MAGNETIC RESONANCE IMAGING

Sytil Murphy

When you go to the doctor's office with an injury, what diagnostic tools is the doctor likely to use to determine your injury? If you've broken a bone, the doctor is likely to want an x-ray. On an x-ray image, the bone will show up white while the surrounding tissues will be black, ideal for looking for a broken bone. But, what if the problem is not skeletal? What if you've torn a ligament or herniated a disk in your back? An x-ray will not be able to see these problems. Therefore, the doctor will have to use a different diagnostic tool. There are a couple of medical imaging techniques that could be used; however, most likely, the doctor will order an MRI.

This activity will help you to discover the answers to the following questions: What is an MRI? How does it work? Why can it see soft tissues but not bones?

SECTION 1: MAGNETISM BASICS

MRI is an acronym that stands for Magnetic Resonance Imaging. Since "magnetic" is the first descriptive word in the procedure's name, a natural starting place for this activity is by gaining an understanding of the basics of magnetism.

? What do you know about magnetism? Write down as many properties of magnets as you can.

♦ Now, let's try out some of the things you mentioned above. Take a moment and play with the bar magnets and compasses in front of you.

Most likely you already knew or just discovered that that sometimes they attract each other, and sometimes they repel. That's because every magnet has two poles, a north pole and a south pole. As you've probably heard, "opposites attract." This phrase applies to magnets: a magnetic north pole attracts a magnetic south pole. However, a magnetic north pole repels another magnetic north pole.

♦? You should have a couple compasses in front of you. Compass needles are typically marked such that one side can be distinguished from the other. What happens when you bring two compasses close to one another? Make sure to arrange them in a variety of ways, and describe the orientation of the needles.

 Modern Miracle Medical machines is supported by the National Science Foundation under a Director's Award for Distinguished Teaching Scholars, Grant DUE 04-27645 . Opinions expressed are those of the authors and not necessarily of the Foundation.

? The needle of a compass is a magnet. How do you know this is true from what you did above?

Now, get a bar magnet. The north pole of the bar magnet should be marked.

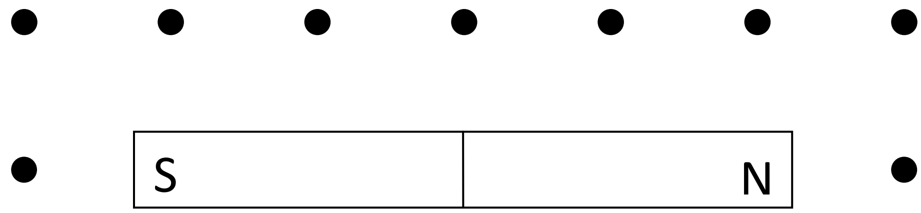
? What happens when you bring the north end of the magnet toward the compass?

? What happens if you bring the south end of the magnet toward the compass?

? What feature (color, symbol, shape, etc…) of the compass needle distinguishes the north pole from the south pole? How do you know?

We can think about the bar magnet as having a *magnetic field*. In general, a compass aligns with the magnetic field – that is, the field and the compass point in the same direction.

♦ Set up a bar magnet as shown below, and place a single compass at each point, one at a time. Then, on the drawing below, draw the direction of the magnetic field at the points indicated. Mark the north pole of the compass with an arrow head.



? What does this activity show about the direction of magnetic field lines?

In the absence of any other magnets, a compass will point along the magnetic field of the Earth. Let's take a moment and investigate this.

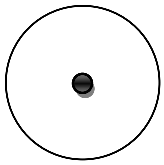
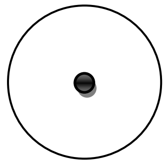
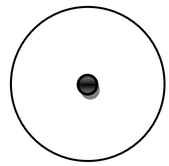
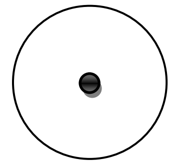
♦ Identify which direction is North in the room you're in. Then, hold a compass in your hand, away from any other magnetic field, ignoring for a moment what the compass needle is doing. Rotate the compass until the "N" on compass dial aligns with the North direction of your room.

? Now, look at the compass needle. Which end of the compass points in the North direction?

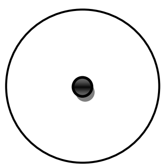
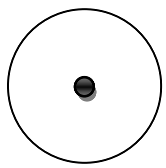
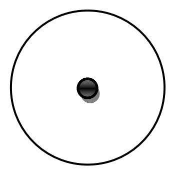
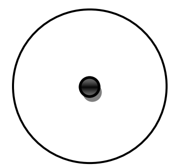
? Given that opposite magnetic poles attract and like magnetic poles repel, what type of magnetic pole must be located in the North? How do you know?

