



# ELECTROMAGNETIC PROPERTIES OF MATERIALS

## TEACHING AND LEARNING ACTIVITIES

*ADAPTED VERSION*



# MATERIALS SCIENCE PROJECT

UNIVERSITY-SCHOOL  
PARTNERSHIPS FOR THE DESIGN  
AND IMPLEMENTATION OF  
RESEARCH-BASED ICT-ENHANCED  
MODULES ON MATERIAL  
PROPERTIES

## SPECIFIC SUPPORT ACTIONS

FP6: SCIENCE AND SOCIETY: SCIENCE  
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# ELECTROMAGNETIC PROPERTIES OF MATERIALS

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**CAUTION:** IN SOME OF THE FOLLOWING ACTIVITIES, YOU WILL BE USING MAGNETS, WHICH CAN INFLUENCE THE OPERATION OF CLOCKS, CREDIT CARDS, TELEPHONES, COMPUTERS, AND OTHER DEVICES PRONE TO DAMAGE BY MAGNETIC FIELDS. IT IS RECOMMENDED THAT YOU DO NOT PLACE THE MAGNETS CLOSE TO THESE OBJECTS.



## Why is it important to learn about “Electromagnetic Properties of Materials”?

Have you ever thought about the amount of magnets that are around you? Probably some cupboards at your home, school or gym have a magnetic lock. There might be plenty of magnets stuck in your fridge. Maybe you have a magnetic chess set. Have you thought about the electric devices that you can find at home? A drill, a blender, a fan ... All these devices are made by an electric motor. And any electric motor has a magnet inside itself! However, it is not a magnet like the ones that you stick in your fridge but an electromagnet.

Understanding how magnets work is even more important than identifying all the magnets around you. Have you ever reflected on how incredible is that a little magnetic piece can be stuck onto a fridge door? How can it be possible? We usually need some kind of adhesive to stick one thing to other but it is not case of magnets.

If you continue thinking about magnets, you will find many interesting questions around magnets:

How many times have you read a precaution sign warning you not to move a mobile phone or credit card up to a magnet? Why do you think that these recommendations are necessary?

Are there natural magnets or is it possible to construct them?

Is it true that in Japan there is a train which levitates thanks to magnets and it does not need wheels? How does it work?

This module will provide you with the scientific and technological tools necessary to answer questions like the previous ones.

# UNIT 1: MAGNETIC INTERACTIONS

Along this section, we will investigate a particular type of physical interaction. Based on our observations, we will invent a simple model that will enable us to account for the behaviour of magnets and magnetic materials.





In Chapter 1, we will examine the different parts of a magnet, its interactions with other objects and we will develop an operational definition for a magnet, that is, we will define a magnet according to how it behaves.

### Experiment 1.1.1. What happens to an object when it is near to a magnet? Do all the objects behave in the same way near to a magnet?

Obtain two magnets and the set of objects made of different materials that your teacher will provide you. In this set you will find coins, paper clips, drawing pins, drink tins, chalk, other magnets, etc. You can add other objects (sheet of paper, rubber, keys, etc) to examine the interaction between magnets and these objects.

- A.** Bring the two magnets near each other, turn them and move them closer or further and examine the interaction between them.

*Record your observations*

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*Do the magnets need to be in contact to interact?*

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*How does the distance between the magnets affect the interaction?*

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- B.** Bring various objects from your set near one another and near a magnet from part A.

*Describe what you observe*

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*Do all the different parts of a magnet interact with each object in the same way?*

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**C. Arrange the objects into at least three different classes based on their interactions with the two magnets and with each other**

1. ....
2. ....
3. ....

*How can you distinguish one class of magnet from another?*

.....

.....

*For each class of object (1, 2, 3), describe how each of them interacts with:*

- other objects of the same class
- objects of each of the other classes

*Do all the metallic objects interact in the same way?*

.....

.....

**D. Based on the observations that you have made in parts A-C, describe the interactions between the different classes of objects that you previously identified.**

TABLE OF INTERACTIONS

	CLASS 1	CLASS 2	CLASS 3
CLASS 1			
CLASS 1			
CLASS 1			

**E. Now you can answer the initial question of this experiment 1.1.1:**

*What happens to an object when it is near to a magnet? Do all the objects behave in the same way near to a magnet?*

.....

.....



One of the objects in the set that you have used in the preceding experiment has the capacity of interacting with other objects from the same class in the same way as the two magnets you were given, or with objects from other class. We call the objects in this class permanent magnets, or simply magnets. The interactions you studied in Experiment 1.1.1. are called magnetic interactions.

### Activity 1.1.2. How can we know whether a certain object is a magnet?

Using the Table in Experiment 1.1.1., write a series of steps that anyone would need to follow in order to identify a magnet. Try to be precise in your wording of the directions so that they cannot be misinterpreted by anyone.

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### Activity 1.1.3. How can we distinguish a magnet from an object which is also attracted by magnets?

A few of the objects that you worked with in Experiment 1.1.1. have been attracted by magnets. Any magnet also can be attracted by another magnet. Describe how you could distinguish such an object from a magnet. State explicitly what operations you would need to perform. Test the designed experiment and write down your conclusions.

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The objects in your set that interact with magnets are said to be ferromagnetic since most of the objects which interact magnetically are made of iron. However, a few other materials such as nickel interact in the same way as iron and are also called ferromagnetic.

### Experiment 1.1.4. Why do we speak in terms of magnetic interactions?

Obtain a magnet and a ferromagnetic object that is not a magnet. Both should be about the same size and mass. Close your eyes and hold them end-to-end near each other.

*Can you tell which one is the magnet solely on the basis of the pull that you sense between them?*

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Up to now, we have used the term “interaction” to describe the magnetic effects between two objects. Discuss why in this case this term is the most suitable one.

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In Experiment 1.1.1 you classified the objects according to the class of interaction that you observed between them. However, there are other kinds of materials apart from magnets and materials attracted by magnets (called ferromagnetic).

When placed near a magnet, ferromagnetic materials are more powerfully attracted by the magnet and they also attract it back equally strongly. A lot of these objects are made of iron but there are also ferromagnetic objects made of nickel or cobalt.

Paramagnetic materials are also attracted by a magnet but their interaction with magnets is much weaker. Powerful magnets are needed to notice this attraction. Some examples of paramagnetic materials are aluminium and chromium.

Diamagnetic materials are repelled by magnets (often the repulsion is weak). Some examples of diamagnetic materials are copper, gold and silver.

**Activity 1.1.5.** As a summary of Chapter 1.1., write what you think that you have learnt.

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SHARE YOUR ANSWERS WITH THE REST OF YOUR CLASSMATES

In Chapter 2, we will examine what all magnets have in common, we will compare the different parts of a magnet and we will learn to identify its poles.

### Experiment 1.2.1. What have all the magnets in common? Do all the magnets behave in the same way near to a certain kind of object?

Read what is explained by a group of students:

*“Today when we have entered in our classroom, our science teacher had prepared an experiment to identify the parts of a magnet. When we perform experiments we usually enjoy them and learn to reason and to draw inferences.*

*The teacher has shown us three magnets, whose ends had been labelled from 1 to 6, and a mysterious box marked with letters from A to E. The teacher has told us that inside the box there is a set of objects located exactly in each of the points (A-E) of the box.*

*The test consists of moving the ends of each magnet closer to the letters of the box and writing down the results about how each of each magnet end interacts with each of the mysterious objects inside the box. She has told us that we can not open the box to see the class of object which is inside.*

*After doing the corresponding observations, ends 1, 3 and 5 have turned out to behave exactly in the same way in front of spots A and D.*

***What could you conclude from these results?”***

Now repeat the experiment with the box and the magnets that your teacher will give you. Place end I near to each of the five test spots. Write down the interactions in the following table. Repeat the same procedure for each of the other ends of magnets.

	MAGNET 1		MAGNET 2		MAGNET 3	
	END I	END II	END III	END IV	END V	END VI
TEST SPOT	A					
	B					
	C					
	D					
	E					



Do some of the magnet ends behave in the same way in front of each test spot? Explain.

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Group ends I-VI of magnets (1-3) in different categories according to their interactions with the five test spots. To do so, you can label the magnet ends with colour stickers. Use the same colour to label the magnet ends that behave in the same way in front of the five test spots.

How many different categories can you identify?

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### Experiment 1.2.2. Do all the parts of a magnet behave in the same way in front of a ferromagnetic object?

**A.** Investigate the different parts of one of the bar magnets used in Experiment 1.2.1. in order to test if a magnet attracts a ferromagnetic object equally in its centre than in its ends. Make rough comparisons of how each part interacts with paper clips or other small ferromagnetic objects. You can do it drawing.

*Write down your observations*

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**B.** Obtain two bar magnets labelled according to the colour code that you have previously chosen and test how their ends interact.

*How does each of the "colour" magnet ends interact with each part of another magnet?*

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**C.** Answer now the initial question:

*What have all the magnets in common?*

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The term magnetic pole is used to identify a portion of a magnet that has magnetic properties like the ends or faces of the magnets that you used in the preceding experiments. In any magnet, there are only two poles. For a bar magnet, the poles are usually located at the ends of the magnet or its opposite faces. However, magnets come in various shapes and the locations of the poles may not be obvious.

### Experiment 1.2.3. How can we identify where the poles of a magnet are located?

**Now you will identify where the poles of magnets with different shapes are located. Try to identify the locations of poles of each magnet, labelling them according to the colour code previously chosen.**

*Are the poles of a bar magnet always located at the ends of the bar?*

.....

.....

**Outline a series of steps whereby you can (1) determine where the poles are located on a magnet, and (2) identify the type ("colour") of each pole. These steps will constitute an operational definition for the term magnetic pole.**

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### Activity 1.2.4. As a summary of Chapter 1.2., write down what you have learnt.

