Purpose and Overview
The purpose of the investigations below is to provide middle school students with a firm understanding of magnetism. The investigations include many experiments using magnets. While work with magnets will be interesting and exciting for most students, understanding the concepts behind magnetism will be a more difficult feat. Each lesson provides opportunities for discussions and development of ideas.

Good discussion and development of these concepts will be aided by using drawings and diagrams. To improve understanding, it is also important to use models and manipulatives as part of discussions. The use of models and manipulatives will facilitate understanding. I use simple "domain cards" to aid discussions. Details of how to build and use these "domain cards" are found in Appendix 1.

Each investigation is framed around one or more questions. For each of the investigations, a set of student questions is provided. These student questions may be used as science log questions, for discussion prompts, for review, or as assessments. Answers and teacher information for leading related discussions are provided in bold italic font.

For each investigation, I have included conclusions that should be drawn from each set of activities and discussion. Students should keep track of these conclusions (in their own words) in a science log. Alternatively, a large poster entitled *What We Know About Magnetism* could be kept by the whole class. As each investigation is completed, the new conclusions can be recorded on the poster.

The first seven investigations are focused on helping students understand what causes magnetism at an atomic level. These first seven lessons are probably best done in the order presented. The rest of the investigations could be done in the any order. The teacher may choose only a few of these investigations to round out the unit.

Prerequisite Knowledge
In order to understand the material presented in the following lessons, students must be familiar with basic atomic structure. They must know what protons and electrons are. In particular they should understand that electrons move at high speeds around the nucleus of each atom. It is also necessary for them to understand that electricity is the result of the flow of electrons.

Teacher Background Information
See http://207.10.97.102/elscizone/lessons/everywhere/magnetism/slide1.htm
Amateur Scientist page http://www.amasci.com/neodemo.html
Science Toys http://scitoys.com/scitoys/scitoys/magnets/magnets.html#magnetism
Exploratorium http://www.exploratorium.edu/snacks/iconmagnetism.html

Science for the Elementary School by Edward Victor and Richard D. Kellough, Macmillan Publishing Company, 1993.

Investigation 1: What is a compass? Where does it point? Why?

Students will build a simple compass using a needle, a cork, bowl of water, and a strong magnet. Students should stroke the needle 20 times in one direction with one pole of the strong magnet. The needle should become magnetic. They should push the needle through the cork, and place the compass in a bowl of water. The needle should slowly point toward magnetic north. Please note that it is best to keep compasses away from large steel/iron objects and from magnets.

Figure 1

Are all the needles pointing in the same direction? ***Yes***
Which direction do they point? ***North***
Why? ***Students may offer many different explanations. The correct explanation is that because the Earth's core contains a great amount of iron and because of the Earth rotation around its axis, the Earth acts like a large magnet with a north pole and a south pole. These north and south poles are more correctly called the north and south magnetic poles. Magnet north and the North Pole are not exactly the same. Magnetic north is actually found some distance away from the North Pole. Despite this inaccuracy, compasses are useful in most parts of the world for finding north.***

A compass works because it, like all magnets, has a north-seeking end and a south seeking end. We call the end of the compass pointing toward the magnetic north the "north pole" of the needle. This is confusing since it seems that the two like poles are attracted to one another. This problem occurs because the poles of magnets were named before the magnetic poles of the Earth were discovered. If the magnetic poles of the Earth had been discovered first, the names of the poles of magnets may have been named differently. To avoid confusion, it might help to refer to the poles of the compass (or any other magnet) as north-seeking and south-seeking poles.

<u>Conclusions:</u>
A compass is free moving magnet. The Earth acts like a huge magnet with a north and south pole. A compass needle, like all magnets has a north-seeking (N) and south-seeking (S) pole.

Investigation 2: What makes a magnet?

Students will discuss their ideas about how magnetism is produced. After this discussion, students will make an electromagnet using a steel nail, a lantern battery (other batteries will work but will not last as long) or an AC/DC adapter, and bell wire (obtained from a hardware store). They should wrap the bell wire around a large steel nail as shown the diagram below. Each end of the wire should be connected to the battery. The current running through the wire will produce a magnetic field, and the nail will become magnetized. Students can use the nail to pick up tacks, paper clips, staples etc…

Figure 2

What causes magnetism? ***Students may have many different responses to this question at the beginning of the investigation. After making and experimenting with the electromagnets, students should have some idea that magnetism has something to do with the movement of electrons since the movement of electrons in the wire produced a magnetic field. As soon as the flow of electrons was stopped, the magnetic field stopped. At this point in the unit, this simple idea that magnetism is connected to electron movement is sufficient.***

Conclusion: The movement of electrons connected to magnetism.