Now, place a compass on a table away from all other magnets.

♦ Starting about 1 m away, slowly bring the north end of a bar magnet in from the East (or West) towards the compass. In the table below, sketch the orientation of the compass, relative to north (the direction it initially pointed) when the bar magnet is the following distances away from the center of the compass.

1m away	50cm away	25cm away	10cm away
			

♦ Do the same thing, but this time by bringing the south end toward the compass.

1m away	50cm away	25cm away	10cm away
			

? What does this activity indicate about the strength of the magnetic field?

Now, let's switch to the computer. Open the visualization called "PhET Magnet and Compass". In this visualization, the direction of the magnetic field around a bar magnet is indicated for many points in space by small compass needles. The red end of these needles is the magnetic north pole.

♦ Take a moment and play in the visualization.

♦? How does the direction of the compass needles in the visualization compare to the directions that you drew above?

? How does the "Flip Polarity" button (located on the right hand side of the screen) affect what you see in the visualization?

? What does the brightness of the needles indicate about the strength of the magnetic field?

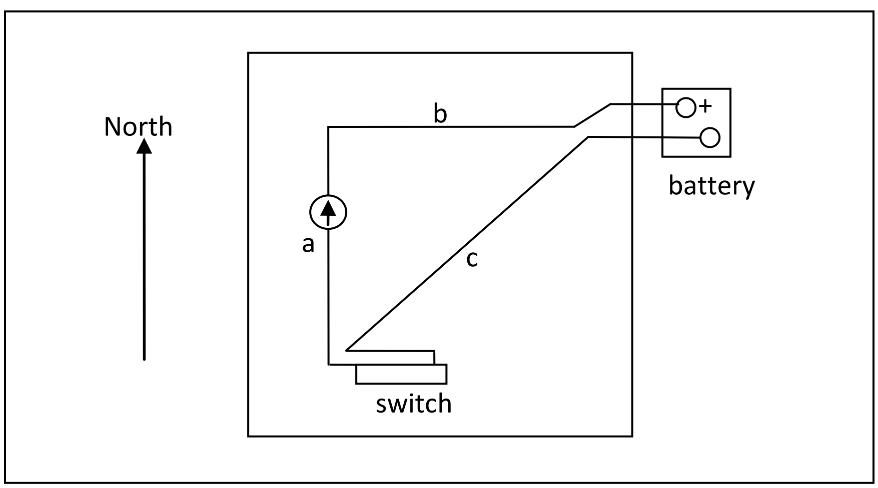
♦? Now check the "Show planet Earth" option. (Hint: if the world is upside-down, flip the polarity!) The Earth can be viewed as a giant bar magnet with its magnetic poles near – but not exactly at – the location of the geographical poles. From what you see with the visualization and the compasses and bar magnets, determine near which geographic pole the magnetic south pole of the Earth is located. How do you know?

Thus far, you've observed that compass needles align with magnetic fields and that the magnetic field decreases in strength as you move away from the source of the field. To this point, the source of the magnetic field has been something you might expect, either the Earth or a magnet you can hold in your hand. However, these are not the only possible sources of magnetic fields.

SECTION 2: ELECTROMAGNETISM

For this part, please remove all other magnets (with the exception of the compasses) from your work area. As you saw earlier, they need to be about 1 m away in order to not affect our compass.

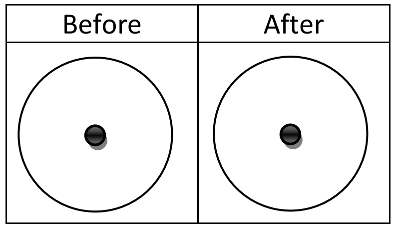
♦ As shown in Figure 2.1, begin by aligning the "apparatus" such that the wire marked "a" is parallel to a compass needle. This is most easily accomplished by placing a compass over the wire "a" and then rotating the entire apparatus until the compass needle points along the wire.



2.1 "Apparatus" set up

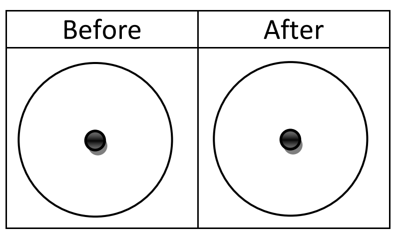
♦? Place a compass over the wire "a" as shown in Figure 2.1. Tap the switch. What do you observe?

