Introduction

NASA's Space Environments and Effects (SEE) Program has developed a "toolkit" that contains educational materials applicable to a high school level course on electricity and magnetism with a particular emphasis in the areas of electromagnetic interference (EMI) and shielding. This material contains laboratory experiments and mathematical calculations to test students on the concepts introduced in the exercises. A vocabulary list is included to give the teacher and student a quick reference to new terms. Hopefully, most experiments will not challenge the teacher by requiring hard-to-find materials, but rather will rely on everyday or household items with just a few exceptions. It is our hope that the elements of this toolkit may be woven into existing curricula and lesson plans on the subject of electricity and magnetism. For more information on EMI, please visit our website at http://see.msfc.nasa.gov.

Introduction to Experiments 1–3

Although the electromagnetic spectrum was not fully described until the latter half of the nineteenth century, it is difficult to imagine modern life without the myriad of technologies which exploit it. To mention radio, television, telephones, radar, and navigation misses the point. Thanks to satellites, we now have instantaneous audio, video, and data communications with any point on the globe, and using a handheld receiver, we can tell exactly where we are at any point on or above Earth. In the mid-nineties, we were still in radio communication with *Pioneer 10*, the first spacecraft to leave our Solar System.

Modern telecommunications and navigation technologies rest on the theoretical work of James Clerk Maxwell (1831–1879). Maxwell integrated the experimental findings of Faraday, Ampere, and others into a comprehensive theory of electromagnetics based on four simple equations (Maxwell's Laws). While today's telecommunication and navigation traffic occurs at millions or billions of cycles per second, there is one form of electromagnetic field-based navigation that occurs at zero cycles per second, and that antedates Maxwell by hundreds of years—the compass. In fact, the compass was an old technology when Columbus discovered the New World.

A compass is a small magnet that aligns itself with the Earth's magnetic field, which is oriented roughly north-south and is unchanging. Knowing one direction allows all directions to be known. From one point of view, the Earth's magnetic field can be considered to be quite weak, since a small magnet placed near a compass will cause it to point towards the magnet. However, the largest man made magnets won't affect a compass a mile away, and the Earth's magnetic field is uniform over the entire surface of the globe. The Earth's magnetic field is weak in intensity, but global in reach. Therefore it is important, if relying on a compass for direction, to establish a compass-safe distance for any object likely to be placed in its vicinity. Such requirements are levied on equipment used on commercial aircraft.

The following three experiments investigate static (unchanging) magnetic fields, compass use, and magnetic interference.

Experiment #1

Can a magnetic field affect the way an object functions?

Materials used:
magnetic compass
two magnets (the size and shape does not matter in this exercise)
wooden table
meter stick

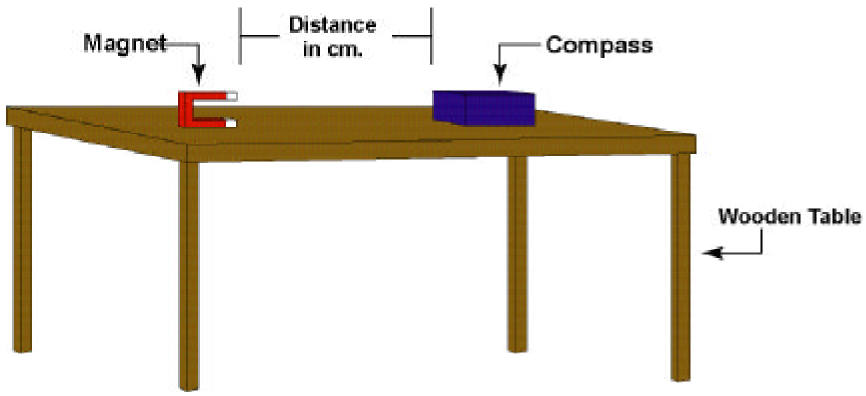

Diagram A.

Procedures:
1. Examine the compass and the way it points to the Earth's magnetic north.

2. Place the magnetic compass on the center of the wooden table away from steel or any magnetic source (see diagram A). Line the compass up with the Earth's north and south poles. (Make sure the wooden table is level.)

3. Examine the magnets and their magnetic fields (NS, SN attract; NN, SS repel.)

4. Place one of the magnets on the east or west side of the table. Measure the length at which you placed the magnet. Examine the compass, and record your results by plotting compass deflection as a function of distance from the magnet. Make sure to note the polarity of the magnet.

5. Take the same magnet and move it closer to the compass. Measure the length at which you placed the compass. Examine the compass and record your results. Make sure to note the polarity of the magnet.