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**SHARE YOUR ANSWERS WITH THE REST OF YOUR CLASSMATES**



# 1.3

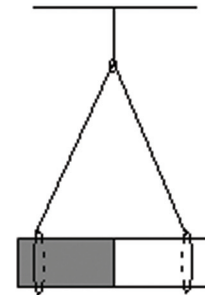
## THE EARTH AS A MAGNET

### Experiment 1.3.1. If we tie a magnet with a string so that it can rotate free, what would happen to it?

Note: Perform this experiment together with your classmates. However, you must first check whether the colour code for poles of magnets that you all use is the same.

- A. Obtain between six and eight cylindrical or bar magnets. Use one of your colour-coded magnets from Experiment 1.2.1 to colour code the poles of the remaining magnets.

Tie all the magnets with a string as it is shown in the figure and hung each magnet in a different place of your classroom. While you are waiting for the magnets to stop moving, draw a map of the room that shows the location of each magnet.



MAP OF THE CLASSROOM

When the magnets have stopped moving, record the orientation of each magnet and its poles on your map, indicating explicitly the "colour" of each pole. Moreover, indicate in the map the cardinal points.



Is there any pattern to the alignment of the magnetic poles? If so, describe the pattern.

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Carefully consider the environment of each magnet. List any objects with which the magnet might be interacting.

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**B. Look around the room for an object made of ferromagnetic material. Suspend a magnet near this object.**

*Does the alignment of the magnet fit the pattern you discovered in part A for the other suspended magnets? Explain how you can account for any differences.*

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*In part A, were there any magnets that did not fit the general pattern you discovered? If so, how might you account for the behaviour of those magnets?*

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**C. Tape a bar magnet onto the table and suspend another, smaller, magnet from a string above it. Hold the suspended magnet with your hand so that each pole of the suspended magnet is above the "like" pole of the bottom magnet.**

*Release the suspended magnet and describe what happens.*

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*How do you interpret the fact that the magnets in part A have oriented following an alignment pattern?*

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**D.** The previous observations in parts A and C could be explained from the following model: We can think the Earth as acting as a large magnet.

On the basis of this model, explain how the situations in parts A and C are similar. (Hint: Imagine that the magnet on the table in part C was very large and the suspended magnet was very small).

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**E.** On the basis of the model of the Earth as a magnet, what colour would you assign to the magnetic pole of the earth that lies towards:

- The geographic North of the Earth?
- The geographic South of the Earth?

*Explain your reasoning.*

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**SHARE YOUR ANSWERS WITH THE REST OF YOUR CLASSMATES**



The poles of a magnet are usually labelled with the terms north pole and south pole. The standard convention consists of labelling the end of a magnet that points towards the Arctic (or geographic North) as a "north pole," and the end that points towards the Antarctic (or geographic South) as a "south pole".

### Activity 1.3.2. If we think that the Earth behaves as a big magnet, where are their magnetic poles situated?

**A.** On the basis of the previous convention, is the magnetic pole of the Earth that lies in the Arctic (north geographic pole) a north or a south pole?

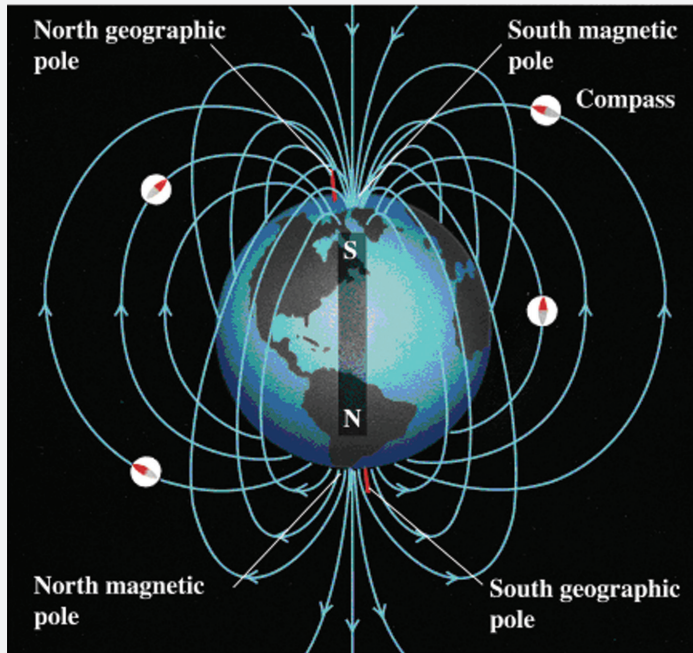
Is the magnetic pole of the Earth that lies in the Antarctic (south geographic pole) a north or a south pole?

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B. Mark the colour-coded ends of your magnets with either an "N" or an "S" so that they are consistent with the standard convention.



### HAVE THE MAGNETIC POLES OF THE EARTH ALWAYS BEEN LOCATED AT THE SAME GEOGRAPHIC POSITIONS?



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The magnetic poles of the earth are the points of the earth where the magnetic interaction is stronger and they are very near to the geographic poles. In contrast, the magnetic Equator of the earth is the neutral zone where the magnetic interaction is less strong. At any point on the surface of the earth, when we place a magnetic needle that is free to rotate, we observe that it always ends up taking a certain direction from south to north. On the surface of the earth, the curve that links the magnetic poles of the earth is called magnetic meridian and it forms an angle  $[\theta]$  with the geographic meridian. This angle is named the magnetic

declination and changes along the time, at each point of the planet. The theory more generally accepted which explains the fact that the earth behaves as a magnet says that a conductor fluid in movement (such as the earth's magma) is able to behave as a magnet, in the same way as the earth does. In most of places, the variation of the magnetic declination along the time is due to changes in the internal flux of the earth's core. In some cases, it is due to underground deposits of iron or magnetite in the earth's surface, which strongly contribute to the magnetic declination.



### Activity 1.3.3. How can we find a way that guides us to a certain place?

The compass is an instrument made of a magnetised needle (that is, it behaves as a magnet) that is free to rotate. It is used to indicate approximately the orientation of the geographic North and South.

In order to help you to understand how it works, you will use a simulation which you can download from the following link: [http://phet.colorado.edu/simulations/sims.php?sim=Magnet\\_and\\_Compass](http://phet.colorado.edu/simulations/sims.php?sim=Magnet_and_Compass).

**A.** When you run the simulation, select only the options “Show earth planet” and “Show compass”.

Move the compass to different points of the earth planet and observe how the needle of the magnet becomes oriented.

**B.** Answer the following questions from the observations that you have made:

*Which end of the needle (white or red) is a north magnetic pole? Justify your answer.*

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*How would you explain the fact that the needle of the compass becomes oriented in a certain direction?*

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*How could you identify the two poles of any magnet using a compass?*

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**Activity 1.3.4.** As a summary of Chapter 1.3., write down the main ideas that you have learnt.

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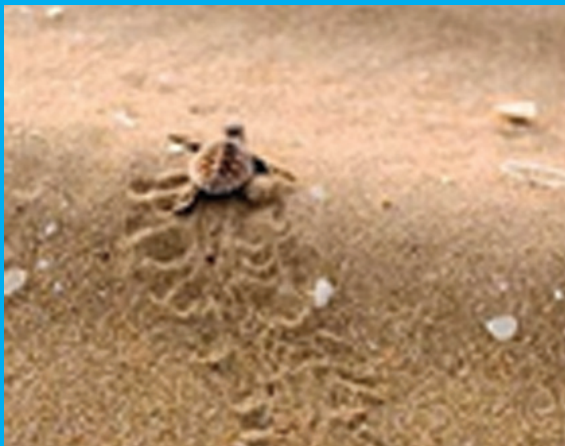
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## INTERESTING READING



There are living organisms (birds, whales, turtles, etc.) that have their own biological compass, which helps them find their orientation by making use of the earth's magnetic field. For example, pigeons have crystals of iron or magnetite incorporated in their beak, which they use as a small compass.



After coming out of the sand, turtles' younglings (which are not bigger than a human palm) find their way to the sea, which they have not seen before, and swim following their migratory roads into the oceans. When they arrive at deep waters where the formation of waves is not a reliable navigator, they use the magnetic field in order to orient themselves. They are able to cross up to 9000 miles in Northern Atlantic in this way before returning as young turtles to the coast, some years afterwards.

### Extension

You can find more information at the following websites:

<http://www.focusmag.gr/articles/view-article.rx?oid=150178>

<http://www.in.gr/news/article.asp?lngEntityID=510358>

<http://www.physics4u.gr/news/2007/scnews3016.html>





**UNIT 2:  
MAGNETIC FIELD**





**Experiment 2.1.1.** What would happen if instead of placing a ferromagnetic object near to a magnet we spread iron filings at its surroundings?

You can test it placing a flat bar magnet under a large piece of paper. Carefully sprinkle iron filings over the surface of the paper. Gently tap the tray or the piece of paper several times. Be careful to keep the iron filings from coming in direct contact with the magnet. You can do it, wrapping the magnet with tape.

*Write down your observations and draw the bar magnet and the pattern of iron filings*

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Considering that magnets interact more strongly with iron filings in the area where there is a greater concentration of them, in what region(s) around the magnet do the iron filings interact:

- strongly with the magnet?
- weakly with the magnet?

*Explain how you can tell in each case.*

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## Experiment 2.1.2. What could we observe if we placed small plotting compasses around a magnet?

Place a large piece of paper on a flat surface far from any magnetic or ferromagnetic materials. Tape a bar magnet to the centre of the paper and label the north and south poles. Sketch the outline of the magnet on the paper. On the paper, indicate the direction of the magnetic north pole of the earth.

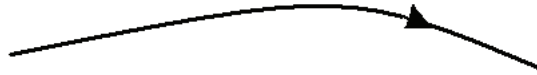
**A.** Take a small compass and determine which end of the needle is north. Place the compass on the edge of the paper far from the magnet and slide the compass over so that it touches the end of the magnet.

(1) Make two dots on the paper: one at the end of the compass needle next to the magnet, the second at the other end of the needle.

