Developing Ideas

ACTIVITY 3: Magnetic and Static Electric Interactions and Energy

Purpose

In the first module of this course (or in the previous activity) you examined magnetic and static electric phenomena, and may even have developed models to explain them in terms of tiny magnets and electrically charged entities within materials. To complete our understanding of these types of interactions, we need to consider how they can be described using ideas about energy.

The key question for this lesson is:

How can we describe magnetic and static electric interactions in terms of energy?

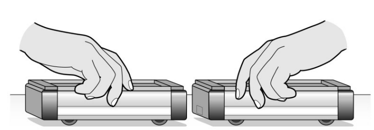
Collecting and Interpreting Evidence

You will need:

- 2 low-friction carts and track (work with another group if necessary)
- 2 disk magnets and tape (or other 'sticky' material)
- Computer with internet access
- Additional masses

Exploration #1: How can we explain 'action-at-a-distance'?

STEP 1. In some earlier activities you examined different examples of contact push/pull interactions. What all of these had in common was that the objects involved had to touch each other in order for an interaction to take place between them. But can objects push or pull on each other without touching?



Place the two carts on the track. Bring them close to each other and make sure there is **NOT** already a magnetic interaction between the two facing ends. If such an interaction exists, try turning both of the carts around. Now use the tape to attach a small magnet to the center of each of the facing ends (one on each cart). Make sure that these magnets are arranged so that they will **repel** each other when the carts are brought close together.

Note: You know that the two carts, on their own, will not interact without touching. However, by attaching the magnets to these carts this will allow you to more easily observe if there is any interaction between the two magnets themselves.

Hold the two magnet-carts so that the magnets are very close together, but not quite touching, and then release both magnet-carts at the **same time**. (If they do not move, try holding them even closer together.)

Now remove one of the magnets and place it back on the end of the cart so that the magnet on the other cart will now **attract** it. Again, hold the two carts close together but not touching and release them. (Again, if they do not move, try holding them even closer together.)

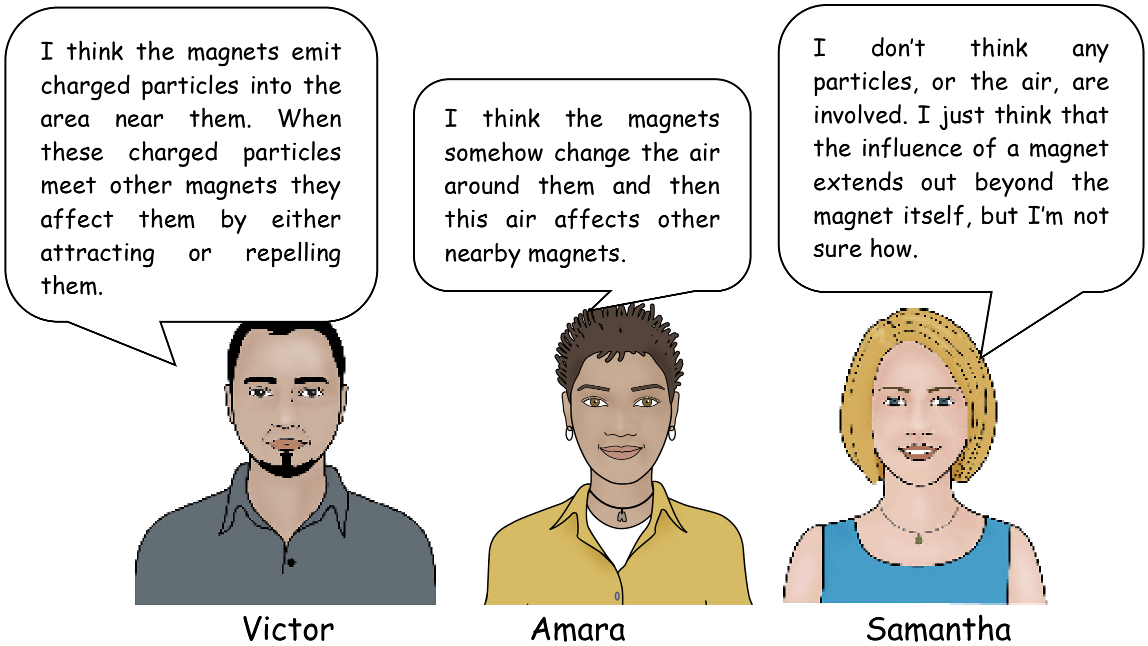
In both cases, was there an interaction between the two magnets? How do you know?