6. Take the same magnet and allow it to make contact with the compass. Examine the compass and record your results. Make sure to note the polarity of the magnet.

7. Take the same magnet, and move it in a circular motion around the compass. Examine the compass, record your results. Make sure to note the polarity of the magnet.

8. Take the same magnet and place it near the compass. Take the other magnet and place it on the other side of the compass. Examine the compass, record your results. Make sure to note the polarities of the magnets.

9. Record any other information that might assist in your results.

Questions:

Can a magnetic field corrupt the way an object functions?

1. Why must the compass be placed on a wooden surface?

2. Predict the outcome of procedure 4.

3. Predict the outcome of procedure 5.

4. Predict the outcome of procedure 6.

5. Predict the outcome of procedure 7.

6. Predict the outcome of procedure 8.

7. Why do you need to know the polarity of the magnet while performing the experiment?

8. What are the results of this experiment?

For answers, see page 25.

Practical Application:
How could the known length at which the magnetic field does not corrupt an object be applied to life?

NASA Application:
NASA engineers must remain aware of sources of electromagnetic fields and the electrical systems that could potentially be affected. As an example, a space station could have communication antennas radiating electromagnetic fields. An astronaut in a spacesuit working on the space station may be required to know the safe distance around that antenna. Getting near the antenna may result in the spacesuit electronics being affected.

Experiment #2

Can an object be shielded from a magnetic field?

Materials used:
magnetic compass
two magnets (the size and shape does not matter in this exercise)
wooden table
piece of angled steel (iron?) (larger than the magnet)
piece of angled aluminum (larger than the magnet)
wood (larger than the magnet)

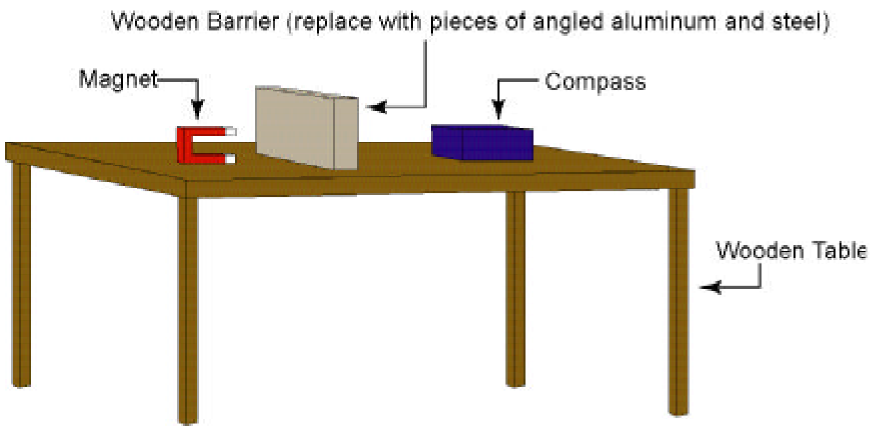

Diagram B

Procedures:

1. Examine the compass and the way it points to the Earth's magnetic north.

2. Place the compass on the wooden table away from steel or any magnetic source. Line the compass up so that the needle points to the 0° mark. Now the compass is aligned with the Earth's magnetic north and south poles.

3. Examine the magnets and their magnetic fields. (NS,SN attract; NN, SS repel).

4. Place one of the magnets on the east or west side of the table. Place the wood between the compass and the magnet (make sure the wood is larger than the magnet). Examine the compass (see diagram B).

5. Replace the wood with an angled piece of aluminum (make sure the aluminum is larger than the mag net). Examine the compass.

6. Replace the aluminum with the angled piece of steel (make sure the steel is larger than the magnet). Examine the compass.

Questions:

Can an object be shielded from a magnetic field?

1. Why must the compass be placed on a wooden table?

2. Predict what the outcome will be in procedure 4.

3. Predict what the outcome will be in procedure 5.

4. Predict what the outcome will be in procedure 6.

5. What were the results in procedures 4, 5, and 6?

Wood:

Aluminum:

Steel:

For answers, see page 25.

Practical Application:
How could this knowledge of magnetic shielding be applied to everyday life?

NASA Application (applies to experiments 2 and 3):
Different materials have different electromagnetic shielding properties. NASA engineers take these different properties into account when designing protective electromagnetic shields around sensitive devices or designing containment shields around devices that emit large amounts of electromagnetic fields.