(2) Move the compass so that the end of the needle that was next to the magnet is now directly over the second dot that you drew above. Make a dot on the paper at the other end of the needle.

(3) Continue to move the compass as in part 2 above until the compass comes back to the magnet or leaves the edge of the paper.

(4) Draw a line (not necessarily straight) through the dots. On the line, place an arrowhead to indicate the direction in which the north pole of the compass needle points. (See the example below.)



**B.** Repeat part A, starting with the compass touching a different part the magnet. Do this at least 6 more times on each side of the magnet.

**C.** Describe the pattern of lines that you have obtained in parts A and B.

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*What do this pattern and the pattern of iron filings around a magnet that you obtained in experiment 2.1.1 have in common?*

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**D. Imagine that you were to remove the magnet from the paper and to repeat parts A and B without the magnet.**

*What would be the pattern of the lines that you drew in this case? Explain. You can do it by drawing.*



**Remove the magnet and check your answer.**

*Is the pattern that you obtain in parts A and B due only to the bar magnet? Where do you think the pattern is most nearly due to the bar magnet alone? Explain your reasoning.*



In Physics the term magnetic field is used to explain the fact that two separated magnets (or a magnet and a ferromagnetic object) interact one with each other. The magnetic field is considered the region of the space around a magnet where the effects of magnetic interaction can be detected (e. g., interaction between iron filings or a compass needle with a magnet). The physicists use the term “field” to define a region of influence. This meaning is not very different from the everyday meaning of this term: when we speak about a grass field, we refer to a region of the space where we find grass.

Once we know how the magnetic field created by a magnet is, we can explain and predict the way an object made of a ferromagnetic material (such as iron filings or a compass needle) will behave when it is placed near a magnet.

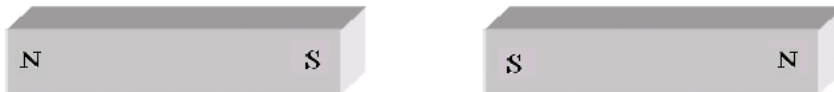
Continuous curves drawn using the procedures outlined in experiments 2.1.1 and 2.1.2 are named magnetic field lines or magnetic force lines. The magnetic field is usually represented by a pattern of lines such as the one that you used in the previous two experiments.

The pattern of iron filings or the pattern of a compass needle near to a magnet helps us to visualize how a magnet interacts with other objects since it gives us an idea of the direction and value of the magnetic force exerted by a magnet over another object.

**Experiment 2.1.3.** Which pattern of magnetic field lines would you observe in the region between two magnets placed with their “like” poles faced with each other?

**A.** For the following arrangement of two magnets, sketch and justify your prediction for the pattern of lines that you would obtain:

- placing compasses in the region between and around the magnets.
- sprinkling iron filings over the magnets.



**B.** Obtain two magnets and check your answer.



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PATTERN OF LINES OF MAGNETIC FIELD WITH COMPASSES



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PATTERN OF LINES OF MAGNETIC FIELD WITH WITH IRON FILINGS



As you have just seen in experiment 2.1.3, the patterns of lines of magnetic field for a certain magnet can be also used to predict magnetic effects where there is more than one magnet. In this case, the effect of individual magnets does not change, but the effect of each of them must be taken into account. The resulting iron filing or compass needle pattern reflects the additive effects of all the magnets.

### Experiment 2.1.4. Do all the magnets produce the same pattern of magnetic field lines?

In order to test it, obtain several magnets that are not bar magnets. Make an iron filing pattern for each magnet.

Make sketches of the patterns that you obtain. Indicate the region(s) where the each magnet interacts strongly with iron filings.



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PATTERN OF LINES OF MAGNETIC FIELD



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PATTERN OF LINES OF MAGNETIC FIELD

What similarities and differences do you find between these patterns of lines of magnetic field?

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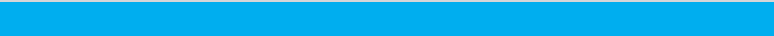
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As you have tested along this chapter, magnets create a magnetic field in their surroundings. However, in experiment 2.1.1. you have tested that a magnet does not interact with iron filings as strongly in any point of the space. Therefore, we can say that the magnetic field produced by a magnet in a certain point of the space is more or less intense depending on the amount of lines of magnetic field located in that point. In order to measure this intensity of magnetic field produced by a magnet in a certain point of the space, we can use different instruments. One of them is a magnetic field sensor (such as the one presented in the figure).



This sensor, connected to the computer through an interface, allows measuring the magnetic field produced by any magnet in a certain point of the space. The unit to express values of magnetic field intensity is tesla (T) in the SI system and gauss (G) in the CGS system. The relationship between these two units is:  $1\text{T} = 10000\text{G}$ . The value of magnetic field intensity on the Earth surface is approximately 0,5 G.



**UNIT 3:  
MODEL OF  
MAGNETIC  
MATERIALS**





# 3.1

## COMPARING THE FORCE THAT DIFFERENT MAGNETS EXERT ON OBJECTS

**Activity 3.1.1.** How can we determine if one magnet is more powerful than another magnet?

Chloe and Maria have each of them a cylindrical magnet that is 12 cm in length and 1 cm in diameter. They often argue about what magnet is stronger. Describe a procedure that they may follow to determine who has the stronger magnet and specify the units of the magnitude that you will measure.

*You can illustrate it with a drawing.*



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**Experiment 3.1.2. Are two physically identical magnets equally stronger? Does the size of a magnet make the magnet more or less powerful?**

**A.** Now you will perform an experiment to test whether the force exerted by different magnets on a ferromagnetic object is equal. To do so, obtain several magnets of various sizes and shapes. Use a compass needle to identify the north and south poles of each magnet. Label these “N” and “S.”

In the first column of the table below, sketch each of your magnets. Show the dimensions of each magnet on your drawing as well as the locations of the poles.

Use the method you described in Activity 3.1.1. to determine the force exerted by each of the poles of each magnet on the chosen object. Record your results.

SKETCH OF THE MAGNET	FORCE EXERTED BY THE NORTH POLE OF THE MAGNET	FORCE EXERTED BY THE SOUTH POLE OF THE MAGNET

**B.** Base your answers to the following questions on the results of the experiment in part A. Perform additional experiments if necessary.

*Is a larger magnet necessarily stronger (or weaker) than a smaller magnet?*

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*Do the north and south poles of a magnet seem to always interact equally strongly with ferromagnetic objects? Explain how you could tell from your observations.*

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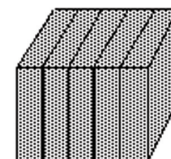
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SHARE YOUR ANSWERS WITH THE REST OF YOUR CLASSMATES

### Experiment 3.2.1. How can we make a bigger magnet using smaller magnets?

- A.** Obtain a set of small magnets that are assembled into a magnetic stack as shown at right.



Explore the magnetic properties of the stack. Identify the similarities and differences between the behaviour of the stack and that of a bar magnet.

*Does the stack behave as though it were a single large magnet? If so, locate the north and south poles and indicate the locations on a diagram. If not, how does the behaviour of the stack differ from that of a single magnet of the same size and shape? Examine the interaction between paper clips and the centre of the stack (midway between the ends). Describe your results and compare them with the results you obtained in experiment 1.2.2.*

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- B.** Break the stack of magnets in half. Examine both ends of each half of the stack.

*Does each half have a north and a south pole? If so, where are the poles located?*

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### Experiment 3.2.2. If a magnet breaks, how does each of the pieces behave?

- A.** In this experiment you will examine what happens when a magnet is broken into smaller pieces. Try breaking a magnet in two parts and examine the behaviour of the ends of each of these parts with a compass.

- B.** However, rather than actually break a magnet you will use the magnet stack from experiment 3.2.1.

*Justify if you think that using a magnetic stack instead of breaking a magnet in smaller pieces is appropriate.*

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- C.** The original stack consists of several individual magnets, each with its own north and south poles.

*Do the poles of the individual magnets appear to act like poles when individual magnets are part of the stack? Explain.*

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### Experiment 3.2.3. If the number of magnets of a magnetic stack is increased, does the force that the stack exerts on an object increase too?

Now you will test whether the force exerted by a magnetic stack on an object is stronger, weaker or equal than the exerted by one magnet.

To do so, you will use little identical magnets.

- A.** Measure the force exerted by the poles of an individual magnet using the procedure from Experiment 3.1.1. and write down your results in the first line of the table below. Then, place two magnets together to form a magnetic stack. Repeat the experiment, this time measuring the strength exerted by the poles of the magnetic stack. Keep adding to the stack a magnet each time. In every stage, measure the force exerted by the resulting magnetic stack.

*Write down your results.*

NUMBER OF MAGNETS	MAGNETIC STACK	
	NORTH POLE	SOUTH POLE
1		
2		
3		
4		
5		
6		

- B.** Represent graphically the force exerted by the poles of the magnetic stack versus the number of magnets that are part of the magnetic stack. Represent the force exerted by both poles of the stack on the same graph. Label your graph and the axes.



GRAPH



*Describe the graph of the variation of the force exerted by a magnetic stack as magnets are added to the stack, one at a time.*

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*Is the force exerted by the magnetic stack at each stage equal to the sum of the forces exerted by the individual magnets that form the stack? Explain how you can tell from the graph.*

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*Does the force exerted by the stack increase without bound (i.e., could you make the stack as strong as you like just by adding magnets?) or does the force seem to approach a limiting value? Explain.*

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### Experiment 3.2.4. Which possible arrangement of two magnets makes stronger the interaction between the stack and an object?

A. Arrange two bar magnets as shown below. Test whether each of these arrangements of magnets are stable, that is, the two magnets are able to rest together without any repulsion. If not, use a rubber band or tape to keep the magnets together. Use the procedure from experiment 3.1.1. to determine the force exerted by each end or side of this magnetic stack.