Did the two magnets have to be in contact to interact with each other?

When two magnets either attract or repel each other (or with another magnetic material), we call this a *magnetic interaction*. Since the magnets affected each other without touching, the magnetic interaction is an example of what scientists call an ***'action-at-a-distance'*** type of interaction. That is an interaction in which objects can exert pushes or pulls on each other **without touching**.

How are 'action-at-a-distance' type interactions different from the contact push/pull interactions you have examined in previously?

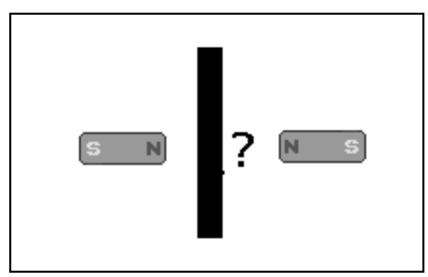
STEP 2. When asked how they think two magnets can interact without touching, three students gave the following suggestions.



Do you agree with Victor, Amara, or Samantha, or do you have another way of thinking about how two magnets can affect each other without touching? Briefly explain your thinking.

Now consider two simple experiments that could be used to support or refute some of these ideas.

First, suppose you placed a barrier between two interacting magnets. In this situation, would you still expect the two magnets to interact with each other?

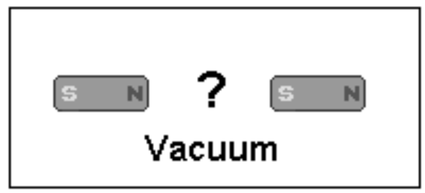


If they did interact, which (if any) of the ideas above be supported or refuted? What about if they did not interact?

To check your thinking, place your two disk magnets in approximately the same location on either side of a large presentation board and determine whether they still interact or not.

Do the two magnets still interact when there is a physical barrier between them? How do you know?

Now suppose you placed two interacting magnets in a container and then pumped the air out. After this is done, do you think the magnets would still interact with each other or not?



If they did interact, would any of the students' ideas on the previous page be supported or refuted? What about if they did not interact?

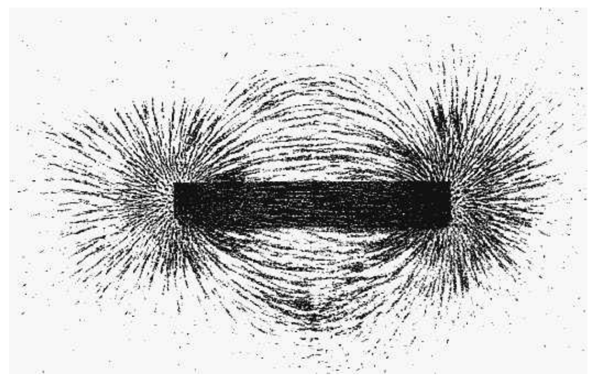
Watch ***UPEF-A3 Movie 1***, in which two magnets will be brought close together in a container in which the air is being pumped out.

Describe what you observe. Do the two magnets still interact when there is little or no air in the container?

Taken together, do the results of these experiments support or refute any of the students' ideas? Explain why.