Experiment #3

Magnetic Shielding

Materials used:
magnet
two pieces of cardboard
two 1/4-in. diameter dowels (pencils are okay)
paper clips
popsicle stick or other nonmetallic material
butter knife (not plastic)
glue

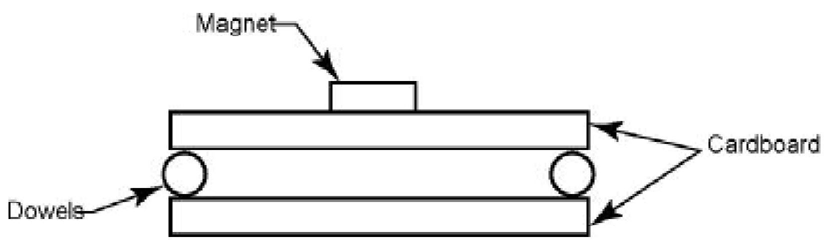

Diagram C.

Procedures:

1. Attach the dowels (pencils) to the outer edge of one of the pieces of cardboard. Attach the other piece of cardboard so you will have a cardboard, dowel, cardboard structure (see diagram C).

2. Place the magnet on top of this structure, center it on the edge, and glue it to the cardboard.

3. Raise the paper clips to the bottom of this structure. Record your results.

4. Now insert the popsicle stick between the two pieces of cardboard. Record your results.

5. Next insert the butter knife between the two pieces of cardboard. Record your results.

Questions:

1. Predict the outcome of procedure 4.

2. Predict the outcome of procedure 5.

3. What was the outcome of procedure 4?

4. What was the outcome of procedure 5?

5. Why did this occur?

For answers, see page 25.

Introduction to Experiments 4 and 5

Most electrical phenomena can be understood by analogy to water flow. In fact, James Clerk Maxwell used a hydrostatic/hydrodynamic analogy to derive and explain Maxwell's Laws. The four equations of Maxwell's Law comprehensively explain all electrical/electromagnetic phenomena. A basic electrical circuit[1] consists of a battery, wire, and a load which draws current through the wire from the battery? (see diagram D).

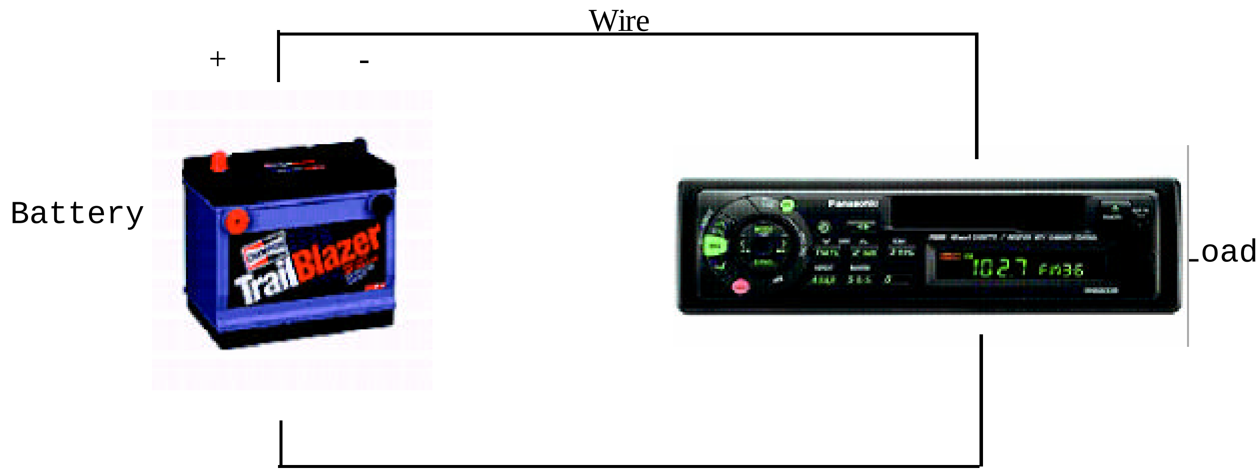

Diagram D. Simple electrical circuit

The battery is a power source, the load is a power consumer, and the wire is a low-loss path allowing power from the battery to flow into the load with minimal loss in transmission. If we think of the load as an electric motor (a device that converts electrical energy into mechanical motion), then a very close analogy may be drawn between the above circuit and the old water-driven mills of the preelectrical era. Water from a source located above the mill was ducted (via a trough) to fall onto a waterwheel (see diagram E). The resultant wheel motion could be used to grind grain. The first machine shops also drove their rotating machinery (lathes, drills) from a single axle emanating from the waterwheel.