B. Write down your observations in the following table:

ARRANGEMENT OF THE MAGNETS	IS IT STABLE?	FORCE EXERTED BY ONE END OR SIDE	FORCE EXERTED BY THE OTHER END OR SIDE

C. In this experiment, you have made magnetic stacks using two magnets with their “like” poles together and also with their opposite poles together.

What arrangement of these two magnets leads to a stronger magnetic stack?

In short, you have been able to empirically test that:

- The arrangement of two magnets like is more / less strong than the arrangement like .
- The arrangement of two magnets like is more / less strong than the arrangement like or



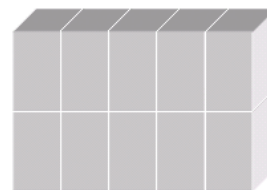
SHARE YOUR ANSWERS WITH THE REST OF YOUR CLASSMATES

## 3.3

## A MODEL FOR MAGNETIC MATERIALS

### Activity 3.3.1. Which arrangement of magnets creates a more powerful magnetic stack?

Consider ten little magnets arranged to make a magnetic stack as the one shown in the figure. Draw how you would arrange these magnets in order to make the stack as stronger as you can.



*Justify your drawing.*

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As you have been working through this module, you may have begun to develop an idea of the behaviour of magnets which helps you to make sense of your observations. Some important observations that you have made include the behaviour of magnets when they are broken or stacked. A model that can help you to account for these observations and to predict some similar phenomena consists of the representation of a magnet as the collection of many smaller pieces, each of them acting like a tiny magnet. Each of these smaller pieces that act like individual magnets and are part of an only magnet is called magnetic domain. A magnet can be represented at a microscopic level in the following way:



Each of the arrows indicates the direction of magnetisation of each magnetic domain inside a magnet. Therefore, the magnetic effects of a bar magnet can be thought of as the cumulative effect of many interactions arising from the small magnetic pieces composing the bar magnet. That is, if two magnetic domains are aligned in the same direction but in an opposite way, their effects counteract whereas if they are aligned in the same direction and way, their effects are added up. For this reason, the difference between an object made of any ferromagnetic material (without being magnetised) and a magnet (magnetised) is the alignment of their domains.

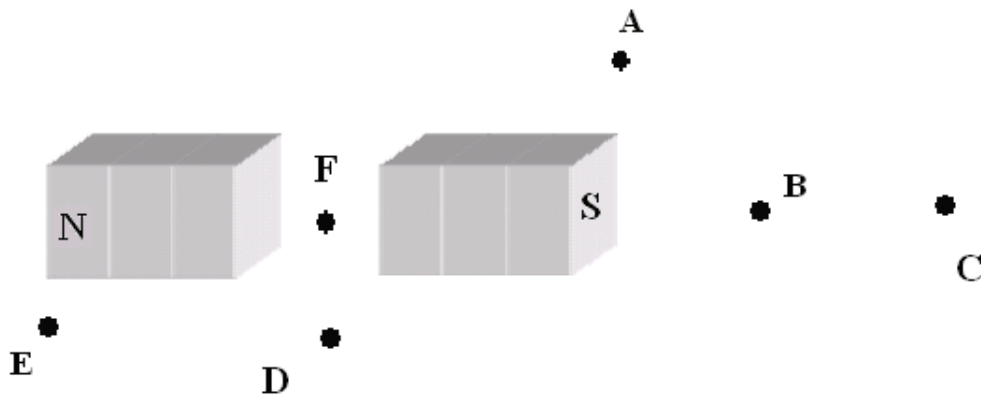


### Experiment 3.3.2. What are the magnetic field lines inside a magnet like?

In this experiment you will explore how a set of compasses behave when placed near a bar magnet and also how a compass would behave if it was possible to place it inside a magnet.

- A. Obtain some small magnets and place them together to form a magnetic stack. Separate the magnetic stack in half, so that you can place a compass at the centre of this stack (point F). All the magnets should have the same orientation. Place the magnetic stack on a large piece of paper.**

*Use a compass to show the direction of the magnetic field for point A-E. Draw an arrow to show the direction for each of the points.*



- B. Use the compass to investigate the direction of the magnetic field for point F. Compare the direction of the Magnetic field for point F and D. Describe the similarities and differences.**

*How do you explain that the compass needle is aligned in the way it does in these two points?*

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- C. Once you have compared how the compass needle becomes aligned in points D and F, what are your conclusions of this experiment about the direction of the lines of the magnetic field inside a bar magnet?**

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**D. According to these observations and the aforementioned model of magnetic material, how do you think that magnetic domains inside a magnet are aligned?**

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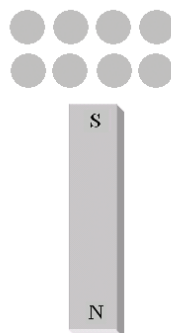
Some of the observations you have made in this module concern the interaction of magnets with ferromagnetic materials. You found that objects made of ferromagnetic materials can become magnetized when placed near a magnet, which means that magnetic domains of this material are oriented in the same direction and way. You have also observed that the centre of a magnet, which is not a pole, is attracted to the poles of other magnets. These facts suggest that permanent magnets are made of ferromagnetic material. This close relationship between those objects we call “magnets” and those we call “ferromagnetic” must be taken into account in any model that we develop.

### Experiment 3.3.3. How do ferromagnetic materials behave microscopically?

In this experiment we will explore how a set of compasses behave when placed near a bar magnet. Consider that the set of compasses represents a ferromagnetic object and each of the compasses that are part of it corresponds to a magnetic domain.

**A. Obtain between 6 and 8 small compasses and place them close together. Do all your compasses initially point in the same direction?**

**B. Bring the north end of a bar magnet up near the set of compasses as shown in the two figures at right. Carefully sketch the alignment of each compass for each location of the magnet.**

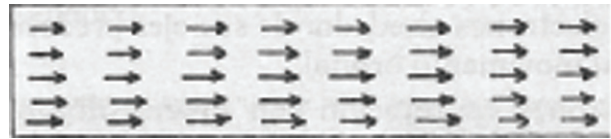
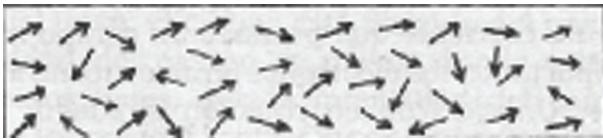


**C. Repeat part B with the magnet reversed (approaching the South pole).**



Thus far, we have been thinking of magnets as consisting of many small magnetic pieces. We can think of ferromagnetic materials in this same way. We can account for interactions between magnets and objects made of ferromagnetic material by thinking of the magnetic domains in the ferromagnetic material as being free to rotate like a compass needle when other magnets are near and, therefore, they can become aligned in a certain direction and way.

According to the model of magnetic material, which of the following representations do you think that corresponds to a little magnetized and to a very magnetized material?



Which of these two materials will behave as a stronger magnet?

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### Activity 3.2.4. When does a ferromagnetic material have magnetic properties?

Use the model for ferromagnetic materials to account for the following phenomena. You can make a drawing or sketch to represent the ferromagnetic materials at a microscopic level.

**A. A ferromagnetic object that is not initially magnetized is attracted to a magnet.**



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**B. Ferromagnetic objects that are not magnetized are not attracted to one another.**



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### Experiment 3.3.5. How can a magnet magnetize a ferromagnetic bar?

**A. A bar magnet is placed next to a ferromagnetic bar, as shown below.**



*Predict the pattern of the magnetic field for this arrangement. Accept that the ferromagnetic bar is not magnetised initially. Draw your prediction and explain your reasoning.*



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*Check your answer using a compass or iron filings.*



**B. Predict what changes would be (in Part A) if the ferromagnetic bar was reversed.**

*Explain.*

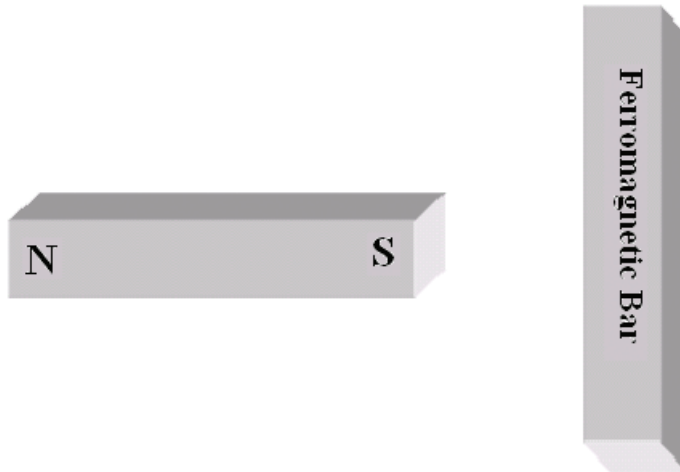
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**C. Predict the pattern of the magnetic field, in the case that the ferromagnetic bar is positioned as shown below.**

*Explain your reasoning.*



*To check your answer perform the experiment using a compass or iron filings.*

*In short, how does the magnet affect the magnetic domains that form the ferromagnetic bar?*

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**Activity 3.3.6. How can we account for the following phenomena from the model for magnetic materials?**

Below you can read some observations that someone has made while conducting experiments with magnets. Use the model that has been developed thus far to account for these observations. Explain your reasoning in each case, using the visual representations of the model.

**A. A compass needle near a magnet may reverse polarity, that is, the North pole can become the South pole and the other way around.**

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**B. A ferromagnetic object becomes magnetized when it is placed very near a pole of a magnet.**

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**C. An iron bar that is initially not magnetized may become a magnet when it is hit with a hammer and the bar is aligned with the magnetic poles of the Earth.**

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*How can you account for the resulting polarity of the bar?*

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*Why do you think it helps to strike the bar?*

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**D. Large ferromagnetic objects that have been left in a room for a long time often have north and south poles.**

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**E. A magnet can lose its magnetic properties when it is heated above a certain temperature.**

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### Activity 3.3.7. Applying the model for magnetic materials

Use your model for magnetic materials to answer the following questions.

