COMPETENCY I. KNOWLEDGE OF THE BASIC NATURE OF PHYSICS

Skill 1.1 Identify the components of the scientific method (e.g., assumptions, observations, hypotheses, conclusions, laws, theories).

The scientific method is just a logical set of steps that a scientist goes through to solve a problem. There are as many different scientific methods as there are scientists experimenting. However, there seems to be some pattern to their work.

A law is the highest-level of certainty science can achieve followed by theories and hypothesis. The scientific method is the process by which data is collected, interpreted and validated.

Law: A law is a statement of an order or relation of phenomena that, as far as is known, is invariable under the given conditions. Everything we observe in the universe operates according to known natural laws.

- If the truth of a statement is verified repeatedly in a reproducible way then it can reach the level of a natural law.
- Some well known and accepted natural laws of science are:

1. The First Law of Thermodynamics

2. The Second Law of Thermodynamics

3. The Law of Cause and Effect

4. The Law of Biogenesis

5. The Law of Gravity

Theory: In contrast to a law, a scientific theory is used to explain an observation or a set of observations. It is generally accepted to be true, though no real proof exists. The important thing about a scientific theory is that there are no experimental observations to prove it NOT true, and each piece of evidence that exists supports the theory as written. Theories are often accepted at face value since they are often difficult to prove and can be rewritten in order to include the results of all experimental observations. An example of a theory is the big bang theory. While there is no experiment that can directly test whether or not the big bang actually occurred, there is no strong evidence indicating otherwise.

Theories provide a framework to explain the **known** information of the time, but are subject to constant evaluation and updating. There is always the possibility that new evidence will conflict with a current theory.

Some examples of theories that have been rejected because they are now better explained by current knowledge:

Theory of Spontaneous Generation
Inheritance of Acquired Characteristics
The Blending Hypothesis

Some examples of theories that were initially rejected because they fell outside of the accepted knowledge of the time, but are well-accepted today due to increased knowledge and data include:

The sun-centered solar system
Warm-bloodedness in dinosaurs
The germ theory of disease
Continental drift

Hypothesis: A hypothesis is a tentative assumption made in order to draw out and test its logical or empirical consequences. Many refer to a hypothesis as an educated guess about what will happen during an experiment. A hypothesis can be based on prior knowledge and prior observations. It will be proved true or false only through experimentation.

Scientific Method: The scientific method consists of principles and procedures for the systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of hypotheses. The steps in the scientific method can be found elsewhere in this text.

While an inquiry may start at any point in this method and may not involve all of the steps here is the pattern.

Observations

Scientific questions result from observations of events in nature or events observed in the laboratory. An **observation** is not just a look at what happens. It also includes measurements and careful records of the event. Records could include photos, drawings, or written descriptions. The observations and data collection lead to a question. In physics, observations almost always deal with the behavior of matter. Having arrived at a question, a scientist usually researches the scientific literature to see what is known about the question. Maybe the question has already been answered. The scientist then may want to test the answer found in the literature. Or, maybe the research will lead to a new question.

Sometimes the same observations are made over and over again and are always the same. For example, you can observe that daylight lasts longer in summer than in winter. This observation never varies. Such observations are called **laws** of nature. One of the most important scientific laws was discovered in the late 1700s. Chemists observed that no mass was ever lost or gained in chemical reactions. This law became known as the law of conservation of mass. Explaining this law was a major topic of scientific research in the early 19th century.

Hypothesis

If the question has not been answered, the scientist may prepare for an experiment by making a hypothesis. A **hypothesis** is a statement of a possible answer to the question. It is a tentative explanation for a set of facts and can be tested by experiments. Although hypotheses are usually based on observations, they may also be based on a sudden idea or intuition.

Experiment

An **experiment** tests the hypothesis to determine whether it may be a correct answer to the question or a solution to the problem. Some experiments may test the effect of one thing on another under controlled conditions. Such experiments have two variables. The experimenter controls one variable, callred the *independent variable*. The other variable, the *dependent variable*, is the change caused by changing the independent variable.

For example, suppose a researcher wanted to test the effect of vitamin A on the ability of rats to see in dim light. The independent variable would be the dose of Vitamin A added to the rats' diet. The dependent variable would be the intensity of light that causes the rats to react. All other factors, such as time, temperature, age, water given to the rats, the other nutrients given to the rats, and similar factors, are held constant. Scientists sometimes do short experiments “just to see what happens”. Often, these are not formal experiments. Rather they are ways of making additional observations about the behavior of matter.