STEP 4. So how can we account for the 'action-at-a-distance' nature of magnetic interactions? Scientists find the idea of there being an invisible 'field of influence' (sometimes called an *interaction field*) around a magnet to be the most useful in accounting for the observation that magnetic interactions can occur without physical contact. They call it a ***magnetic field*** and consider it to be present around the magnet all the time. However, it is only detectable when it produces an effect on another magnet (or an object made of magnetic material). This effect takes the form of pushes or pulls that act on the other magnet (or ferromagnetic material).

Indeed, you may have seen how the magnetic field around a magnet can be demonstrated by allowing small pieces of a magnetic material (iron filings) to feel its influence. You will also investigate the magnetic field around a magnet further in the homework assignment following this activity.

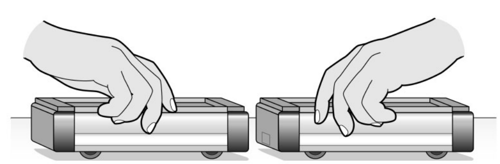


Exploration #2: How can we explain magnetic interactions using ideas about energy?

STEP 1. In Activity 1 you saw two carts joined by a stretched rubber band start to move when released.

In this case the rubber band was the energy giver and it decreased in elastic potential energy as both the carts increased in kinetic energy.

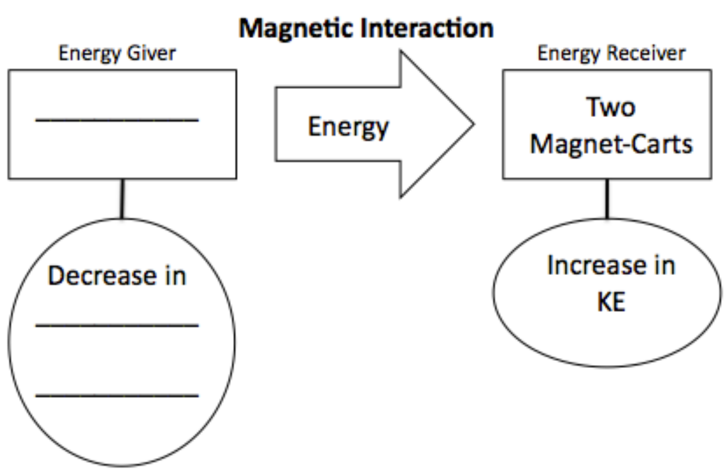
In Part 1 of this lesson you saw that two attracting magnet-carts both started to move when they were held close together (but not touching) and then released.



Do you think there was some object or entity that was an energy source in the interaction that started the attracting magnet carts moving? If so, did some form of energy increase or decrease for this object or entity? Briefly explain your reasoning in terms of your ideas about conservation of energy.

STEP 2. As well as being a useful model for explaining 'action-at-a-distance', scientists also find the idea of a magnetic field useful when thinking about magnetic interactions in terms of energy. As you probably deduced, since there was an increase in the kinetic energy of both magnet-carts in the interactions you examined, by the law of conservation of energy there must have been a decrease in some other form of energy associated with the magnets, which we will call ***magnetic potential energy (MPE)***. Scientists find it useful to think of the magnetic field as being the energy giver during such interactions, with the magnetic potential energy being associated with the magnetic field itself[1]. (For this reason, scientists sometimes also refer to the magnetic field as a particular type of *energy field*.)

Use this idea to complete this G/R diagram for the magnetic interaction that started the attracting magnet-carts moving.



[1] Previously you were introduced to *chemical potential energy* and *elastic potential energy* as forms of energy that are 'stored' in different ways and have the potential to produce changes in other types of energy, such as kinetic energy. In the same way, you can think of *magnetic potential energy* as energy stored in the magnetic fields around magnets that has the potential to produce changes in the kinetic energy of the magnets themselves.

Complete the statement of conservation of energy for this magnetic interaction.

Decrease in ________________ *of* ______________________	=	*Increase in* ________________ *of* ______________________

Compare your diagram and energy statement with at least two other groups and try to resolve any differences.

