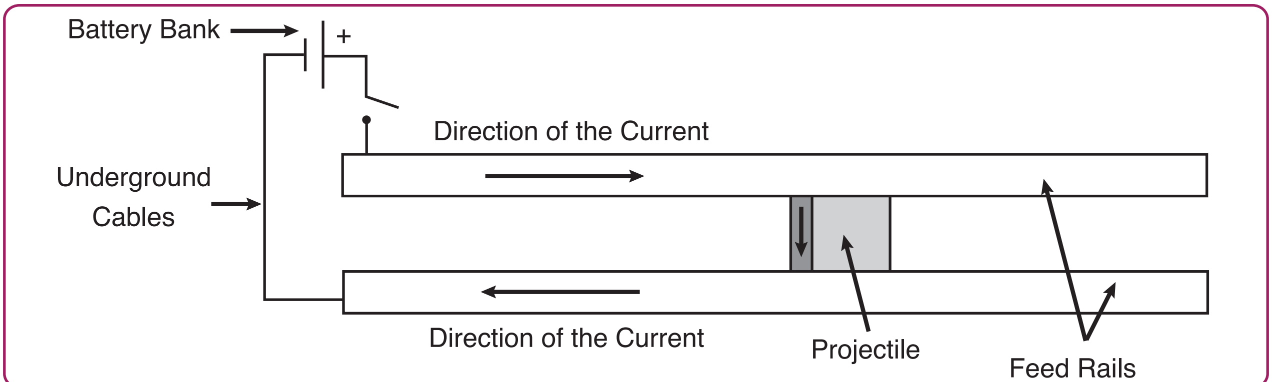


Fig.7.21, Parts of a Railgun

When a large DC current is applied to this setup, a magnetic field is created around the rails as well as the projectile. As you apply the right-hand thumb rule to imagine the direction of the magnetic field, you would also notice that the field around the rails and projectile, add up at the centre and point in the same direction, like a coil. The electric field and magnetic field together generate a force thereby pushing the projectile out of the barrel. Read more about railguns at the end of this chapter.

Question 9

Fig. 7.21 shows the design of a simplified railgun. Given below is an Assertion and a Reason.

Assertion (A): Based on the given diagram and information, the railgun has two loops/turns of conductor.

Reason (R): The current passes through the first feed rail, then through the metal projectile and back to the negative end of the battery through the second feed rail. Hence, it completes one loop.

Which of the following is true about the Assertion (A) and Reason (R) stated above?

a. Both A and R are true and R is the correct explanation of the assertion
b. Both A and R are true, but R is not the correct explanation of the assertion
c. A is true, but R is false
d. A is false, but R is true

Answer

Question 10

Which way will the projectile move in this case (Fig. 7.21)?

a. Right to left	b. Left to right
c. Upwards	d. Downwards

Answer

Question 11

How would you reverse the direction of the projectile?

a. Reverse the whole apparatus
b. Reverse the current
c. Reverse the projectile
d. None of the above

Answer

Case Study D - Electric Bell

A slightly more practical example of the interplay between electricity and magnetism is the electric bell. Fig. 7.22 contains all the essential parts of a simple electric bell.

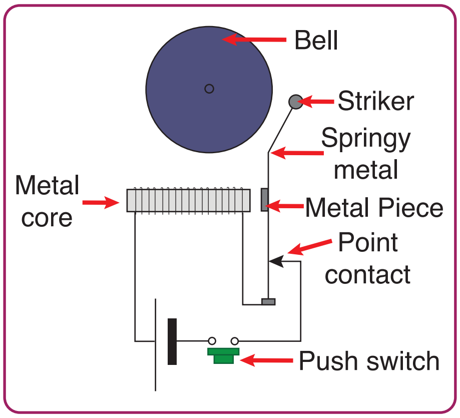


Fig.7.22, Parts of an Electric Bell

Question 12

What is a good choice of metal or alloy for the core and piece?

a. Iron, because it is both attracted to a magnet and can be magnetised only temporarily

b. Brass, for its corrosion resistance and the fact that it's not attracted to a magnet

c. Steel, because it is attracted to a magnet and it can be magnetised permanently

d. Aluminium, because it's conductive, light and not attracted to a magnet

Answer

Question 13

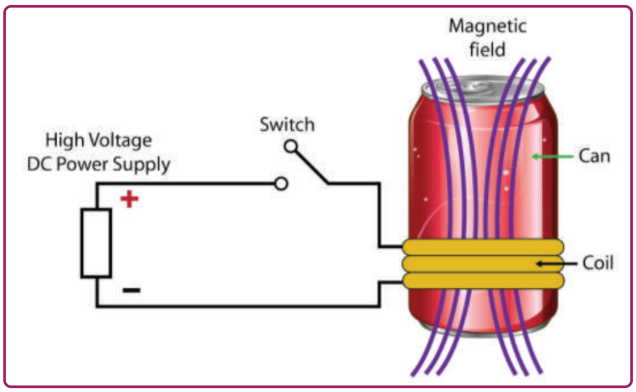


Fig.7.23, A Can Experiment

Here is an example of a science experiment gone wrong, an empty aluminium can is placed in a coil of thick copper wire, then a high voltage DC current is applied to the coil for a short time. Surprisingly the aluminium can, despite not being magnetic, responds to this sudden inrush of current in the coil.

i. Why does the can respond?

a. It just moved because of the current heating the wire.