Investigation 3: If Everything Contains Electrons, Why Isn't Everything a Magnet?

Students and teacher will discussion and explore the question below. Student copies of the graphics presented below are found in Appendix 2.

If everything contains electrons, why isn't everything a magnet? ***To help students understand the answer to this question copies of the graphical depictions below are useful (found in Appendix 1).***

Figure 3 ***Figure 4***

The direction of electron spinning is key to understanding magnetism. The movement of an individual electron creates a small magnetic field around that electron. This effect of this magnetic field, however, is cancelled by the movement of another electron in the atom in the opposite direction. In most atoms, the spinning of electrons cancels

out the effects of one another's magnetic fields, and there is no net magnetic effect. This is depicted in Figure 1.

In some metal atoms (namely iron, cobalt, and nickel), the spins of one electron is not cancelled by the spins of other electrons. This creates a net magnetic effect in each atom. In this way, each atom becomes a tiny atomic magnet with a north and south pole. This is shown in Figure 2.

Conclusions: Electron spinning in opposite directions cancels out the magnetic effect of electron movement in most materials. In some materials (iron, cobalt, and nickel), some electron spins are not cancelled by the spins of other electrons. The net result is that the atoms in these materials act as tiny, atomic magnets, each with two poles.

Investigation 4: If Iron, Nickel, and Cobalt Contain Tiny "Atomic Magnets," Why Isn't Everything Made of Iron, Nickel, and Cobalt Magnetic?

If iron, nickel, and cobalt contain tiny atomic magnets, why isn't everything made of iron, nickel, and cobalt magnetic? ***Students should offer and discuss their own ideas about what causes magnetism.***
What is a domain? ***A domain is a region or area. When discussing magnetism, a domain is an area in which many atomic magnet are all pointed in the same direction.***

The teacher should make available a "domain card" and the atomic magnet chips to each student. Students should cut out each of the atomic magnet chips. Have students place all these chips on the domain card in such a way that all the arrows are pointed in the same direction. This represents what the atomic magnets and domains look like in a magnet. All atomic magnets inside the domain are pointed in the same direction, and all the domains are pointed in the same direction.

Figure 5

What would happen if the arrows in three domains were turned in the opposite direction? Students should turn the arrows in 3 of the 6 magnets on the domain card in the opposite direction. ***The material would no longer be a magnet because for each domain pointed in one direction, there is another pointed in the opposite direction. These domains cancel out the effect of each other. In materials made of iron, cobalt, or nickel that are not magnetic, there are domains, but they are randomly oriented so that they do not have a net magnetic effect.***

Figure 6

<u>Conclusions:</u> The tiny atomic magnets of iron, nickel, and cobalt tend to organize themselves into domains. Domains are regions in material in which these atomic magnets all point in the same direction. If all the domains point in the same direction, the material is magnet. In materials iron, cobalt, and nickel materials that are not magnets, the domains are not all pointed in the same direction. They are randomly oriented.

Investigation 5: How can you take a piece of non-magnetic iron and make it into a magnet? How can you increase the strength of a magnet?

Students will make magnets using two different methods. First they will make an electromagnet by wrapping 20 turns of wire around a steel nail. Secondly, they will stroke a separate steel nail with a magnet. They should stroke the nail with the same pole of the magnet every time. They should start at one end of the magnet and stroke it all the way to the other end. The teacher may want to mark one of poles ahead of time so students can be sure to use the same pole of the magnet every time. They should stroke the nail 10 times. Having made the magnets, students will test the magnets by experimenting with how many staples in a chain can be picked up by each magnet. (Note: I make staple "links" by repeatedly squeezing the stapler to that the ends the staples are curled over. I prefer to use staples because they are light and longer chains can be made with them than can be made with paper clips.) They will then try to increase the strength of electromagnet by wrapping more wire around the electromagnet or by increasing the voltage used. They will test the other magnet by stroking the magnet additional times.