? Now, hold the switch down until the compass needle stops oscillating. Sketch the compass before and after you hold down the switch:

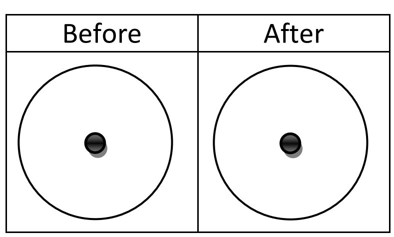


? Based on what you learned in the previous section, why do you think this happens?

♦? Now place the compass **directly** under wire "a." <u>Do not tap the switch.</u> Predict how the compass will behave when you tap the switch. Also, sketch your predictions for what will happen to the compass when you hold the switch down.



♦? Now tap the switch, and then hold it down until the compass needle stops oscillating. Sketch what happens. Does your observation of the compass's behavior agree with your prediction? Why or why not?



? In the table below, sketch the direction of the magnetic field above and below wire “a” when the switch is tapped. Remember, the direction of the compass aligns with the direction of the magnetic field.

Compass Location	**Magnetic field direction:**
Above Wire “a”	
Below Wire “a”	

Next, let’s use two compasses.

♦? Place the compasses at different heights above wire “a”. For example, place one of the compasses directly above the wire and the other about 3 cm above the wire. <u>Do not tap the switch.</u> Do you expect the two compasses to deflect (change direction) the same amount? Why?

♦? Now tap and hold the switch. Does your observation agree with your prediction? If not, what happened and why?

Here are some properties you observed of the magnetic field generated by a single wire:

- A compass placed above the wire deflects in the opposite direction of a compass placed below the wire because the magnetic field forms a circle around the wire.
- The magnetic field decreases as the distance from the wire increases. This relationship caused the compass further from the wire to deflect less than the compass directly above the wire.

One of the great discoveries of Physics is the electromagnet. An electromagnet forms whenever an electric current flows through a wire because, as you observed above, a magnetic field forms a circle around a wire. You interact with electromagnets in your everyday life. They are used to make the small motors that are used in kitchen appliances and also to create the large magnets used to unload cargo boxes from freight ships.

<u>Section 3: MRI magnets</u>

The magnets in an MRI machine are electromagnets formed from loops of wire. While there are several electromagnets within a typical MRI machine, the primary magnet is an electromagnet formed by multiple loops of superconducting wire cooled by liquid helium to very cold temperatures. Figure 3.1 shows a picture of a typical MRI machine. It consists of a table that slides back into a circular opening or tunnel in a larger structure. (That opening is approximately 60 cm (2 ft) in diameter.) The "tunnel" seen in traditional MRI machines is at the center of the main electromagnet. There are several reasons why this type of magnet is used:

- Within the wire loops, the magnetic field points along the axis of the loops. In other words, the magnetic field points parallel to the direction of motion of the MRI table.
- The strength of the magnetic field within the loops is uniform and can be increased by either increasing the current in the wire or the number of loops.
- Superconducting wire has very low internal resistance. (Its resistance is as close to zero as can be achieved with current technologies. It needs cooled in order for the wire to show the characteristics of a superconductor.) Due to its low resistance, a superconducting wire can support a large current.

Typically, the strength of the magnetic field within an MRI machine is a couple of Tesla (T). For reference, the Earth's magnetic field is between 30 – 60 μT (where 1 μT is 10^{-6} T). The magnetic field of an MRI machine is quite large and requires a room with special shielding to prevent it from interfering with other nearby electronics. In addition, special care needs to be taken to prevent any magnetic materials from entering the room. Credit cards can be destroyed by the magnetic fields. Of more concern is that any objects made of magnetic materials (jewelry, carts, coins, etc…) will be attracted by the large magnetic field and could either injure people in the room or damage the MRI machine. The US FDA limits the maximum size of the magnetic field that can be used during an MRI to 8 T.

3.1 Typical MRI machine, from www.teslasociety.com/mri_digest.htm

<u>SECTION 4: RESONANCE</u>

To this point, the "M" in MRI has been the focus of the discussion. It is now time to shift gears and discuss the "R." As you might recall from Section 1, the "R" in MRI stands for resonance. Whether you realize it or not, you see and hear resonant effects everyday of your life. Your voice is a resonant effect and musical instruments would not function without it.