**A. How might you account for one magnet being stronger than another?**

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**B. What will happen to a strong magnet that is repeatedly dropped?**

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**C. Suppose that you had a source of a very strong magnetic field.**

*How could you use the magnetic field to make a magnet out of a ferromagnetic object?*

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**D. Do you think there is a limit to how strong a magnet you could make out of a particular object?**

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### Experiment 3.3.8. How do different materials affect the magnetic field created by a magnet?

Obtain a ring stand, two clamps, a piece of string, a strong magnet, and a ferromagnetic object (e.g., paper clip). Assemble the objects as shown at right. Make the string as short as you can without the paper clip falling.

Place thin objects made of various materials between the magnet and the paper clip.

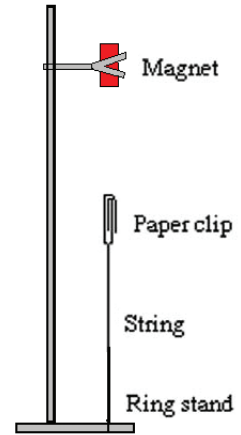
Which types of materials cause the paper clip to fall and which do not?

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**How can you account for the behaviour of the paper clip when ferromagnetic materials are placed between the magnet and the suspended ferromagnetic object?**

*Explain on the basis of the model for magnetic materials.*

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**Activity 3.3.9.** As a summary of Chapter 3.3., write down the main ideas that you have learnt.

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**SHARE YOUR ANSWERS WITH THE REST OF YOUR CLASSMATES**







**UNIT 4:  
ELECTROMAGNETISM**



# 4.1

## MAGNETIC FIELD CREATED BY CURRENT-CARRYING WIRE

### Relation between electricity and magnetism

Before 1820, the only magnetism known was that of iron magnets and of lodestones. This was changed by a little-known professor of science at the University of Copenhagen, Denmark, Hans Christian Oersted.

In 1820, Oersted arranged at his home a science demonstration to some university students. He planned to demonstrate the heating of a wire by an electric current, and also to carry out demonstrations of magnetism, for which he provided a compass needle mounted on a wooden stand. However, he had not imagined what would happen later ...



### Experiment 4.1.1. Oersted's experiment

**A. What do you think that Oersted could observe when the compass was placed near a current-carrying wire?**

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**B. Let's perform the experiment!**



**CAUTION:** WHENEVER YOU CLOSE THE SWITCH, THE WIRE AND BATTERY MAY BECOME HOT. KEEP THE SWITCH OPEN FOR ALL BUT THE BRIEF PERIODS DURING WHICH YOU ARE MAKING OBSERVATIONS.

Draw a sketch to show how the compass is oriented before the switch is closed. Later, connect the wire to a battery following the indications of your teacher. Slowly, bring the wire near the compass, placing it parallel to the direction of the compass needle. Observe what is happening and write down your observations.

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DRAWING BEFORE CONNECTING THE WIRES TO THE BATTERY



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DRAWING AFTER CONNECTING THE WIRES TO THE BATTERY

**C. Why has the compass needle become oriented when closing the circuit connecting the wires to the battery?**

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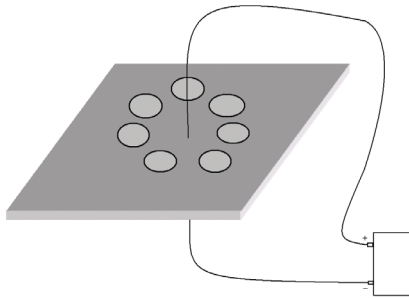
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## Experiment 4.1.2. How are the magnetic field lines created by a current-carrying wire?

To check the pattern of lines of magnetic field created by a current-carrying wire, you can prepare the following experiment. Use a ring stand and clamp to hold a piece of cardboard horizontally as shown. Then pass the thread wire through a hole in the cardboard and connect the wire to a battery and switch. Place several small compasses on the cardboard around the wire.

**A. How does the strength of the magnetic field due to the current carrying wire vary with the distance from the wire?**

*Explain how you can tell.*



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**Draw a sketch of the magnetic field lines near the current-carrying wire.**





*Explain how you decided to draw the lines as you did.*

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*Explain how the field lines that you drew differ from those of a bar magnet.*

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**Compare the magnetic field for a current-carrying wire to the magnetic fields of other objects, such as a horseshoe magnet or a pair of bar magnets.**

*Are any of the magnetic fields that you have previously studied similar to the field of a current-carrying wire?*

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*Explain how you took into account the magnetic field of the earth.*

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**B. Reverse the connecting leads to the battery and repeat part A.**

*Record your observations*

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**Sketch the magnetic field due to the current-carrying wire in this case.**



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*How does reversing the leads to the battery affect the magnetic field due to the current-carrying wire?*

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**SHARE** YOUR ANSWERS WITH THE REST OF YOUR CLASSMATES

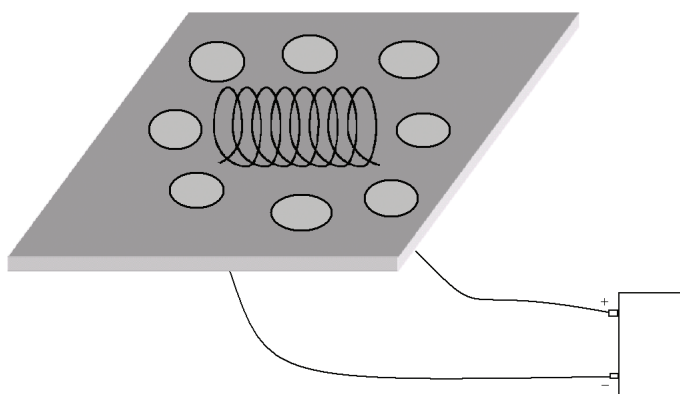




In the previous Chapter we studied the magnetic field of a current-carrying wire. In this Chapter we will investigate how the configuration of the wire affects the magnetic field.

### Experiment 4.2.1. What are the magnetic field lines created by a current-carrying coil like?

Wrap a 20 cm piece of insulated wire around a pencil several times. Remove the pencil and place the wire coil on the cardboard from Experiment 4.1.2. Connect the coil to a fresh battery through two holes in the cardboard. Do not close the switch yet. Place several compasses around the coil as shown below.



- A.** Before you connect the wires to the battery, sketch the coil and compasses in your notebook. Draw arrows to show the orientations of the compass needles when the switch is open. Briefly close the switch. Quickly observe the orientations of the compass needles, and open the circuit. Make a sketch of the coil. Indicate the direction of the current through each winding of the coil.

Draw a sketch with small arrows to show the orientations of the compass needles around the coil



DRAWING BEFORE CONNECTING THE WIRES TO THE BATTERY



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DRAWING AFTER CONNECTING THE WIRES TO THE BATTERY

**Draw lines to represent the magnetic field due to the current-carrying coil. Base the sketch on your observations of the compass needles.**



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MAGNETIC FIELD LINES AROUND THE CURRENT-CARRYING COIL



What have these magnetic field lines in common with those of the bar magnet?

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Could you identify a North and South pole of the current-carrying coil? Explain your reasoning.

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**B. Suppose you wanted to replace the current-carrying coil with a magnet that produces a similar magnetic field.**

Describe the approximate location of the poles, the value, and the direction of the magnetic field.

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**C. Reverse the leads to the battery in the circuit and repeat part B.**

Describe how the magnetic field lines in this case differ from those you sketched in part A.

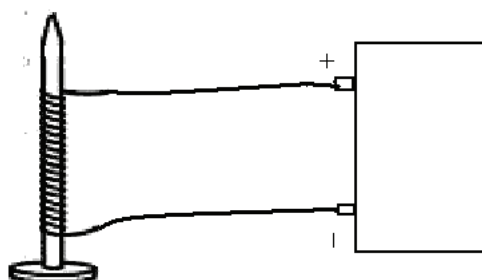
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### Experiment 4.2.2. How can we make a magnet using a current-carrying coil?

Wrap a piece of insulated wire around a ferromagnetic object (e.g., a nail) that is not a permanent magnet. Connect the wire to a battery as shown in the figure. Use a fresh battery for this experiment. Do not close the circuit yet.



**A. While the circuit is open, bring the nail near several paper clips. If the nail attracts paper clips, find a nail that is not a magnet. Because it will mean that the nail was already magnetized initially.**

**B. Bring the nail near some paper clips and then briefly close the circuit.**

*Describe your observations*

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*While the circuit is closed, does the nail attract paper clips? If so, how many paper clips can the nail pick up?*

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*Are the paper clips still attracted to the nail after the switch is opened? If so, does the nail pick up as many as when the switch is closed?*

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**C. Wrap, anticlockwise, a piece of insulated wire around a nail, starting from the head of the nail. Use another nail and repeat the process, this time wrap the wire clockwise (head to bottom).**

*Is the polarity of the two electromagnets different? State your opinion.*

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**D. Connect both nails with a battery. Connect the positive terminal of the battery with the coil end where the head of the nail is. Briefly close the switch and determine the poles of the electromagnets using a permanent magnet. Record your observations.**

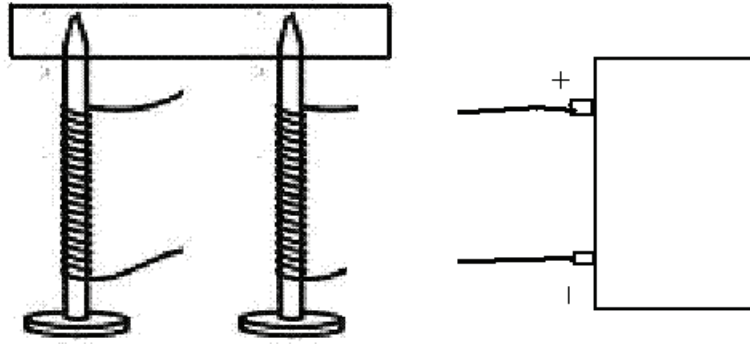
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### Experiment 4.2.3. How can a magnet be moved by using electromagnets?