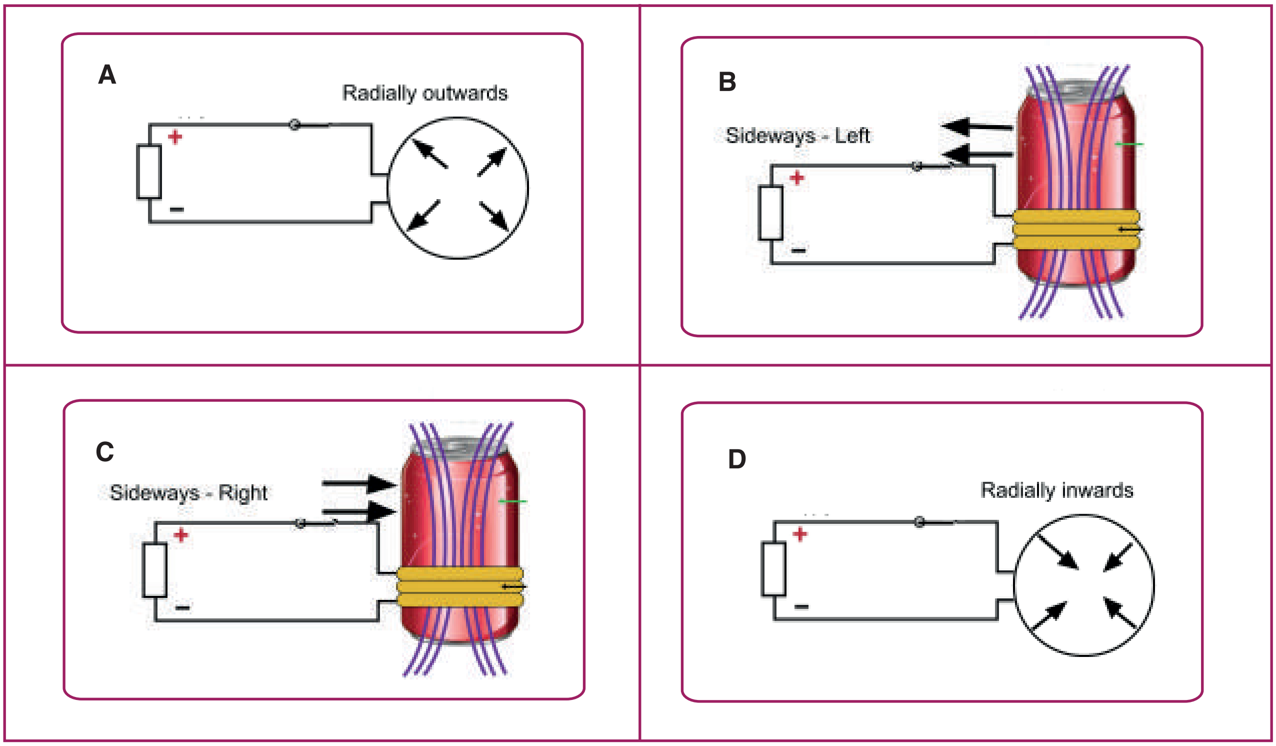
b. The coil's magnetic field induced an electric current in the can, which led to the can having its own magnetic field.

c. The can was responding purely to the electric field.

d. The can repels all magnetic fields thereby floating above the coil momentarily.

Answer

ii. Which way is the force acting on the part of the can inside the coil?



a. Radially outward	b. Sideways - Left
c. Sideways - Right	d. Radially inwards

Answer

Further Reading - Railguns

In 1917, in the midst of World War I, French inventor Andre Louis Fauchon-Villeplee made the first prototype of an electromagnetic cannon (so-called Railgun), but it was never field-tested or improved upon. This was because, while it worked in principle, the amount of power it would require to fire it was deemed unfeasible. The idea languished for years, till in 1985 the Yugoslavian Military Technology Institute made a railgun with 7 kilojoules of kinetic energy, under a project called EDO-0. Project EDO-1, a successor to project EDO-0, was created in 1987. It used a projectile with a mass of 0.7 g and achieved bullet speeds in the range of 3,000 m/s. In more recent times, the US military has many working prototypes of railguns, but there are still none in active use on the battlefield. One of the applications being researched is railguns as the main guns for a large battleship, but once again the energy requirements would mean that the ship would need to have a sizable nuclear reactor to power it. How much energy? Well, The Office of Naval Research set a world record by conducting a shot with muzzle energy (kinetic energy imparted to the bullet) of 33 megajoules, which was all released in a small fraction of a second. Even with no other losses in the system, 33 megajoules of electrical energy is enough to power an average Indian household for a little over three days! With so much energy being input over such a small time, a truly massive power source is required. Furthermore, the rails undergo immense stresses during firing, due to the gargantuan amounts of current being conducted through them, so much so that a challenge with initial railgun prototypes was to stop the bullet welding itself to the rails because of the heat and sparks generated. The plume of fire in Fig. 7.24 is an indication of just how much heat; it shows a railgun bullet (on the left) as it exits the barrel.