In most experiments, scientists collect quantitative data, which is data that can be measured with instruments. They also collect qualitative data, descriptive information from observations other than measurements. Interpreting data and analyzing observations are important. If data is not organized in a logical manner, wrong conclusions can be drawn. Also, other scientists may not be able to follow your work or repeat your results.

Conclusion

Finally, a scientist must draw conclusions from the experiment. A conclusion must address the hypothesis on which the experiment was based. The conclusion states whether or not the data supports the hypothesis. If it does not, the conclusion should state what the experiment *did* show. If the hypothesis is not supported, the scientist uses the observations from the experiment to make a new or revised hypothesis. Then, new experiments are planned.

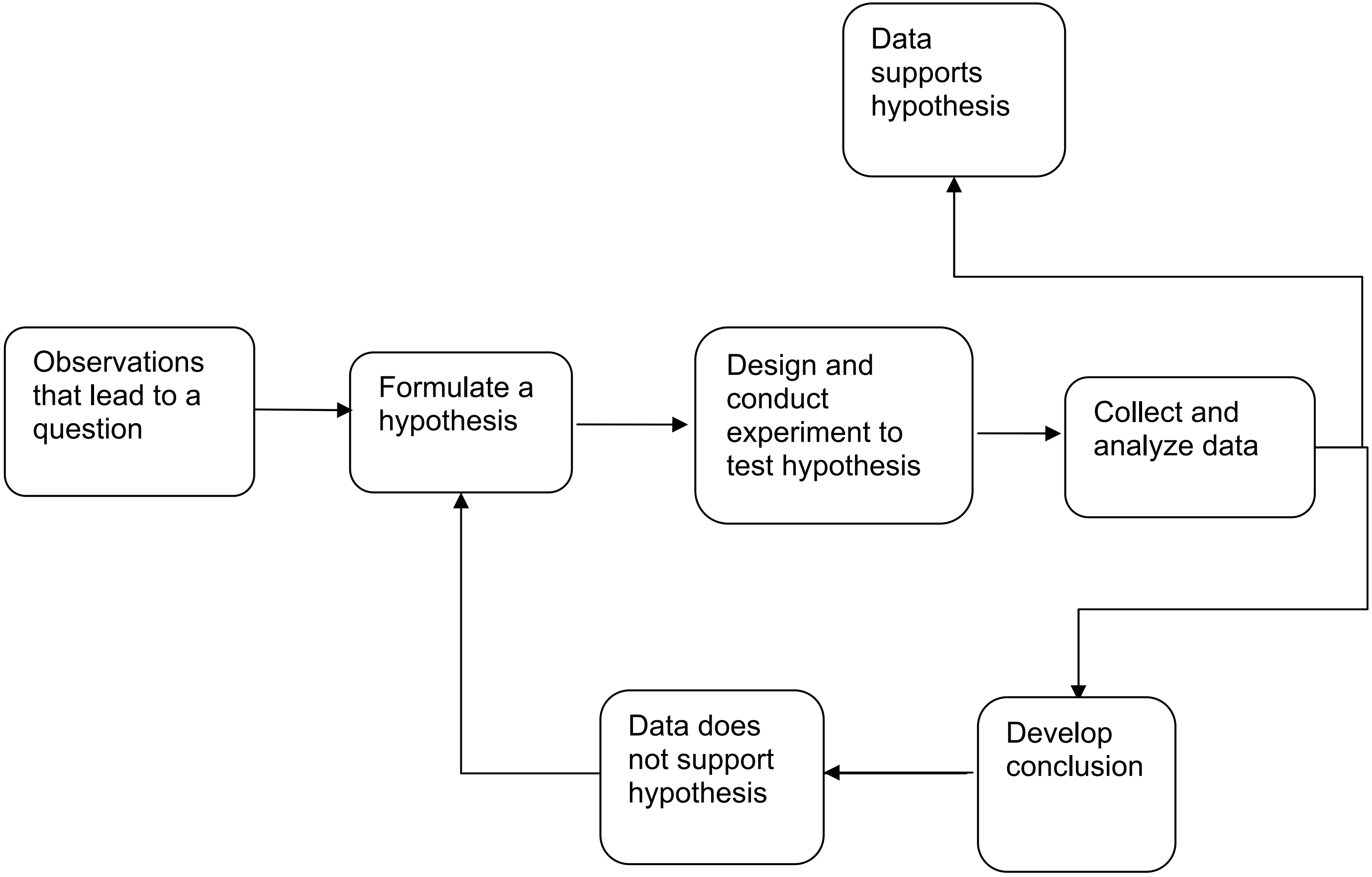
Theory

When a hypothesis survives many experimental tests to determine its validity, the hypothesis may evolve into a **theory**. A theory explains a body of facts and laws that are based on the facts. A theory also reliably predicts the outcome of related events in nature. For example, the law of conservation of matter and many other experimental observations led to a theory proposed early in the 19th century. This theory explained the conservation law by proposing that all matter is made up of atoms which are never created or destroyed in chemical reactions, only rearranged. This atomic theory also successfully predicted the behavior of matter in chemical reactions that had not been studied at the time. As a result, the atomic theory has stood for 200 years with only small modifications.

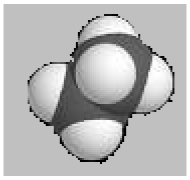
A theory also serves as a scientific **model**. A model can be a physical model made of wood or plastic, a computer program that simulates events in nature, or simply a mental picture of an idea. A model illustrates a theory and explains nature. For instance, in your science class you may develop a mental (and maybe a physical) model of the atom and its behavior. Outside of science, the word theory is often used to describe someone’s unproven notion about something. In science, theory means much more. It is a thoroughly tested explanation of things and events observed in nature.

A theory can never be proven true, but it can be proven untrue. All it takes to prove a theory untrue is to show an exception to the theory. The test of the hypothesis may be observations of phenomena or a model may be built to examine its behavior under certain circumstances.

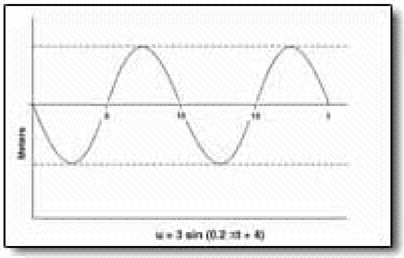
Steps of a Scientific Method



A scientific model is a set of ideas that describes a natural process and are developed by empirical or theoretical methods. They help scientists focus on the basic fundamental processes. They may be physical representations, such as a space-filling model of a molecule or a map, or they may be mathematical algorithms.