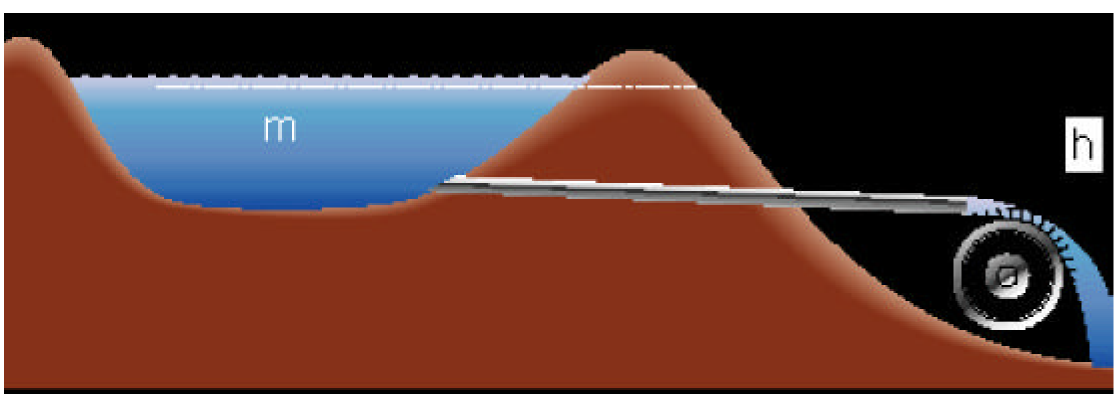

Diagram E. Waterwheel analogy.

[1]The word "circuit" derives from the Latin word for circle, and has the same root as the word circus. The first circus was an oval track on which Romans raced chariots. An electrical circuit must be a closed curve, meaning that there is a complete conductive path for current to flow.

In this analogy, the energy source is water above the wheel and functions as does the battery. The battery potential (V) corresponds to the height of the water reservoir above the water wheel. The water mass (m) corresponds to the amount of current the battery can source, commonly denoted in ampere-hours. Differences in amp-hour ratings account for the difference in battery sizes. For instance, all AAA, AA, C, and D batteries are rated at 1.5 volts potential, but differ in amp-hour rating. The trough, ducting the water from the pool to the wheel, functions as the electrical wiring, and the turning wheel performs the same function as the electric motor.

One portion of the analogy that may not be clear is that it appears that the water does not have to return to the source in order to flow, but there must be a closed path (circuit) in order for electrical current to flow. The water is flowing in a closed path. The potential energy of the water is mass • gravity • height ($m*g*h$). The height (h) is not an absolute number, but is taken with respect to another position in space (p) to which the water can fall. As long as the path between the water and point (p) is connected, a circuit exists, and water can flow. If the path is broken, no water can flow. That is, if a valve in the trough were closed, then the circuit is broken and no water can flow, even though the potential continues to exist.

Experiment #4

Conductors and Insulators

Materials used:
two D-size batteries
tape
two pieces copper wire
flashlight bulb
paperclip
pencil
eraser
ruler
wire (any type)
penny
any other materials you would like to use

Procedures:
1. Tape the two batteries together, with the positive end of one contacting the negative end of the other.

2. Attach one piece of copper wire to the batteries (positive side) and attach the same wire to the flashlight bulb base (the metal flange or threads).

3. Attach the second wire to the other side of the batteries (negative side).

4. Now test the objects you picked out by attaching the negative-side wire to the object and touching the object with the center button on the base of the bulb.

5. Pay close attention to the light bulb when doing this experiment.

6. Complete the worksheet that accompanies this experiment.

Conductors and Insulators Worksheet

1. An _______________ is a substance with strong electron bonds that does not transmit electricity.

2. A _______________ is a substance with weak electron bonds that readily transmits electricity.

Now list the materials you tested and the results of each:

3. ____

4. ____

5. ____

6. ____

7. ____

8. ____

9. ____

10. Which type of materials were most likely conductors?

For answers, see page 26.

Practical Application:
How can the knowledge of conductors and insulators be applied to everyday life?

Experiment #5

Ohm's Law

Ohm's Law states that voltage (V) across a resistor (R) is directly proportional to the current (I) flowing through it (see diagram F). This gives us the simple equation:

$V = I*R$

V = voltage, measured in units of volts (V)

R = resistance, measured in units of ohms (Ω)

I = current, measured in units of amperes (A)

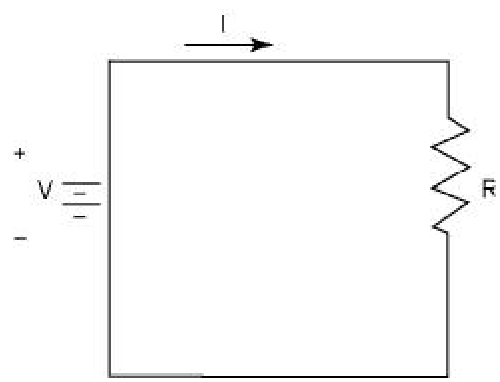

Diagram F. A simple direct current (DC) circuit.