What are some ways I could make a nail into a magnet? ***We have made magnets by wrapping wire around a nail and connecting the wire to a battery or power source. We also found that we could make a needle into a magnet by stroking it with a magnet. We could do the same thing with a nail. Wrap twenty turns of wire around a nail to make a magnet. Stroke another nail 10 times with a strong magnet. Make sure to use the same pole of the magnet every time.***
Using your domain cards, show what the nails look like before wrapping wire around them or stroking them with magnets? ***Before magnetizing the nails, the domains should be disordered.***

Figure 7

What will the domains look like after the nails are magnetized? ***After magnetizing the nails, the domains should be oriented in the same direction. Which direction would depend on the direction stroking or current flow.***

Figure 8

How could we test the strength of these magnets? ***We could see how long of a staple chain we could make with each magnet?***
How could we increase the strength of the magnets? ***We could increase the number of coils around the nail. We could add another battery in series or increase the voltage using an AC/DC adapter. We could stroke the nail more times with the magnet.***
How do these methods increase the strength of these magnets? ***Increasing the number of coils makes a stronger magnet because it increases the number of electrons moving around the nail at any one time.***

Figure 9

Increasing the voltage makes the electrons move through wire faster which in turn increases the strength of the magnet.

Figure 10

Rubbing the nail more with the magnet causes more domains to be oriented in the same direction and increases the strength of the magnet.

after a few strokes *after many strokes*

Figure 11

What would probably happen if we switched the terminal of the battery to which each wire was connected? What would happen if we stroked the nail in the opposite direction?
The domains would be oriented in the opposite direction.

Figure 12

Conclusions: A steel (iron) nail can be turned into a magnet by wrapping wire around it and running a current through it. By increasing the number of coils around the nail or by increasing the voltage, the strength of the magnet increases. A nail can also be turned into a magnet by rubbing it with a strong magnet. By stroking the nail more, the strength of the nail can be increased.

Investigation 6: What happens when a nail "sticks" to a magnet? How happens to the domains inside the nail?

Appendix 2 contains an outline of a nail with four domains and atomic magnets. Have students cut out these nails and atomic magnets.

How will the domains inside the nail look before bringing it close to the magnet? ***The domains will be disordered.***

Figure 13

Arrange the domain card so that it represents a magnet. With the domain card and the nail diagram, show what would happen with the domains of the nail. ***The domains of the nail would go from being disordered to ordered with the same orientation as the magnet.***

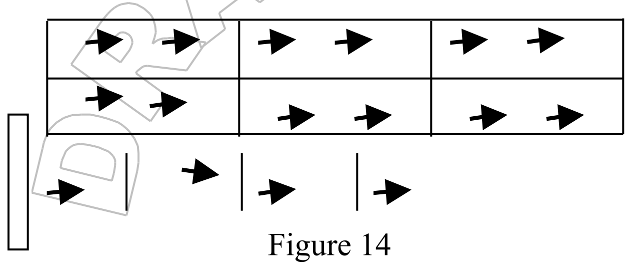

Figure 14

Conclusions: Before being brought close to a magnet, the domains in a nail are randomly distributed and are oriented in many different directions. As the nail comes close to the nail, the domains in the nail become aligned with the domains of the magnet. The nail acts like a magnet and sticks to the magnet.

Investigation 7: What causes attraction and repulsion?

Give each pair of students two magnets. Students should experiment with feeling the attraction and repulsion between the two magnets. They should try to spin one magnet with the other. They can "chase" one magnet with the other. Each student in the pair should arrange his domain card to represent a magnet.

With the two domain cards, show what is happening when two poles of a magnet are attracted to one another. ***When two magnets are attracted to one another, their orientations are the same as illustrated below.***

Figure 15

What happens when two poles are repelled by one another? ***When two poles repel one another, it is because their domains are oriented in opposite directions as shown below.***

Figure 16

Conclusions: Attraction occurs when domains are oriented in the same direction. Repulsion occurs when domains are oriented in opposite directions.

Investigation 8: Can magnetism be destroyed or disrupted? How?

Students should magnetize a steel nail by stroking it with a magnet as in previous investigations. They should magnetize the nails enough that it is able to pick up at least one paper clip. After they have magnetized the nails, students should pound them several times with a hammer or drop them on the floor several times.

What happens to the nails magnetism after it is pounded or dropped? ***It loses its magnetism?***

Why? ***When the nail is pounded or dropped, the domains in the nails are disordered again, just as they were before the nail was magnetized.***

Set up the Curie temperature experiment according to the directions in Appendix 3. They Curie temperature of a metal is the temperature at which a metal loses its magnetic properties.