Whatever form they take, scientific models are based on what is known about the systems or objects at the time that the models are constructed. Models usually evolve and are improved as scientific advances are made. Sometimes a model must be discarded because new findings show it to be misleading or incorrect.



Models are developed in an effort to explain how things work in nature. Because models are not the “real thing”, they can never correctly represent the system or object in all respects. The amount of detail that they contain depends upon how the model will be used as well as the sophistication and skill of the scientist doing the modeling. If a model has too many details left out, its usefulness may be limited. But too many details may make a model too complicated to be useful. So it is easy to see why models lack some features of the real system.

To overcome this difficulty, different models are often used to describe the same system or object. Scientists must then choose which model most closely fits the scientific investigation being carried out, which includes findings that are being described, and, in some cases, which one is compatible with the sophistication of the investigation itself. For example, there are many models of atoms. The solar system model described above is adequate for some purposes because electrons have properties of matter. They have mass and charge and they are found in motion in the space outside the nucleus. However, a highly mathematical model based on the field of quantum mechanics is necessary when describing the energy (or wave) properties of electrons in the atom.

Scientific models are based on physical observations that establish some facts about the system or object of interest. Scientists then combine these facts with appropriate laws or scientific principles and assumptions to produce a “picture” that mimics the behavior of the system or object to the greatest possible extent. It is on the basis of such models that science makes many of its most important advances because models provide a vehicle for making predictions about the behavior of a system or object. The predictions can then be tested as new measurements, technology or theories are applied to the subject. The new information may result in modification and refinement of the model, although certain issues may remain unresolved by the model for years. The goal, however, is to continue to develop the model in such a way as to move it ever closer to a true description of the natural phenomenon. In this way, models are vital to the scientific process.

Skill 1.2 Identify potentially hazardous situations in a physics laboratory and classroom, methods or prevention, and corrective actions.

Safety is a learned behavior and must be incorporated into instructional plans. Measures of prevention and procedures for dealing with emergencies in hazardous situations have to be in place and readily available for reference. Copies of these must be given to all people concerned, such as administrators and students.