I = ?

V = 5 V

R = 30 Ω

Given this simple DC circuit, calculate the current in amperes.

If $V = I*R$, then simple algebra tells us that $I = V/R$

So..... I = 5V/30W

I = ? *(see page 26 for answers)*

Alright, now it's your turn...

Directions: Solve the following problems using Ohm's Law.

1. A DC circuit has 4 V and a resistance of 15 Ω. Find the current.

2. A DC circuit has a 2 A current and a resistance of 10 Ω. Find the voltage.

3. A DC circuit has 8 V. How much resistance would it take to have a current of 4 A of current?

For answers, see page 26.

NASA Application:
NASA engineers use Ohm's Law to determine the amount of current that will be drawn out of the Space Shuttle's batteries.

Vocabulary Terms —Electrical Currents
Alternating Current (AC)—Electric current that reverses the direction of its flow many times a second (measured in amperes).

Ampere (or amps for short)—The unit of electric current (1 coulomb per sec).

Batteries—Structures that change chemical energy into electricity.

Charge—A definite quantity of electricity. An excess or deficiency of electrons in a body.

Conductor—A substance with weak electron bonds that transmits electric current easily.

Coulomb—Basic unit of electric charge.

Culprit (in EMI terms)—Device or phenomenon which produces interference.

Direct Current (DC)—Current that flows at a constant rate (amps).

Electric Circuit—The path or paths followed by an electric current generally along a conductor.

Electric Current—The flow of electrons.

Electricity—Electric current and voltage used as a source of power.

Electromagnetic Interference (EMI)—Manmade radiation that interferes with equipment by voltages, conducted currents, or by radiated electric or magnetic fields.

Energy—The capacity for doing work (measured in watts or joules).

Insulator—A substance with strong electron bonds that does not transmit electricity.

Negative—A charge that has an excess of electrons. (–)

Ohm's Law—States that voltage (V) across a resistor (R) is directly proportional to the current (I) flowing through it.

$V = I*R$

Positive—A charge that has a deficiency of electrons. (+)

Resistance—The opposition to flow of an electric current in a circuit (measured in ohms).

Transformer—A device that increases or decreases the voltage of alternating current.

Victim (in EMI terms)—Device whose operation is being negatively affected by interference.

Voltage—The difference in energy level between any two points in a circuit; can also be called "potential" and is measured in volts.

Vocabulary Worksheet

1. A ___________ is an excess or deficiency of electrons in a body.

2. ____________ is electric current and voltage used as a source of power.

3. ____________ is the opposition to flow of an electric current in a circuit.

4. A ___________ is the basic unit of electric charge.

5. A ____________ charge has a deficiency of electrons.

6. ____________ states that voltage across a resistor is directly proportional to the current flowing through it.

7. Measured in joules, _________ is the capacity for doing work.

8. A __________ is a substance that contains weak electron bonds that transmit current easily.

9. ____________ is electric current that reverses direction many times a second.

10. Structures that change chemical energy into electricity are called ___________.

11. The ___________ is the path or paths followed by an electric current generally along a conductor.

12. ____________ is current that flows in a constant rate.

13. A substance with strong electron bonds that does not transmit electricity is known as an____________.

14. A ___________ charge has an excess of electrons.

15. The device that increases or decreases the voltage of alternating current is the ____________.

16 . ______________ is the flow of electrons.

17. The unit of electric current is the ______________.

18. The difference in energy level between two points in a circuit is ___________. It is also called the potential or "electronic pressure" in a circuit.

For answers, see page 26.

Electric Field Calculation

Given the parameters of a transmitter such as radar, one can calculate the electric field, or E-Field, at the location of a satellite using the following equation:

$$E = \frac{\sqrt{30PG}}{r}$$

where,

E: electric field (volts/meter–V/m)

G: antenna gain (no units)

P: power (watts)

r: distance (meters)