STEP 3. In Activity 1 you considered what factors affected how much kinetic energy (KE) was gained by each of the two carts connected by a rubber band when they were released. Let us now consider this same question for two attracting magnet-carts.

First re-attach your disk magnets to the two carts so that they attract each other. Hold them a short distance apart and then release them so they move together. (This is the same as you did in Exploration #1.)

What effect did this magnetic interaction have on the KE of each of the magnet-carts? Did they both seem to increase in KE by about the same amount or did one increase by much more than the other? Why do you think this is?

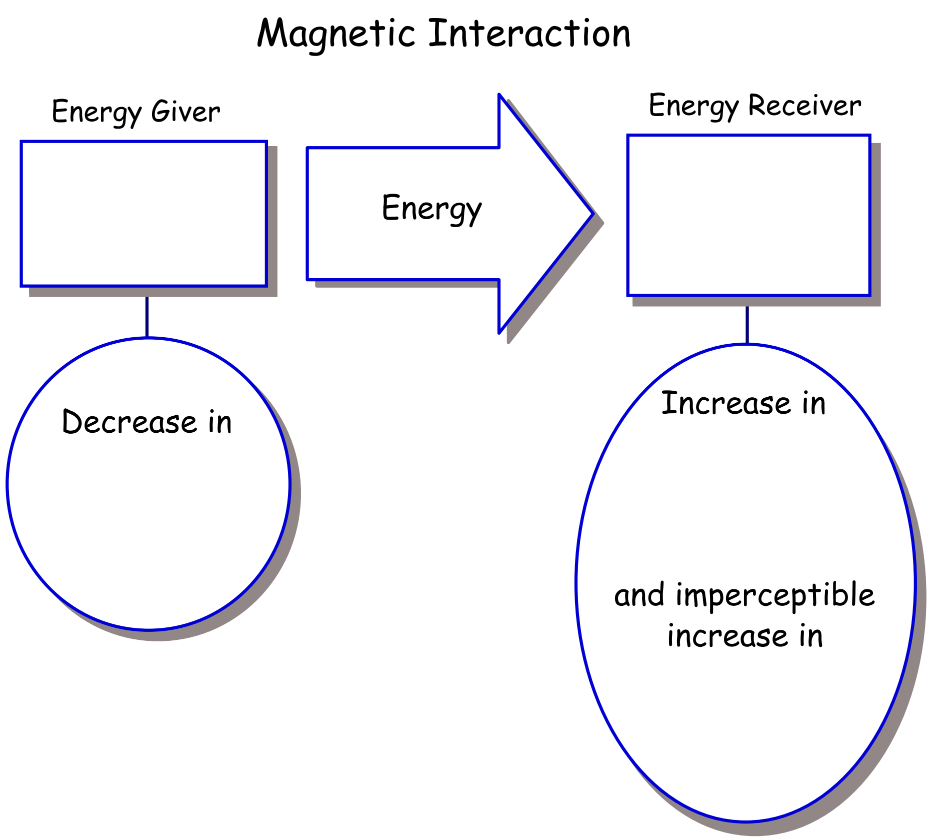
Suppose one of the two attracting magnet-carts had more mass than the other. How would the increases in each of their KE after they were released compare to when they both had the same mass? Explain your reasoning.

To check your thinking, add several extra masses to one of the carts and perform the experiment again.

If the carts do not behave as you predicted, describe what does happen.

In a situation in which the magnet-carts have very different masses, which one do you think would gain the most KE, the one with less mass or the one with more mass?

Complete the G/R energy diagram below for a situation in which the magnet-carts had very different masses.



STEP 4. In Activity 1 you saw that when two carts were connected with a rubber band, the further apart they were held when released, the more KE they gained. This was because the rubber band was stretched further and so had more EPE stored in it that could be transformed into KE. Now consider the same situation for two attracting magnet-carts.