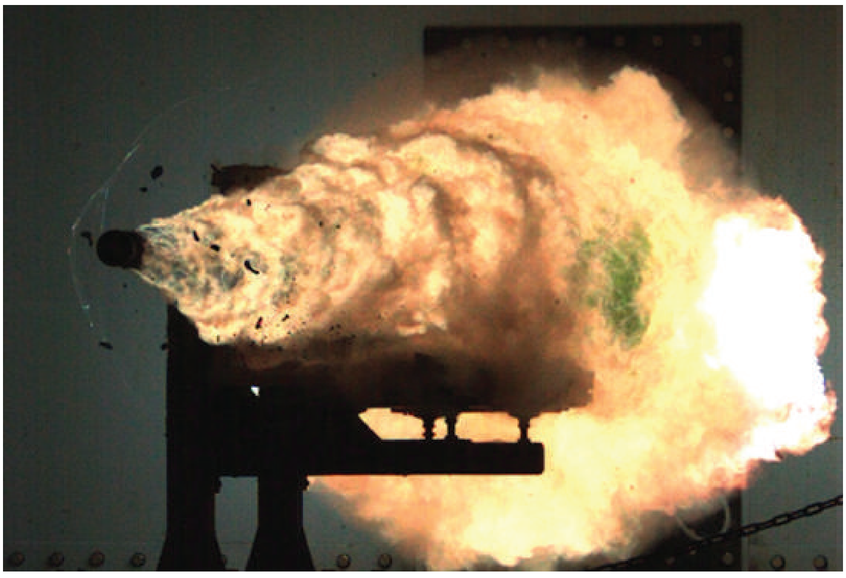
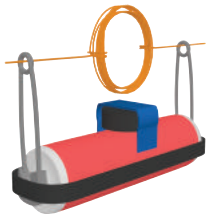


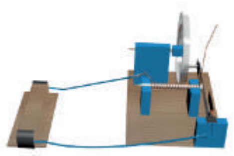
Fig. 7.24, The Firing of a Railgun; Image by U.S. Navy via Wikimedia Commons

Exploration Pathway



DC Motor model

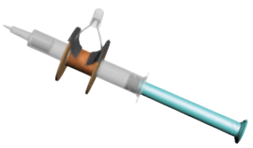
This amazingly simple model of a DC Motor allows you to experience various facets of electromagnetism first-hand. The simple design and materials allow you to play with, experiment and tinker with this model and discover the properties of electricity and magnetism yourself. Current from the battery flowing through the copper coil makes it an electromagnet (Oersted's Law), which in turn interacts with permanent magnets, providing a thrust for the copper coil to rotate. All electric motors in the world work on the same principle. Here you make, play with, tinker and experiment with a brilliantly simple model first-hand.



DIY Electric Bell

A current carrying conductor produces a magnetic field, i.e. it becomes an electromagnet. This principle can be used to make an electric bell, which is a mechanical bell that functions by means of an electromagnet.

In this TACtivity, we wind enamelled copper wire around a nail and fix the two ends of the wire to metal strips. As you pass current through the metal strips, the nail turns into an electromagnet the strip would get attracted and produce sound.

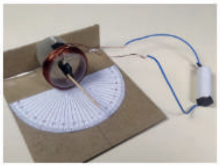


Generator Model

Using a 5ml syringe as the core, we wind 35-gauge insulated copper wire making 500 loops on it. Within the syringe, we place a magnet that moves as we shake the syringe. The two ends of the copper wire are connected to an LEDs. As the syringe is moved up and down, the LEDs should light up!

DIY Headphone

Sound is heard due to the rarefaction and compression of a column of air, i.e. a pressure wave, usually caused by a vibrating string or membrane. Speakers do the incredible job of converting an electric signal into a sound wave. How is this achieved?? In this stand-out TACtivity, you make your very own Headphone using thin copper wire, a neodymium magnet, a plastic container and an audio jack. Connect the jack to your phone or MP3 player and listen to all the music you want!!



DIY Galvanometer

Measuring the current and voltage in a circuit, or across components in a circuit, is vital to carrying out a host of experiments. The fundamental instrument used for doing so is called a Galvanometer, named after the famous Italian scientist Luigi Galvani, a pioneer in the field of electricity more than 200 years ago. In this TACtivity, we use copper wire, a container and other household items to make your very own galvanometer: a marker that distinctly deflects when a current is passed through the coil!

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