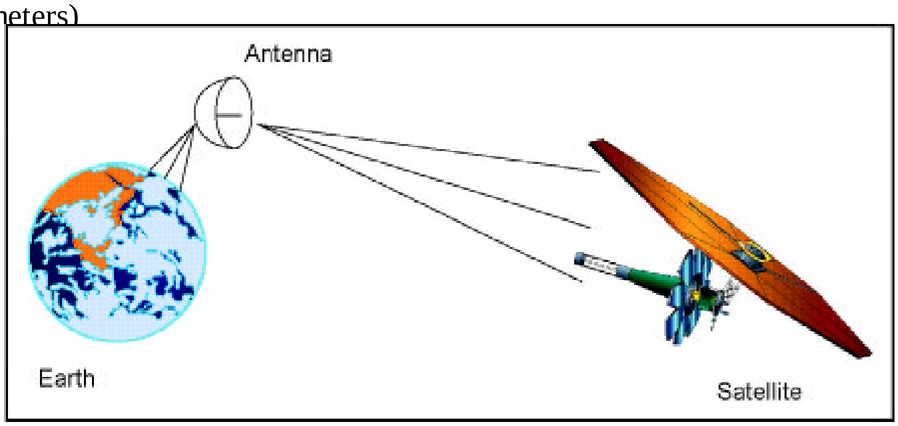

Diagram G. A typical transmitter system.

Solve the following problem for the following transmitter parameters:

P = 3 MW (i.e., 3,000,000 watts)

G = 1,000

r = 250 km (i.e., 250,000 meters)

Calculate the E- field at the satellite location.

For answers, see page 26.

NASA Application:
NASA engineers perform E-field calculations using radar data to determine the E-field environment through which the spacecraft will fly.

Introduction to Experiments 6 and 7

The concept of interference is fairly easy to grasp. You are talking on the telephone, and someone starts vacuum cleaning the rug. You can no longer hear the other party. Your audio reception has been interfered with. Take a football analogy. The quarterback throws a pass. A defender jostles the receiver just prior to his making the catch, preventing reception. This is pass interference. Now, think of yourself driving in your car, your car radio is tuned to a weak AM station. You drive under an overhead power-line and lose all reception. This is EMI.

Back to the telephone/vacuum cleaner analogy. If instead of listening to a voice over the phone, you had been listening to music at rock concert sound levels, you might not even be aware that someone was running the vacuum cleaner until it was almost upon you. The probability of interference is inversely related to the strength of the signal that is being received. The stronger the signal you receive, the more difficult it is to disrupt it. And conversely, the weaker the signal you receive, the easier it is to interfere with its reception. Hence weak signals are much more often interfered with than strong signals. Among the weakest signals that can be received are radio transmissions. A good AM radio can receive a signal power of one femtowatt (10^{-15} watt). That is one millionth of one billionth of a watt.

For this reason, EMI is most likely to occur to radio reception. In fact, the original term was not EMI, but radio frequency interference (rfi). The term EMI is more generic than rfi. EMI also occurs when a fly-by-wire aircraft flies too near a high-power radio transmitter and crashes[2]. Or, more prosaically, an illegally high-power citizen band (CB) radio transmitter is installed on a modern automobile equipped with a computer-controlled engine—keying the CB shuts down the engine.

EMI can range from a nuisance to a catastrophe. Losing AM radio reception for a few seconds near an overhead power line falls in the nuisance category. If an aircraft is making a final approach to a landing strip under instrument flight rules (IFR) conditions, the pilot is relying on navigation-radio signal reception to make his descent and landing. If the navigation radio is tied into an autopilot, where the autopilot guides the aircraft based on the navigation signal, then interference can be catastrophic. This is why personal electronics must be turned off prior to take-off and landing of commercial aircraft. An incident occurred a few years ago with a DC–10 type aircraft and precipitated the new rule. The DC–10 was making a final approach, reception of the ground-based navigation system was disrupted due to electromagnetic emissions from a personal electronic device in the first class section. The autopilot suddenly "thought" the aircraft was way off course and made a large correction in attitude, which actually jerked the aircraft off its course just moments prior to landing. Luckily, the pilot was able to wrest control and land the aircraft manually.

Broadcast radio transmissions can also cause EMI. An electroencephalograph (EEG) is used to measure brain activity. Tiny sensors taped to the skull measure minute (sub-millivolt) electrical potentials caused by neural circuits. One application of EEG measurements is to locate sources of undesirable activity such as epileptic seizures. The seizure prone area is mapped and then surgically excised. It is critical to remove the afflicted area while leaving other brain tissue undamaged. The EEG readings are used not only to map the areas to be removed, but as a check that they have been removed. At one hospital, EEG readings were disrupted by a local AM broadcast station. The disruption occurred only when the modulation index was highest, so this was an intermittent problem impossible to predict. The susceptibility of EEG measurements had to be solved in order to provide a safe operating environment.