If two attracting magnet carts started further apart, do you think they would gain more KE, less KE, or the same amount of KE, as when they started closer together? Explain your answer in terms of how you think the amount of magnetic potential energy (MPE) in the magnetic fields might (or might not) be different depending on how far apart the attracting magnets are.

Now open ***UPEF-A3 - Movie 2***. In this experiment two very powerful magnets are mounted on carts, one of which is fixed in place (which is effectively the same as having a lot of extra mass added to it). The low-mass magnet cart is released at different distances from the higher mass magnet-cart and its speed is measured using a motion sensor.

As the starting distance between the magnet-carts is increased, does the speed of the lighter cart just before they collide increase or decrease?

Does this mean the carts gained more, or less, KE when they started further apart?

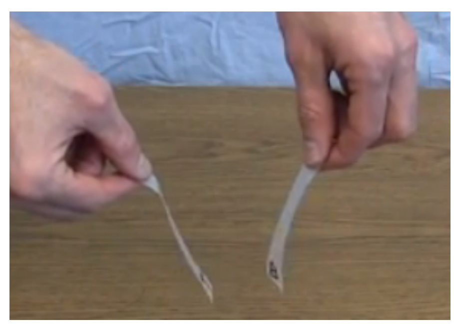
Does this mean there was more, or less, MPE in the magnetic field when the attracting magnets started further apart? Explain how you know in terms of conservation of energy.

(Note that if the magnets were **repelling** each other we would find that the carts would gain more KE the closer together they started. From this we can infer that in a system of repelling magnets there is more MPE the closer they are together. Compare this situation with the elastic potential energy in the spring that was compressed between two carts in the previous lesson.)

Static Electric Interactions and Energy

As you may have seen in a previous activity, objects that are charged with static electricity can also attract and repel each other (and attract uncharged materials) without touching. This means that the *static electric interaction* is another example of an 'action-at-a-distance' interaction that can be accounted for using the idea of an *interaction/energy field*.

Watch ***UPEF-A3 - Movie 3***, in which two strips of sticky tape, labeled B and T, are given a static electric charge by peeling them apart very quickly. They are then held close together and it can be seen that they attract each other and begin to move toward each other. (You should have either seen this movie before, or actually done the experiment yourself.)

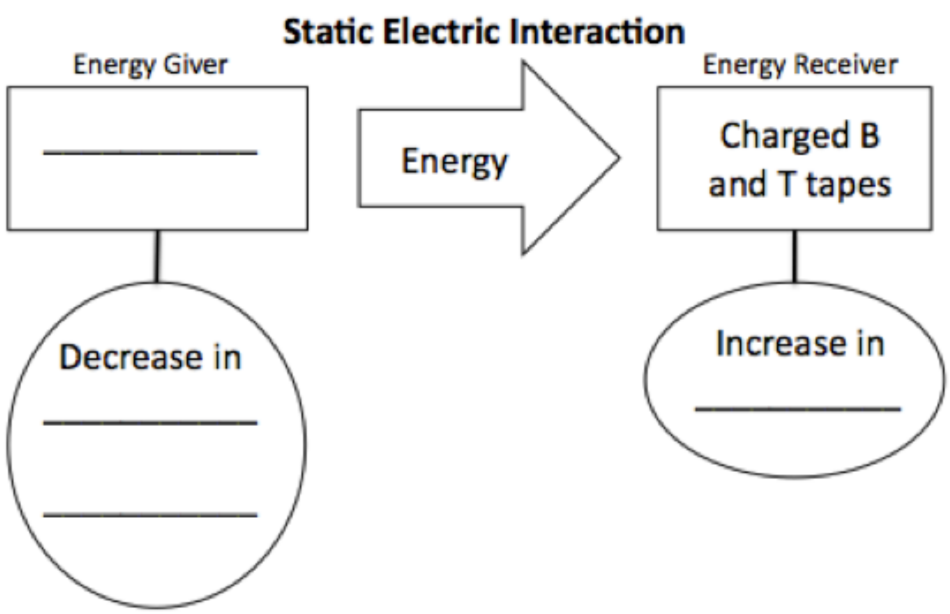


Now consider how you could use ideas about energy to explain why the tapes begin to move in this static electric interaction. Note that, though you should use the general ideas developed for magnetic interactions in this activity to guide you, you will need to 'invent' some different terms because you have seen that static electric interactions have different characteristics to magnetic interactions. (For example, magnets only affect certain types of metal, whereas static electricity affects all materials.)