Prepare two electromagnets; follow the same procedure as before. Then, nail them in a piece of wood, as shown in the figure below.



How these electromagnets should be connected with the battery and between them, in order for the ends of the nails to have different polarity?

*Draw the correct connection and then carry out the experiment.*

*Explain your reasoning.*

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**B. Take a flat magnet and identify the poles. Place the magnet on the top of the wooden surface in an equal distance between the two electromagnets. Briefly close the circuit.**

*Write down your observations.*

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**C. Change the direction of the current in the circuit by inverting the cables on the battery terminals. Briefly, close the circuit.**

*Explain the movement of the magnet.*

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SHARE YOUR ANSWERS WITH THE REST OF YOUR CLASSMATES



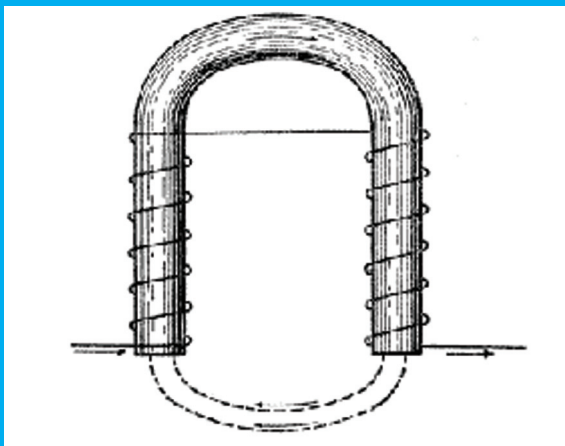
## INTERESTING READING



### ELECTROMAGNETS

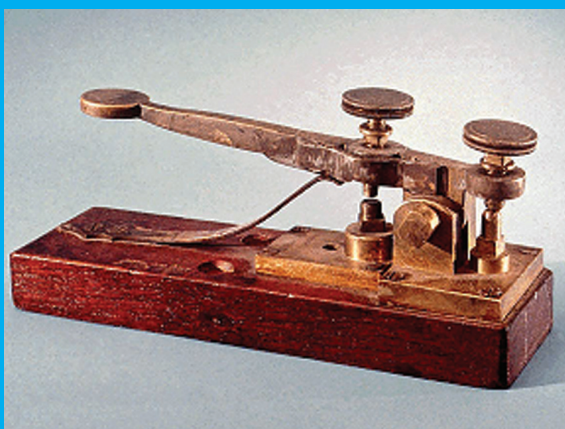
An electromagnet is a device in which magnetism is produced by an electric current.

A British electrician, William Sturgeon, invented the electromagnet in 1825. The first electromagnet was a horseshoe-shaped piece of iron that was wrapped with a loosely wound coil of several turns. When a current was passed through the coil; the electromagnet became magnetized and when the current was stopped the coil was demagnetized. Sturgeon displayed its power by lifting nine pounds with a seven-ounce piece of iron wrapped with wires through which the current of a single cell battery was sent.



Sturgeon could regulate his electromagnet; this was the beginning of using electrical energy for making useful and controllable machines and laid the foundations for large-scale electronic communications.

Five year later an inventor called Joseph Henry - made a far more powerful version of the electromagnet. American, Joseph Henry (1797-1878), demonstrated the potential of Sturgeon's device for long distance communication by sending an electronic current over one mile of wire to activate an electromagnet which caused a bell to strike. Thus the electric telegraph was born.



# 4.3

## A SCIENTIFIC INVESTIGATION WITH ELECTROMAGNETS

### Activity 4.3.1. Which factors affect the strength exerted by an electromagnet?

John and Andrea have constructed two different electromagnets following the procedure described in Chapter 4.2.2. The electromagnet that was constructed by John is able to attract five paper clips while Andrea's electromagnet is able to attract 8 paper clips, in vertical series each hanging below the other. John and Andrea are discussing about what may have caused this difference in the force exerted by each of the two electromagnets.



**John:** "I think that the factor that influences the force exerted by the electromagnet is the number of turns of the coil"



**Andrea:** "You might be right... However, I believe that the crucial factor is the length of the wire used in the coil"

*Do you agree with John, Andrea, both or neither? Explain your reasoning.*

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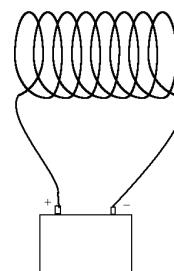
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### Activity 4.3.2. Design an experiment

To analyze the factors that affect the force exerted by an electromagnet on paper clips, Andrea and John have designed the following experiment:

They have connected the wire of the coil to a fresh battery as it is shown in the figure. Using a magnetic field sensor, they have determined how different changes affect the intensity and direction of the magnetic field near the ends of the coil. In each measurement, they have closed the circuit briefly.

Andrea and John have planned on changing the following variables in the setting: adding various elements to the circuit (e. g., a battery or a bulb), changing the size or number of turns of the wire coil, putting various materials inside the coil (e. g., a pencil or a nail).



You can also check what changes proposed by Andrea and John produce a significant effect on the intensity of the magnetic field created by the current-carrying coil.

*Choose one of the identified variables and carefully describe an experiment that will allow you to determine whether it does influence the magnitude of the force exerted by the electromagnet.*

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In science, we often seek to design and conduct valid experiments that allow us to determine whether one factor influences another. Before proceeding to design an experiment it should be useful to clearly formulate the investigable question under consideration.

An investigable question can be expressed in the format shown below:

Does **VARIABLE A** influence **VARIABLE B**?

### Activity 4.3.3. Formulate a research question

Formulate the investigable question relevant to the variable you have chosen to address.

Does the variable ..... influence the variable .....?

### Activity 4.3.4. Control of variables

In any given experiment, some of the variables need to be **KEPT CONSTANT, MEASURED OR ALTERED**.

Fill the table below by specifying the factors to be kept constant, measured or altered so as to address your investigable question. Select the factors to be placed in each column in a manner that could lead to a valid experiment that will allow you to address the question at hand in a reliable manner.

FACTOR(S) TO BE ALTERED	FACTOR(S) TO BE KEPT CONSTANT(S)	FACTOR(S) TO BE MEASURED

If an experiment is to lead to valid conclusions we should only vary one variable at a time, making sure that we keep all other factors constant and measure just one other variable.

### Activity 4.3.5. Prepare your experiment

*What do you need to do in order to vary Variable A in your experiment?*

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.....

.....

*How would you measure Variable B in your experiment?*

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.....

.....





*How would you ensure that all other variables that might influence the outcome are kept constant?*

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### Experiment 4.3.6. Carry out your experiment

Set up and carry out the experiment you have designed.

**Use the space provided below to construct a table and record your measurements.**

*What do the results of this experiment suggest with respect to the investigable question you sought to address?*

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### Activity 4.3.7. When can we say that an experiment is valid?

Below there is a description of the experiment designed by a group of students to address the question “does the number of turns in a coil influence the force exerted by the electromagnet?”

“In an attempt to address this question we have constructed two electromagnets. The coil in the first one had 10 turns while the other had 20 turns. We used the same type of wire but the core of the two electromagnets was different. The first electromagnet used a nail made of iron while the other used a nail made of steel. Our results demonstrated that the electromagnet with the iron nail attracted more paper clips than the other. This suggests that the number of turns influences the force exerted by the electromagnet.”



*Would you consider the experiment described above valid? Explain your reasoning.*

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*In case you consider this experiment as invalid suggest possible ways to render it valid.*

.....

.....

.....

### Activity 4.3.8. Design another experiment

Choose another variable that you would like to test and formulate a second research question.

.....

Design an experiment in order to address this question:

- We will alter the following variable: .....
- We will keep the following variables constant: .....
- We will measure the following variable: .....

### Experiment 4.3.9. Carry out your experiment

Set up and carry out the experiment you have designed.

**Use the space provided below to construct a table and record your measurements.**



*What conclusion could be drawn from the results of your experiment?*

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*Provide an overview of an approach that could be generally followed in order to address investigable questions that could be stated in the form «Does variable A influence variable B?».*

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CHECK YOUR REASONING WITH YOUR TEACHER



**UNIT 5: TECHNOLOGY  
PROJECT - DESIGN  
AND CONSTRUCTION  
OF A MAGNETIC  
LEVITATION TRAIN**





### Designing Process Diagram

The methodology that has been recommended for the designing of your train and the construction of your models can be summarized by the following designing process diagram.

1. In the first phase of the design process, you should formulate the problem in a scientific way, based on the description of the context.
2. You should write down the detailed specifications of the solution that you want to propose.
  - What aspects should you take into account?
  - Which limitations do you foresee and which parameters the proposed solution/model/construction should fulfil?
3. Search information about the topic.
  - Search solutions already proposed. Describe different options.
  - Briefly describe how each of the proposed solutions works.
4. You should draw a sketch or diagram of your initial ideas.
5. Select the idea that you consider more appropriate, based on what is considered that will work better according to the detailed specifications. Analyze the idea in depth, draw more detailed sketches and include information on the dimensions and performance mechanisms of each part.
  - Try to improve gradually the design and make more specific plans.
6. Collect appropriate materials and instruments.
7. Construct models that contribute to the different aspects of the solution.
8. Examine whether the constructed models work as it was foreseen.
9. Evaluate the result with regards to the specifications and repeat previous steps in order to improve gradually the design towards the desired model.



### 5.1.1.Context

Following the overt encouragement of many visitors and also the European Commission, Cyprus is exploring the possibility of creating its own trains and railway network.

The Minister of Transport has requested that we develop a model train and make a presentation of our design. Your train must be economic, must operate in a way that does not require excessive amounts of energy and, at the same time must be fast.