A simple system that displays the characteristics of resonance is a pendulum. Build a pendulum by tying an object to a piece of string. Pay attention to the pendulum's period – that is the amount of time the pendulum takes to complete one oscillation. In other words, the time it takes to return to the starting position.

? Write down as many characteristics of pendulum motion as you can.

? Predict how a pendulum’s period will depend on the object’s mass.

♦? Check your prediction by using a couple of different masses for the same string length, and a stopwatch to measure the period.

Object (mass)	Period

? Does a pendulum’s period depend on the object’s mass?

? Next, predict how a pendulum’s period depends on the length of the string.

♦? To determine this, choose one mass, and then vary the length of the string and use a stop watch to measure the period. (String lengths should be chosen that are at least 30 cm apart.)

String Length	Period

? Does a pendulum’s period depend on the length of the string?

As you saw above, a pendulum's period is dependent on length, but not on mass. A pendulum's period is also dependent upon one other factor – gravity. This is very hard to see here on Earth because the acceleration due to gravity near the surface is constant. However, if we could take a pendulum to the moon where the acceleration due to gravity is smaller than it is on Earth, we would find that the period of the pendulum increases and if we could take it to Jupiter, where the acceleration due to gravity is larger, the period would decrease.

One other note: though we didn't test it here, the period of the pendulum's motion does not depend on the *amplitude*. In other words, no matter how far you initially pull the pendulum back, it will always have the same period.

Another way to describe oscillating motion is with frequency. The frequency of oscillation is the inverse of the period, which can be written as

$$Frequency = \frac{1}{Period}$$

Every resonant system has a frequency at which it wants to oscillate. This special frequency is called the *natural frequency*.

? What does the natural frequency of a pendulum depend on and why?

While playing with the "apparatus" in Section 2, you might have noticed that after you tapped the switch, the compass needle oscillated before returning to rest. This oscillation occurs at the natural frequency of the compass needle. The next part of this activity is going to help us decide what determines the compass needle's natural frequency.

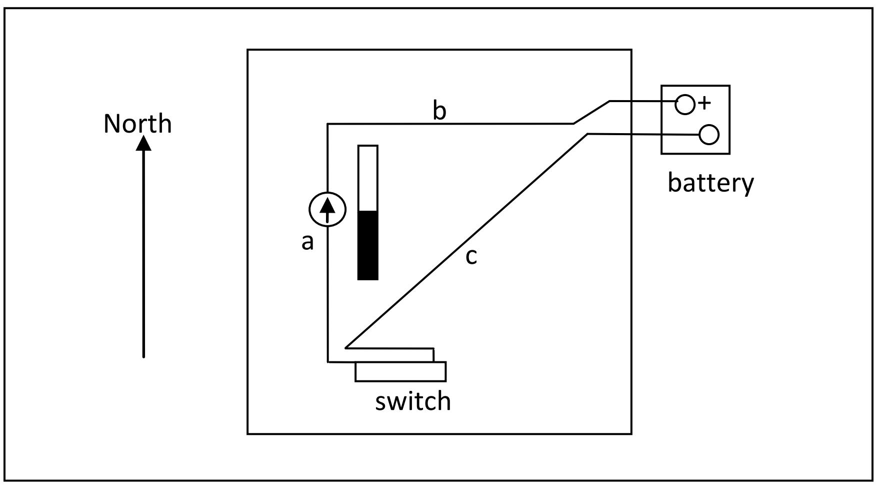
♦ Begin by aligning the "apparatus" as shown in Figure 2.1. Place a compass above wire "a". Tap and hold the switch until the compass stops oscillating. Release the switch and watch the compass oscillate. This oscillation frequency will be the standard which you compare others to in this section, or in other words, this is the "standard compass".

? To the best of your abilities, measure the period and natural frequency of the "standard compass."

♦? Now place a second, similar, compass about 2-3 cm above wire "a" but far enough away from the first compass so that they don't interact. Then, hold the switch down till both compasses stop oscillating. Release the switch. Compare, by eye, the natural frequency of the compass that is 2-3 cm above wire "a" with the natural frequency of the "standard compass". (Keep in mind that two objects can have different amplitudes but the same frequency.)

♦? Now let's compare two different compasses. Place the standard compass and a different compass directly over wire "a". Hold the switch down until both compasses stop oscillating, and then let go. How do the natural frequencies of these compasses compare?

As you saw above, the natural frequencies of identical compass needles are the same, regardless of their height above the wire. However, the natural frequency changed when we used a different compass. Now let's see what happens when a bar magnet is present.