What are the energy receivers in this interaction and what type of energy increased for them? How do you know?

What do you think is the energy giver in this interaction and what type of energy associated with it decreased? Explain your reasoning.

Complete the G/R energy diagram and statement of conservation of energy below for the static electric interaction shown in the movie, in which a pair of charged B and T tapes were held near to each other and started to move together.



Decrease in ________________ *of* ____________________	=	*Increase in* ________________ *of* ____________________

Compare your diagram and energy statement with at least two other groups and try to resolve any differences.

Chemical Potential Energy revisited

Recall that in the previous unit, when referring to people and dry cell batteries, we said that it was *chemical potential energy* (CPE) that decreased in them when they were the energy giver in an interaction. Now that we have seen how to explain static electric interactions in terms of energy, we can also see that CPE can be regarded as just another name for the potential energy stored in the energy field around the charged particles that form the atoms and molecules of the materials. When a chemical reaction occurs, some of the electrons get rearranged, meaning the distance in between them (and between them and the positively charge protons in the nucleus) changes. Thus the amount of potential energy stored in the associated energy field may increase or decrease depending on the details of this rearrangement. When we say that the chemical potential energy of an object has decreased, this is another way of saying that the electrons in the object have been rearranged such that the potential energy stored in the associated energy field has decreased.

Summarizing Questions

S1. Three elementary students are discussing an engineering project in which they have been asked to design a way for an astronaut to keep his tools handy while he is working outside in space.

Jada: "Let's put small magnets inside his belt and some other small magnets on the tools. Then the tools will stick to the belt."

Patrick: "That won't work because, if the magnets are inside the belt there will be a barrier between the magnets so they won't interact. If we put the magnets on the outside of the belt, it would work because there would be nothing between them."

Katie: "That won't work either because there's no air in space, so the magnets won't stick together"

Which student's thinking do you agree with, if any, and why?

S2. Imagine you were to hold two equal-mass attracting magnet-carts close together, but instead of simply releasing them you give them a quick push away from each other. After your push they would get further apart, **decreasing in speed** as they do so. (Note that this decrease in speed is due to the magnetic attraction between them and would happen ***even in the absence of any frictional effects***.)

a) What is happening to the KE of the magnet-carts as they move further apart (after your push)? How do you know? Does this mean they are the energy giver or energy receiver in this magnetic interaction?

b) What is happening to the MPE in the magnetic field as the magnets move further apart? How do you know? Also justify your answer in terms of conservation of energy. Does this mean the magnetic field is the energy giver or energy receiver in this magnetic interaction?

c) Draw a G/R energy diagram and write a statement of conservation of energy for this situation. (The attracting magnet-carts decreasing in speed as they get further apart.)

S3. Watch ***UPEF-A3 - Movie 4***. It shows an experimenter giving two plastic coffee stirrers a static electric charge by rubbing them both with wool. One charged stirrer is placed on a 'float' and the other is held close to it. Because they both have the same type of charge, they repel each other, and so the floating stirrer begins to move away from the held stirrer.

Draw a G/R energy diagram and write a statement of conservation of energy for the static electric interaction that made the floating stirrer start to move. Briefly explain the reasoning behind your diagram. (Note: The hand is not involved in this static electric interaction. However, a contact push/pull interaction with the hand is what is preventing the other stirrer from moving – do not try to include this in your diagram or statement.)