### Your Mission

Your mission is to think of innovative ideas for the design of a new train that will rely on advanced technologies. You will need to make an elaborate design that synthesizes what you have learnt in order to explain how the various mechanisms of the train operate. You will also construct three models, one for each basic function of the train: levitation, propulsion and magnetic shielding (safety measures for the health of consumers). Finally, you will prepare a poster and present it in public, in a way that your audience will be able to understand how each mechanism works.

**Attention:** You can find more information about the project's evaluation criteria in the brochure **Design and Construction of an Electromagnetic Train.**

### 5.1.2. Gathering Information

Examine the problem you are facing and search for relevant information and alternative solutions to the problem. Describe the several potential solutions and the way each of them works.

Hint: How did others solve this problem? (Among the information you will be collecting, you may find it useful to include other research on the same topic, photographs or actual designs of Maglev trains, and information about materials that can be used – name of material, size, its use, endurance, ergonomics, and cost.)



ONCE YOU ARE DONE WITH THIS STAGE, **DISCUSS** WHAT YOU HAVE DONE UP TO THIS POINT WITH YOUR TEACHER. ANOTHER THING YOU SHOULD DO IS TO GO BACK TO YOUR WORKING PLAN AND THINK OVER HOW YOU WISH TO ORGANIZE YOUR WORK. MAKE SURE YOU SHARE THE WORK APPROPRIATELY, SO THAT YOU COMPLETE THE PROJECT IN THE TIME YOU HAVE AVAILABLE.

### 5.1.3. Ideas

FABRICATE and draw three or more ideas that may provide a solution to your problem for each of the three models you have to build. Even the craziest of ideas can underlie a good solution. If you feel the need return to the gathering of information stage for further inspiration!



DISCUSS YOUR IDEAS WITH YOUR TEACHER.

### 5.1.4. Development of ideas – Construction plans

The following text provides you with the steps you must go through in order to build the levitation model by only using permanent magnets. There are detailed instructions for constructing the first out of the three models, so that you get a sense of what you must do in order to build the other two models. It is very important that you read the instructions one time before moving on to the construction of your train.

Once you have read these guidelines, organize the work that has to be done and determine what actions each team member should undertake in order to complete your model.

#### CONSTRUCTION STEPS

##### Step 1: The Wood Track Foundation

Line up four of the wood blocks (15cm) as shown in [Figure 1](#). Place strips of tape on the three breaks between sections to hold all four sections together.

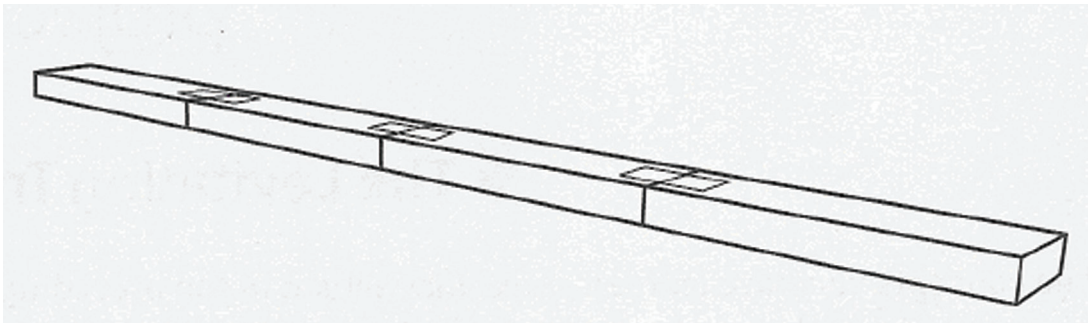


FIGURE 1

Turn the blocks over and mark two guidelines spaced 1.6cm from the edges as shown in [Figure 2](#).

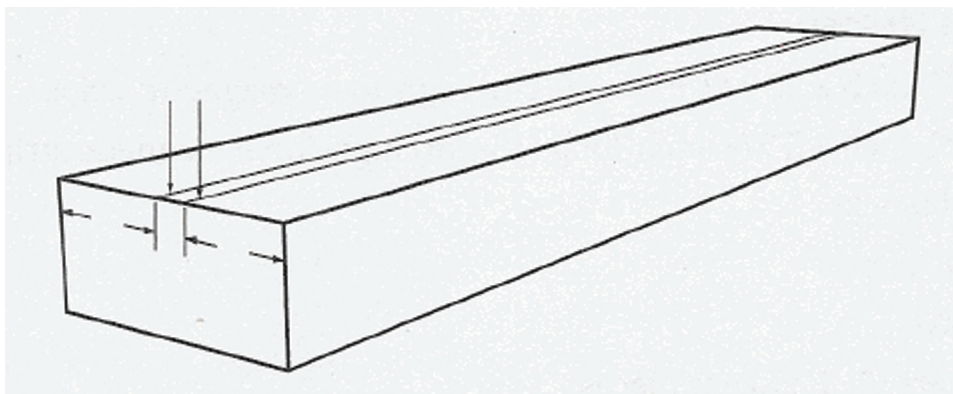


FIGURE 2



These two pencil marks down the centre of the foundation will serve as guidelines for the separation of the plastic sections.

**Step 2: Mounting the Plastic Angles**

Stick the plastic angles to the wood-track foundation, so that the edge of each plastic angle is aligned with the guidelines you have already drawn on the wooden foundation. See **Figures 3 and 4.**

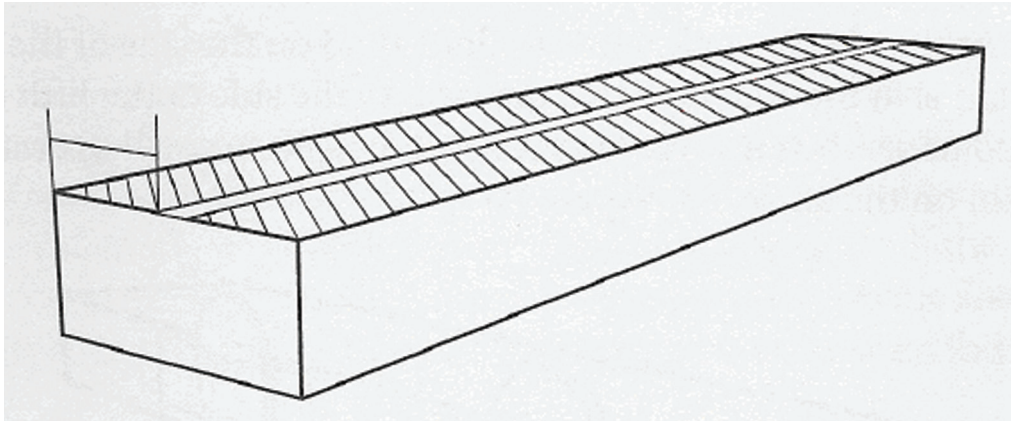


FIGURE 3

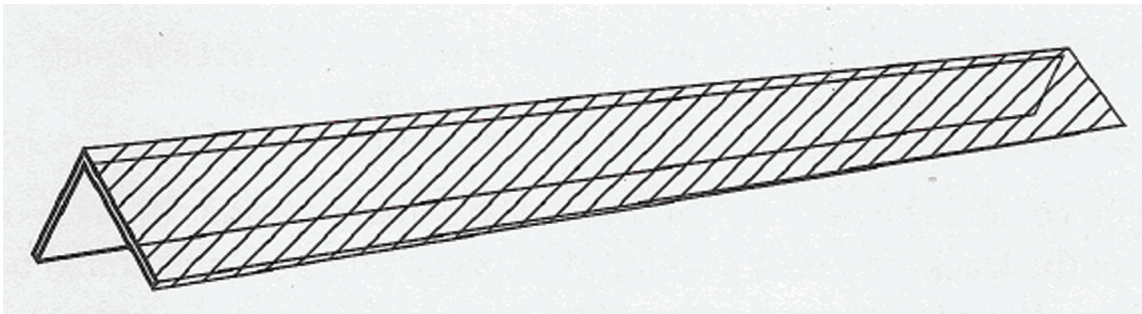


FIGURE 4

Mount the first three plastic angle sections on the right side of the track as shown in **Figure 5.**

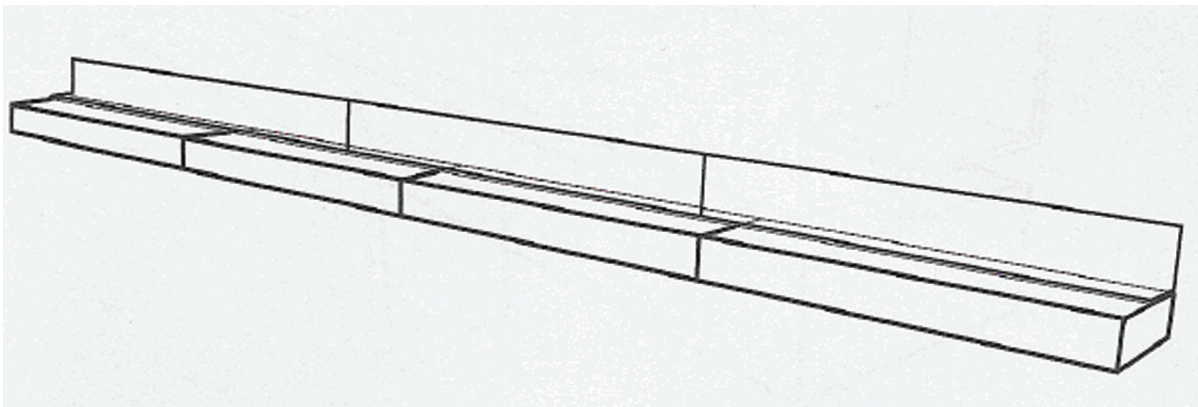


FIGURE 5

One way to reduce friction between your train and the plastic angles is to tape two coins to the side of the fifth block of wood. The coins serve as a guide for the spacing between the train and the plastic angle sections. See [Figure 6](#). Apart from using coins, can you think of other ways to reduce friction?