4.2 "Apparatus" set up. The compass is the circle with the arrow in it above wire "a" and a bar magnet is placed parallel to the wire, centered on the compass. The bar magnet's South pole is shown in white and the North pole in black.

♦? Remove the second compass from the "apparatus" so that you are now working only with the standard compass. Place a bar magnet on the "apparatus" parallel to wire "a" as shown in Figure 4.1. How does the natural frequency of the compass depend on the position of the bar magnet relative to wire "a"?

? In the above setup, the bar magnet served as an external magnetic field. What was the source of the external magnetic field before the bar magnet was added? (Hint: Think about what did and did not change when you added the bar magnet to the apparatus.)

? Why do you think the natural frequency of a compass when the bar magnet is present is different from the natural frequency of the "standard compass"?

So far in our discussion, we've discovered that resonate systems have a frequency, their natural frequency, that they want to oscillate at. This natural frequency is dependent on some things but not on others. For example, the frequency of the pendulum was dependent on the pendulum's length but not on the mass. The compass's natural frequency was dependent on the type of compass and strength of the external field, but not on the distance from the wire.

There is one more aspect of resonant systems that we need to discuss. To do so, let's return to the pendulum.

? Let's think about the mechanism that creates the oscillation – with the compasses, it was holding down the switch. What is the equivalent action when working with the pendulum?

♦? Set the pendulum swinging again. What can you do to increase the amplitude of the pendulum's oscillation once it has been set into motion? (If you are confused, you might consider what you did as a child when playing on a swing set. In that situation, how did you increase the amplitude of the swing's motion?)

? How does the frequency of your action compare to the pendulum's natural frequency? (In other words, how often do you have to "kick" the swing?)

A *resonant system* is one that displays periodic motion and where the amplitude can be increased by applying a force (a 'kick') at a frequency equal to the natural frequency of the motion. A pendulum is a common example of a resonant system.

Now, let's see if we can get a compass to resonate.

? Make a prediction: what would you have to do to make a compass sitting above wire "a" resonate? When in resonance, the compass needle will continuously spin.

♦? Try to make it work. What is the frequency of your action?

? Is the frequency of your action the same as the natural frequency of the "standard compass" that you determined above? If not, try performing your action at that frequency. What happens?

In this section, you learned about resonant systems. All resonant systems have a natural frequency they want to oscillate at and, when kicked, the amplitude of the motion increases. In the case of a compass, the natural frequency is determined by the strength of the magnet that forms the compass needle and the strength of an external magnetic field provided either by the Earth or a bar magnet. The natural frequency does not depend on the field associated with the wire – this field just provides the kick.

Now, you may be wondering what compasses and magnetic fields have to do with MRI. In the next section, you will learn exactly how they relate.

Section 5: NMR

NMR, or Nuclear Magnetic Resonance, is the basis for MRI. At this point, you have learned enough from playing with magnetic fields and compasses in order to understand the basics of NMR.

While not the only element in your body that can work for NMR, hydrogen is the most commonly used because of its prevalence. You've probably heard that your body is mostly water. The actual amount of water in your body depends on your age, gender, and how much body fat you have (because lean muscle has more water in it than fatty tissues). However, the percentage of water in your body is typically above 50%. Remember, water is composed of one oxygen atom and two hydrogen atoms.

Open the visualization called "PhET Simplified MRI". Begin by looking at the tab marked "Simplified NMR." In this visualization, the atoms within your body are represented by red, blue, and white three-dimensional arrows. The direction of the external magnetic field is indicated by block arrow outlines and points upward.

There are several things that you can control – the power in the radiowave source (bottom left), the frequency of the radiowave source (bottom middle), the type of atom (bottom right), and the strength of the main magnet (center right). For reference, in this visualization, resonance looks a bit different than it did with the compasses. In the simulation, atoms in-resonance will flip upside down and emit light energy (photons) to the side.

♦ Take a moment and play within the visualization.

? How do the block arrows in the NMR visualization change in order to depict magnetic fields of different strengths?

There are three things important to the “apparatus” used in Sections 2 and 4 are listed below that correspond to features of the NMR visualization. Let’s think about those now:

? What does the compass in the last section correspond to in the NMR visualization? How do you know?

? What does the external magnetic field due to the bar magnet (or Earth) correspond to in the NMR visualization? How do you know?

? Finally, what does the magnetic field due to the wire and tapping switch correspond to in the NMR visualization? How do you know?