What happened when the wire was heated? ***The wire no longer stuck to the magnet.***
What happened when the wire cooled again? ***It regained its magnetism.***
Why? ***Just as with pounding the magnet nail earlier in the investigation, heating the wire to a high temperature caused the wire to lose its magnetism. When the wire***

cooled, the domains could again be influenced by the magnet and oriented in the same direction as the magnet's domain.

What would happen if we heated a magnet up to high temperature? ***It would lose its magnetism if we were to heat it to high enough temperatures. Upon cooling, however, it would not regain it magnetic properties because the domains would be permanently disordered. This is different than heating since the wire's magnetism depends on the magnet. When the wire is cooled, its domains can be realigned with the magnet's domain.***

<u>Conclusions:</u> Magnetism can be destroyed by very high temperatures. The high temperatures cause atomic movement that disrupts the alignment of domains. At high temperatures, aligned domains become disordered, and the material loses its magnetic properties. Pounding a magnet with a hammer can also disrupt or destroy a magnet by disordering the domains.

Investigation 9: Do other materials have magnetic properties?

Hold a strong neodymium magnet near a piece of thin copper or aluminum foil.

What happens? ***The copper is attracted to the magnet.***

Why? ***Some materials are very weakly attracted to magnets. Aluminum and copper are examples of these materials. They are called <u>paramagnetic</u> materials. Iron, cobalt, and nickel are strongly attracted to magnets and are called <u>ferromagnetic</u>.***

Set up the grape pushing experiment as illustrated and explained in Appendix 4.

What happens as the magnet is brought near the grape? Bring the other pole near the grape. What happens in both cases? ***The grape is repelled by both poles of the magnet and moves away from it.***

Why? ***Some materials are <u>diamagnetic</u>. This means that they are weakly repelled by both poles of a magnet.***

Can these experiments be done with refrigerator magnets? ***No, they require very strong neodymium magnets***

Students should test the magnetism of many kinds of objects. Each small object should be hung by a string. Then students should bring a strong neodymium magnet near the object. If the object is strongly attracted, it is ferromagnetic. If it weakly attracted it is paramagnetic. If it is repelled, it is diamagnetic. Some materials will exhibit no magnetic properties at all. Possible objects include chunks of watermelon (contains large amounts of water which is diamagnetic), pencil lead (graphite), iron-fortified cereals (which contain small bits of iron), coins, rocks, other metal objects, and plastic objects.

Investigation 10: How does MRI work?

Conclusions: MRI works by using the magnetic properties of hydrogen nuclei. During an MRI scan, hydrogen nuclei are aligned using a large magnet. When the large magnetic force is removed, the hydrogen nuclei return to their normal, lower energy state. The release of energy that accompanies this return to a lower energy state can be detected and transformed into 2D and 3D images.

Investigation 11: Magnetic fields
Includes traditional iron fillings experiments. Also includes iron fillings suspended in oil in a bottle in order to see 3D fields. This unit will include use of magnetic viewing paper.

Investigation 12: Magnetic Suction
This is based on an Exploratium experiment. An electromagnetic tube sucks in a nail.

Investigation 13: Water Distortion
An Amateur Scientist idea. A strong neodymium magnet is place in a shallow pan of water. Because water is diamagnetic, a small convex shape is observed above the magnet.

Investigation 14: **Oil and Water**
Another Amateur Scientist idea. An oil ball is suspended in a mixture of alcohol and water. As a neodymium magnet is brought near the container, the water is repelled and the oil ball is pushed closer to the side of the container.

Investigation 15: Magnetic Pendulum
Using magnets and copper wire, a current is induced and a pendulum set into motion.

Investigation 16: Magnetic Shielding
Students explore magnetic fields as they find out how shielding works.

Investigation 17: Diamagnetic Levitation
Students learn how a magnet can be levitated in the air use the diamagnetic properties of graphite.

Investigation 18: Magneto-resistant fluids
Students observe the fascinating behavior of MR fluids.

Investigation 19: The Search for Micrometeorites
Students use the magnetic properties of some micrometeorites collect them from rain water.

Investigation 20: Strange Attractor

Based on an Exploratium device. Students build a magnetic pendulum that has strange and seemingly unpredictable patterns of movement.

Investigation 21: Magnet Races
An idea from Amateur Scientist. Students roll magnets down thin aluminum, thick aluminum, and wooden surfaces. They observe that the movement of the magnet induces a current in the aluminum, causing small magnetic field to develop, and slowing the magnet as it moves.

Investigation 22: GMR

Investigation 23: Cassettes, Disks, and Videotapes
Students learn about the importance of magnetism in cassettes, disks, and videotapes.