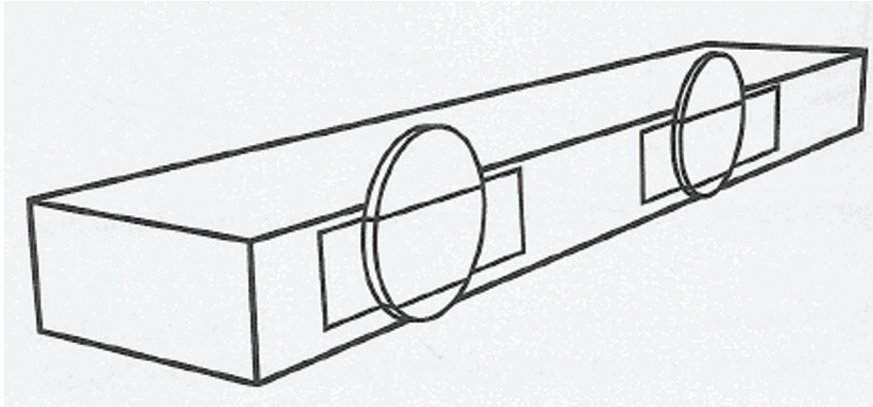


FIGURE 6

Before taping the other three plastic angle sections in place on the left side of the track, as a set, position the spacer (the train and the coins) between the angle sections to ensure a correct fit. [Figure 7](#) shows the proper alignment of the plastic angle sections and the spacer block.

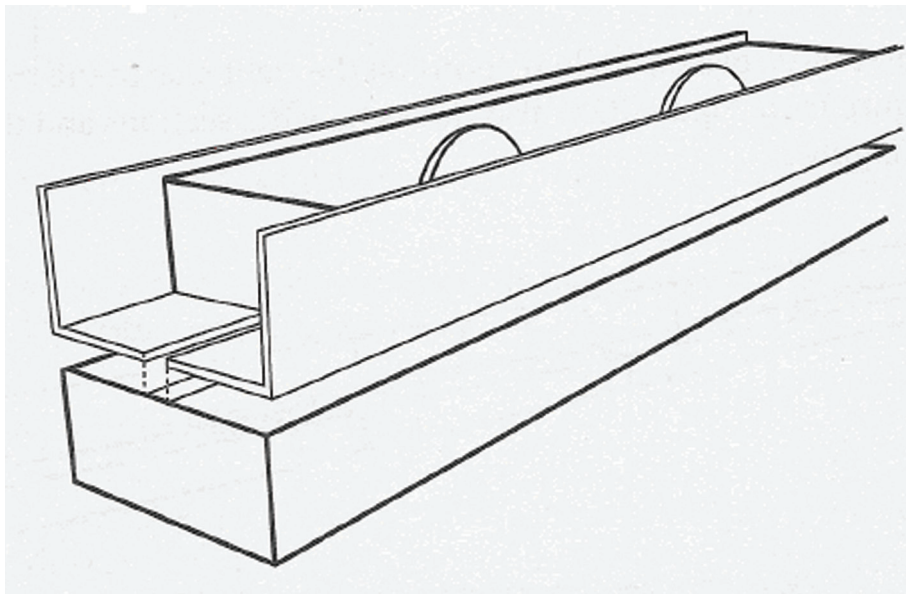


FIGURE 7

Carefully place the remaining three plastic angle sections on the wood foundation. Be especially careful to line up the ends of the angle sections so that there is a smooth transition from one section to another.

The coins help us maintain the gap between the train and the plastic angle sections. If the gap is too great or too narrow, the train will not operate smoothly. If it turns out that the gap is too narrow for the train block you can always lightly sand the sides of the train.

### Step 3: Mounting the High Force Magnetic Strip

Take the high force magnetic strips (60cm) and determine which side is north and which is south pole. Now that you know where the poles are for your magnets, tape the magnetic strips on the plastic angle sections, as shown in [Figure 8](#). Carefully lay the magnetic strips so that their inner side lines up with the inner side of the plastic angle section and the pencil guidelines you marked on the foundation.

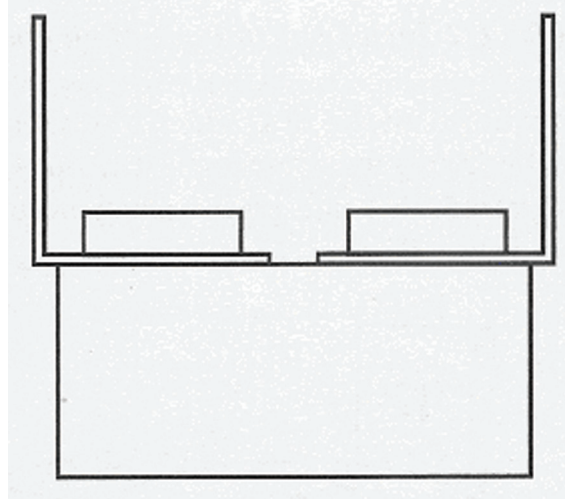


FIGURE 8

### Step 4: Mounting the High Force Magnetic Strip to the Train

To place the high force magnetic strips into position on the train block, you must determine the position of the north and south magnetic poles. Afterwards, follow the same mounting directions as for the track. In this case, however, use the edge of the train block as the guide for placing your magnetic strips. See [Figure 9](#).

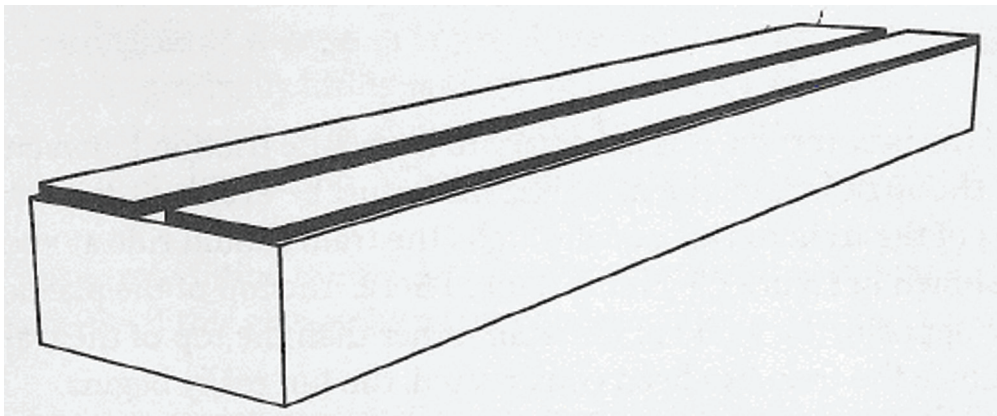


FIGURE 9

### Step 5: Set the Train on the Track

You are now ready to place your train on the track and to evaluate your results – have you accomplished to solve the problem of levitating a train by using permanent magnets.

For best results, the magnetic strips on the bottom of the train should be intentionally spaced wider than the strips on the track. This allows for better magnetic balance of the train. See [Figure 10](#).

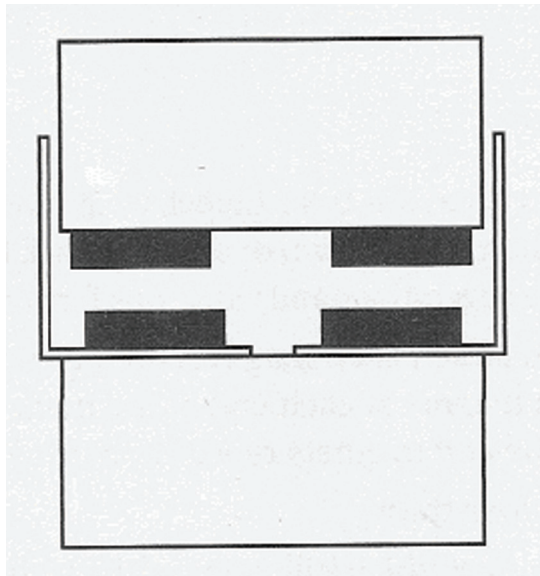


FIGURE 10

### Fine Tuning

To obtain the best results, it is necessary to have little friction between the train and the angles. Also, the magnetic field must be evenly distributed for both sides of the train to ride equally high.

Think of other ways to reduce friction the train and the angles. Record your ideas and go on to making improvements to your model.



DISCUSS YOUR WORK WITH YOUR TEACHER



5.1.5. Construction Process

Write down the stages you went through while you were making your model:

Lined writing area for the construction process.

Write down the materials you used:

Lined writing area for materials used.



DISCUSS YOUR WORK WITH YOUR TEACHER

## 5.1.6. Testing - Evaluation

**Test your train and record the results.**

The model:

Solves our problem  YES  NO  PARTLY

Achieves its objective  YES  NO  PARTLY

It indicates how the magnets operate  YES  NO  PARTLY

**What were the difficulties you encountered?**

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**What could you change about the model and the way it operates?**

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**What would you have changed if you were to rebuild the model?**

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*(Note: Do not forget that the evaluation of the whole project will be conducted according to the evaluation criteria that have already been given.)*



**DISCUSS YOUR WORK WITH YOUR TEACHER**



Using a similar working pattern, advance to the design and construction of the other two models concerning the following train mechanisms:

**Train Propulsion**

Set detailed specifications. Make sure that the mechanism you will choose includes means for acceleration, deceleration, as well as motion at a constant velocity.

**Passenger’s Safety Precautions from Electromagnetic Radiation**

Devote enough time in gathering information so that you will have the appropriate information about the acceptable exposure limits to electromagnetic radiation for a human being. Describe the potential effects on a human’s body by exposing oneself to high levels of electromagnetic radiation and how you aim to prevent such effects. Also, explain the shielding mechanism you have chosen to use for your train. Make some measurements of the magnetic field in order to evaluate your model. The following instructions will help you organise such measurements.



**DISCUSS** YOUR IDEAS AND WORK WITH YOUR TEACHER







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