The natural frequency of oscillation for an atom like hydrogen in a magnetic field is called the *Larmor frequency*. This frequency is dependent on the same types of factors as the natural frequency of the compasses:

- The Larmor frequency of an atom in a magnetic field is dependent on the type of atom. This is equivalent to the natural frequency of the compasses above being dependent on the type of compass.
- As with the compasses above, an atom's Larmor frequency is dependent on the external magnetic field strength.

In order to calculate the Larmor frequency for a particular atom, it is necessary to know two quantities: the element's gyromagnetic ratio and the strength of the external magnetic field. The gyromagnetic ratio is the ratio between the Larmor frequency and the magnetic field and is a well known, measured quantity, for each atom. Here is a partial list:

Atom	Gyromagnetic Ratio (MHz/T)
Carbon-13	10.7
Chlorine	4.2
Helium	32.4
Hydrogen	42.5
Lithium	6.3
Nitrogen	3.1
Oxygen	5.8
Sodium	11.3
Sulfur	3.3
Xenon	11.8

(Recall that MHz means "megahertz" and is equivalent to 10^6 Hz.) Given the gyromagnetic ratio of a particular element, the Larmor frequency is calculated by:

$$Larmor\ frequency = gyromagnetic\ ratio * external\ magnetic\ field$$

? For practice, calculate the Larmor frequency for hydrogen given a 1 T external magnetic field.

♦? When you were playing with the visualization, could you make the atoms resonate? If so, at what frequency and main magnet strength did the resonance occur. Does this agree with the formula for the Larmor frequency given above? If not, consider what you know about the Larmor frequency for Hydrogen at 1 T and try again.

? Describe the orientation of the red, blue, and white three-dimensional atoms as compared to the direction of the magnetic field when resonating.

? Describe the orientation of the red, blue, and white three-dimensional atoms as compared to the direction of the magnetic field when not resonating.

? Does the resonant frequency depend on the power of the radiowave source?

With the "apparatus", you saw that the resonant frequency did not depend on the distance the compass was from the wire – the wire only provided the kick to the compass. In the NMR visualization, the resonant frequency of the atoms also does not depend on the strength of the kick. In other words, if the frequency of the kick (the frequency of the radiowave source) and the strength of the main magnet are adjusted properly, then the atoms will resonate whether the power of the radiowave source is 10% or 100%.

♦? What happens to the resonant frequency of hydrogen when you increase the strength of the main magnet? To test this, first double the strength of the main magnet – now what do you have to do to keep the atom in resonance?

? With the power at 100% and the frequency at 42.5 MHz, over what range in main magnet strengths will hydrogen atoms resonate?

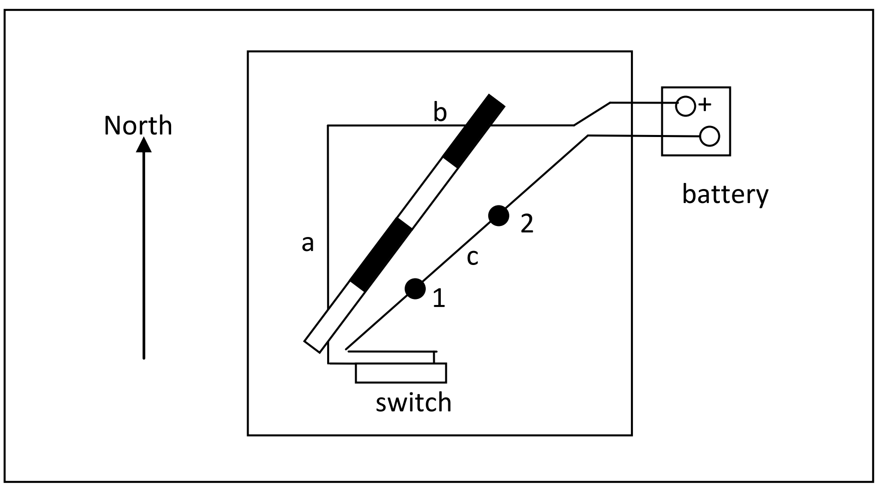
? With the power at 100% and the main magnet strength at 1 T, over what range in frequency will hydrogen atoms resonate?