[1]Fly-by-wire means that control stick movements do not directly actuate flight control surfaces, but rather only inputs electronic data into a flight computer.

In conclusion, unintentional electromagnetic emissions can cause rfi, while intentional electromagnetic energy transmissions can cause susceptibility to unintentional receivers, with consequences ranging from nuisance level to life-threatening.

Experiment # 6

Electromagnetic Interference

The following analogy may be used to help students visualize EMI. EMI can be defined as man made radiation that interferes with equipment by voltages, conducted currents, or by radiated electric or magnetic fields.

Shouting Analogy:

The following is an audio frequency example of interference by radiated emissions:

Two students stand at opposite ends of a football field. One student, the “transmitter,” begins to shout a message to the other, the “receiver.” While doing this, a third student, the “culprit” located somewhere between the transmitter and the receiver, loudly shouts nonsense noise (interference). This can make it difficult for the receiver to capture the transmitted message intact.

This analogy contains all the elements of an EMI problem: (1) the victim—the receiver, who isn’t able to receive the message, (2) the culprit—the nonsense shouter who provides the audio interference, and (3) the coupling path, which in this case, is the air through which the sound waves travel.

Experiment # 7

Can you produce an EMI generator?

Materials used:
cordless power drill
aluminum foil
AM radio

In this example, the drill is the EMI culprit, emitting interfering electromagnetic noise which can easily be heard on the victim AM radio as popping and static noises. The drill's motor acts as a transmitter (of broadband noise or noise that is present across a wide range of frequencies), radiating a magnetic field that interferes with the radio, which is the receiver. The coupling path is the unshielded free space through which the drill's fields radiate. When foil is wrapped around the drill, it shields the victim from the field, thereby removing the coupling path. Thus, the noises that were being caused by the drill can no longer be heard.

Procedures:

1. Take the radio and make sure it is on AM band.
2. Tune the radio between two channels.
3. Hold the cordless power drill near the radio and slightly press the trigger.
4. Be sure to listen closely to the radio while using the drill.
5. Record any differences you may hear.
6. Now, take the aluminum foil and wrap it completely around the drill.
7. Again, hold the drill near the radio and slightly press the trigger.
8. Be sure to pay close attention to the radio.
9. Record any differences you may hear.

Questions:

1. What do you predict will happen when you hold the drill near the radio and press the trigger?

2. What does happen when you perform this portion of the experiment?

3. What do you predict will happen once the drill is wrapped in aluminum foil?

4. What does happen in this portion of the experiment?

5. Are there other ways that the radio can be shielded from electromagnetic interference?

____

____

____

____

6. Now that you know what EMI is, list other instances of EMI that you have witnessed.

____

____

____

____

For answers, see page 27.

NASA Application:
At NASA, EMI engineers test all the electronics on the spacecraft prior to launching it to ensure that no EMI occurs during spacecraft operations.

Radiation and Electromagnetic Interference
The Sun is a natural source of radiation. It is constantly emitting radiation across the entire electromagnetic spectrum. Not just visible light waves but also radio waves, microwaves, infrared rays, ultraviolet (UV) rays, x rays, and gamma rays. Although many of these can be harmful to us, we are naturally protected from many of the harshest forms of radiation by the Earth's atmosphere. For example, the ozone layer reduces the amount of UV that can pass through to the Earth's surface. We can still get a sunburn from UV radiation but we would not be able to go outside at all without the protection afforded by the atmosphere. Another example of natural radiation is lightning. A lightning strike emits broadband electromagnetic waves that can be heard as interference on radios and televisions.

Man made radiation is generated by things such as microwave ovens, radio and television broadcast towers, cell phones, radars, communications satellites, and electric brush motors. Most of these examples are intentionally produced at specific frequencies of interest. Therefore you must tune your radio or television to a particular channel that uses a particular frequency. Microwave ovens generate microwave radiation at a power and frequency that would be harmful to people if the oven was not shielded to protect us. You can even produce radiation yourself! On a dry winter day, after shuffling your feet across the carpet, you may shock yourself on the doorknob—that is electrostatic discharge (ESD), an arc that is very much like a lightning strike. Both are caused by a buildup of charge. When your charged finger gets close to the doorknob, it creates an oppositely charged area in the doorknob. The resulting potential can be as high as 20,000 volts! This energy discharge gives us a mildly painful shock and produces an audible "pop!" ESD is also a source of broadband noise although it obviously does not contain as much energy as a lightning strike.