Even though the equation for the Larmor frequency would have you believe that the atoms will only resonate at a single combination of frequency and main magnet strength, in reality there is a range over which resonance will occur. In the visualization, for a given frequency, the atoms will resonate at the main magnet strength determined by the Larmor frequency plus or minus roughly 0.7 T. For example, if the frequency is set at 85 MHz, then the equation for the Larmor frequency tells you that Hydrogen will resonate at a main magnet strength equal to 2 T. However, resonance will actually occur from 1.92 T to 1.06 T. If, on the other hand, you require the main magnet strength to be fixed, then the atoms will resonate at the Larmor frequency plus or minus roughly 3 MHz. For example, if the main magnet strength is fixed at 2 T, then the atoms will range at any frequency between 82 MHz and 88 MHz.

? Are there any adjustments you can make such that only the atoms at the top of the head resonate?

While NMR forms the basis of MRI, it is not the complete story. An MRI requires that small areas within the body be imaged. Thus, we need to talk about the "I" in MRI.

♦? On the apparatus, place two identical compasses along wire "c". Distribute them evenly along the length of the wire, as shown by the black dots in Figure 5.1 below. Can you cause only one compass to resonate at a time? Why or why not?



Error! No text of specified style in document.**1 Apparatus set-up for section**

Now take two bar magnets and place them on the apparatus as shown in Figure 5.1. The ends shaded black are the north poles of the bar magnets. The locations of the compasses are indicated by the numbered black dots.

♦? Which compass has the highest resonant frequency? The lowest?

? Why do the resonant frequencies for each compass differ?

Recall that with NMR, we could not selectively resonate atoms in a given area of the head. However, you just saw above that when the bar magnets were added, each compass had a different resonant frequency!

? How can we combine these ideas to create conditions where only a small group of atoms will resonate?

In NMR, atoms resonate at a frequency determined by the type of atom and the strength of the external magnetic field. Another field, a radio wave source, is used to kick the atoms. But there is no way in NMR to cause only a selected area of the body to resonate – a characteristic needed for MRI. From what you've learned in the last two sections, you might be able to guess how an NMR system could be modified to allow this to happen. Either way, the next section will guide you to the answer.

SECTION 6: MRI

Now, open the visualization called "PhET Simplified MRI", and click on the tab entitled "Simplified MRI.". As before, the atoms are shown as three-dimensional red, blue, and white arrows. The magnetic field due to all of the magnets within the MRI machine is shown by block arrows. On the right, there are a couple of new controls which allow you to change the field due to "gradient" magnets. These magnets allow you to adjust the strength of the magnetic field both vertically and horizontally.

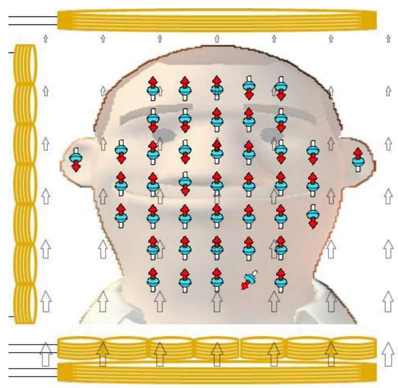
♦ Take a moment and play within the visualization.

? How do the block arrows change to depict a field that is not uniform strength?

? When you turn on the horizontal gradient field, where (in relation to the outline of the head) does the magnetic field strength remain equal to the main magnet strength? Where does magnetic field decrease in strength? Where does it get stronger?

? When you turn on the vertical gradient field, where (in relation to the outline of the head) does the magnetic field strength remain equal to the main magnet strength? Where does magnetic field decrease in strength? Where does it get stronger?

By observing the change in the block arrows that indicate the external magnetic field strength, we can see that the magnetic field at the center of the head does not change when the gradient magnetic fields are adjusted. However, adjusting the vertical gradient makes the total field strength at the bottom of the head larger and the total field strength at the top of the head smaller than they were with the main magnet alone. Specifically, as shown in Figure 6.1, if the main magnet strength is 2 T and the vertical gradient field is set at 0.05 T, then the magnetic field would be:



6.1 Example of gradient magnetic field

? Using all the above information about magnetic fields, predict how you could make only the atoms at the top of the head resonate.

Earlier you learned that there is a range of magnetic field strengths over which the atoms will resonate for a given frequency. As a reminder, if the frequency is set to 42.5 MHz, then the atoms will resonate when the strength of the main magnetic is set anywhere between 39.5 T and 45.5 T.

♦? Set the frequency of the radio wave source to 42.5 MHz, the main magnet to 1.2 T and the power of the radiowave source to 100%. What can be adjusted so that only the atoms at the top of the head resonate?

As you may have just seen, when you increased the strength of the main magnet and added a vertical gradient magnetic field, only the atoms at the top of the head resonated. This happened because the main magnetic field (1.2T) was decreased by the gradient magnetic field at the top of the head. Therefore, at the top of the head, the overall (or total) magnetic field was in the range of values that you determined earlier from the NMR visualization, causing the atoms to resonate.

♦ Now unclick "Show atomic nuclei" and then click the "Add Tumor" button on the lower right.

The part of the head with the tumor will behave differently than the parts without the tumor. But, because you can no longer see the atomic nuclei, you, like a real doctor, can only use the emission from the MRI process to determine where in the head the tumor is.

♦Describe the process you will use to try to find the tumor.

♦? Did you find the tumor? If so, in which quadrant of the head is the tumor located?

If not, try setting the frequency and adjusting first the main magnet and the vertical gradient field, keeping the horizontal gradient field at zero.   This allows you to scan the head from top to bottom. Then, repeat the process scanning from side-to-side by adjusting the main magnet and the horizontal gradient field with the vertical gradient field at zero.

♦? After you have made your best attempt to find the tumor, reclick "Show atomic nuclei." Were you correct?

? What about the emission from the area containing the tumor allowed you to determine the tumor's location?

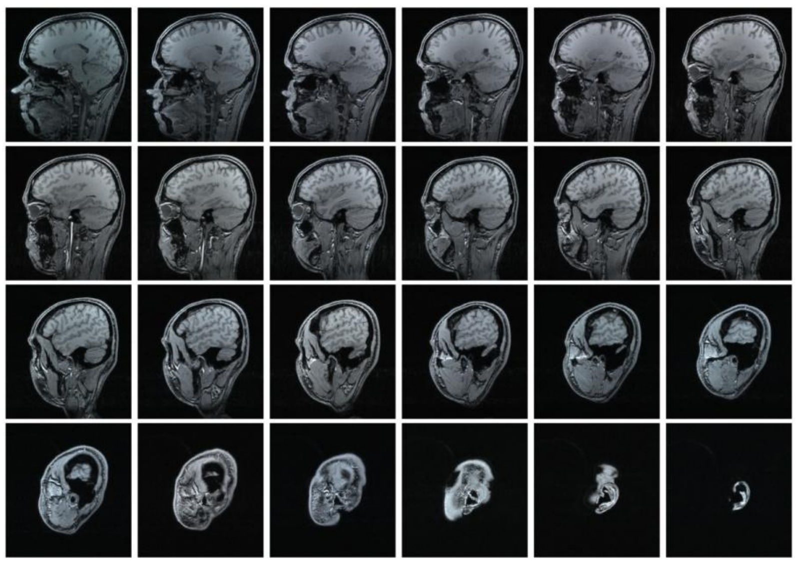
? In your own words, explain how a doctor can determine the location of a tumor within a person's body using magnetic resonance imaging techniques.

SECTION 7: SUMMARY

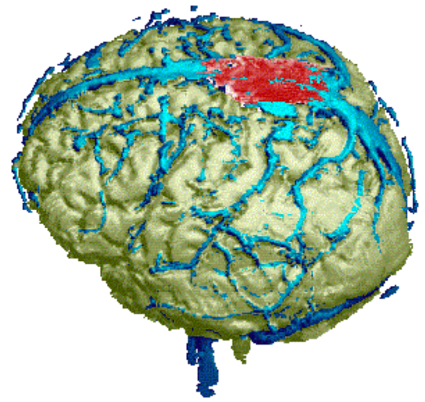
The first three sections of this activity focused on the “M” in MRI. In those sections, you learned about electromagnetism and its applications to MRI technology. The last three sections dealt with the “R” and “I” in MRI. Using the magnetic field due to a wire and a compass, you explored resonance and then applied that knowledge to a visualization where you caused “atoms” to resonate in a magnetic fields, and showed how particular compasses or areas within an object can resonate while others do not.

The simplest type of MRI image is made by adjusting the magnets, main and gradient, and then measuring the emission, much as you did above when finding the tumor. A complex computer system detects the signal from the resonant atoms. Different tissues within the body can be distinguished by the characteristics of the received signal allowing, for example, a tumor to be seen within the healthy tissue surrounding it. To help with this, contrast agents are sometimes injected into the area to be imaged.

Below are some MRI images to show you some of the capabilities of this imaging technique.



7.1 A series of images showing MRI slices of the head, from http://commons.wikimedia.org/wiki/File:MRI.png



7.2 A 3-D MRI of the brain, from
http://www.scienceofspectroscopy.info/edit/index.php?title=Magnetic_Resonance_Imaging