The Earth's ozone is our protection from the harmful rays that the Sun radiates; yet just as the ozone protects us, spacecraft must also be shielded. Not only must the spacecraft be shielded from the Sun's harmful radiation, but also the equipment on the spacecraft must be shielded from other equipment. That's where EMI comes into play. EMI is man made radiation that interferes with equipment. This can cover things like equipment interfering with each other on spacecraft and cell phones interfering with hospital equipment.

We can reduce the effects of EMI by shielding equipment or moving an object (interference culprit) to a certain distance from another object (interference victim). Now, consider this situation:

There is a magnet on the table. Near this magnet is a computer disk storing large amounts of important data. If the magnet gets too close to the disk, its magnetic field may erase the data on the disk. Is this a type of electromagnetic interference? If so, what can be done to prevent it?

____

____

____

____

____

____

____

____

Now, come up with another instance in which EMI is a problem, then explain ways it can be corrected.

____

____

____

____

____

____

____

____

For answers, see page 27.

Answers

Experiment 1

Results:
The compass points to the Earth's magnetic north. When the magnet's magnetic field is first imposed upon at the farthest point, the needle of the compass makes slight movement from that of magnetic north. When the magnet is moved closer, again the needle moves, but this time the move is more noticeable. The point at which the magnet touches the compass, the needle points to the magnet instead of magnetic north. When the magnet is moved in a circular motion around the compass, the needle of the compass follows. In all of these cases the needle moved toward the magnet because its magnetic field blocked out the Earth's magnetic field. The magnet's field was stronger than the Earth's. When the second magnet is introduced, the needle stays on the magnet whose field is stronger. This reaction proves that a magnet's field can and will corrupt another object's functioning. The compass is designed to point to magnetic north. This shows that it is susceptible to change due to any magnetic field, since a small magnet disrupted the Earth's own magnetic field. This relates to electromagnetic interference; the magnet (source) has a field (radiated influence) and affects the functioning of the compass (receiver).

Experiment 2

Results:
Initially, the compass points to the Earth's magnetic north. Then, when the magnet is placed on the table, the needle moves to point either toward or away from the magnet (about 90° or 270°). When the wood is placed between the compass and the magnet, it has no affect on the magnet and the needle of the compass remains pointing either toward or away from the magnet. The wood does not shield the compass from the magnet's field. When the aluminum is placed between the compass and the magnet, again the needle remains unaffected. The aluminum does not shield the compass from the magnet's field. When the steel angle is placed between the compass and the magnet, the needle returns to about 0° or magnetic north. The steel can shield the compass from the magnet's field. The concept of shielding can be applied in many areas. One in particular is in the space industry. An object that produces a magnetic field can potentially interfere with another object's function. If shielding can be inserted in the coupling path between the interfering (culprit) object and the victim object, the magnetic field can be contained in a way that it cannot interfere with the victim object's function.

Experiment 3

Results:
The magnet's field passes through the cardboard. This field attracts the paper clips to the bottom of the cardboard. Some materials, such as the popsicle stick, allow the magnet's field to pass through it. These materials are called nonpermeable. Other materials, such as the butter knife, do not allow the field to pass through it. These materials are called permeable. When the butter knife is placed between the two pieces of cardboard, it shields the paper clips from the magnetic field, allowing the clips to fall.

Experiment 4

Results:
The results of this experiment may vary between students. The outcome depends solely on the materials that are used in the experiment. A conductor of electricity will allow the electric current to pass through it. This will allow the light bulb to light up. An insulator is the opposite. It does not allow electric current to flow through it; therefore, the bulb will not light up. Metals such as copper, aluminum, silver, gold, and steel are all good conductors. Plastic and rubber tend to be insulators. We use metal wire to carry electric current from one point to another and that wire usually has a plastic or rubber insulation to keep us from being shocked when we touch the wire.

Experiment 5

I = 0.167 A

1. 0.266 Amperes
2. 20 Volts
3. 2 Ohms

Vocabulary Worksheet

1. charge
2. electricity
3. resistance
4. coulomb
5. positive
6. Ohms law
7. energy
8. conductor
9. alternating current
10. batteries
11. electric circuit
12. direct current
13. insulator
14. negative
15. transformer
16. electric current
17. ampere
18. voltage

E =1.2 V/m

Experiment 7

Results:

When the drill is operated near the radio, the AM band picks up the field that the drill radiates, causing popping and static noises. This is a prime example of EMI. The drill's motor (transmitter) radiates a magnetic field that interferes with the radio (receiver). When the foil is wrapped around the drill, the field cannot be emitted; therefore, it cannot interfere with the radio. Thus, the noises that were being caused by the drill can no longer be heard.

http://see.msfc.nasa.gov

EG-2000-03-068-MSFC
Pub 8-1145