The single most important aspect of safety is planning and anticipating various possibilities and preparing for the eventuality. Any Physics teacher/educator planning on doing an experiment must try it before the students do it. In the event of an emergency, quick action can prevent many disasters. The teacher/educator must be willing to seek help at once without any hesitation because sometimes it may not be clear that the situation is hazardous and potentially dangerous.

There are a number of procedures to prevent and correct any hazardous situation. There are several safety aids available commercially such as posters, safety contracts, safety tests, safety citations, texts on safety in secondary classroom/laboratories, hand books on safety and a host of other equipment. Another important thing is to check the laboratory and classroom for safety and report it to the administrators before staring activities/experiments. We will discuss below areas that need special attention to safety.

1. **Electricity:** Safety in this area starts with locating the main cut off switch. All the power points, switches, and electrical connections must be checked one by one. Batteries and live wires must be checked. All checking must be done with the power turned off. The last act of assembling is to insert the plug and the first act of disassembling is to take off the plug.

2. **Motion and forces:** All stationary devices must be secured by C-clamps. Protective goggles must be used. Care must be taken at all times while knives, glass rods and heavy weights are used. Viewing a solar eclipse must always be indirect. When using model rockets, NASA's safety code must be implemented.

3. **Heat:** The master gas valve must be off at all times except while in use. Goggles and insulated gloves are to be used whenever needed. Never use closed containers for heating. Burners and gas connections must be checked periodically. Gas jets must be closed soon after the experiment is over. Fire retardant pads and quality glassware such as Pyrex must be used.

4. **Pressure:** While using a pressure cooker, never allow pressure to exceed 20 lb/square inch. The pressure cooker must be cooled before it is opened. Care must be taken when using mercury since it is poisonous. A drop of oil on mercury will prevent the mercury vapors from escaping.

5. Light: Broken mirrors or those with jagged edges must be discarded immediately. Sharp-edged mirrors must be taped. Spectroscopic light voltage connections must be checked periodically. Care must be taken while using ultraviolet light sources. Some students may have psychological or physiological reactions to the effects of strobe like (e.g. epilepsy).

6. Lasers: Direct exposure to lasers must not be permitted. The laser target must be made of non-reflecting material. The movement of students must be restricted during experiments with lasers. A number of precautions while using lasers must be taken – use of low power lasers, use of approved laser goggles, maintaining the room's brightness so that the pupils of the eyes remain small. Appropriate beam stops must be set up to terminate the laser beam when needed. Prisms should be set up before class to avoid unexpected reflection.

7. Sound: Fastening of the safety disc while using the high speed siren disc is very important. Teacher must be aware of the fact that sounds higher than 110 decibels will cause damage to hearing.

8. Radiation: Proper shielding must be used while doing experiments with x-rays. All tubes that are used in a physics laboratory such as vacuum tubes, heat effect tubes, magnetic or deflection tubes must be checked and used for demonstrations by the teacher. Cathode rays must be enclosed in a frame and only the teacher should move them from their storage space. Students must watch the demonstration from at least eight feet away.

9. Radioactivity: The teacher must be knowledgeable and properly trained to handle the equipment and to demonstrate. Proper shielding of radioactive material and proper handling of material are absolutely critical. Disposal of any radioactive material must comply with the guidelines of NRC.

It is important that teachers and educators follow these guidelines to protect the students and to avoid most of the hazards. They have a responsibility to protect themselves as well. **There should be not any compromises in issues of safety.**

Skill 1.3 Identify the function and use of various common physics instruments (i.e., electrical meters, oscilloscopes, signal generators, and spectrometers).

Oscilloscope: An oscilloscope is a piece of electrical test equipment that allows signal voltages to be viewed as two-dimensional graphs of electrical potential differences plotted as a function of time.

The oscilloscope functions by measuring the deflection of a beam of electrons traveling through a vacuum in a cathode ray tube. The deflection of the beam can be caused by a magnetic field outside the tube or by electrostatic energy created by plates inside the tube. The unknown voltage or potential energy difference can be determined by comparing the electron deflection it causes to the electron deflection caused by a known voltage.

Oscilloscopes can also determine if an electrical circuit is oscillating and at what frequency. They are particularly useful for troubleshooting malfunctioning equipment. You can see the “moving parts” of the circuit and tell if the signal is being distorted. With the aid of an oscilloscope you can also calculate the “noise” within a signal and see if the “noise” changes over time.

Inputs of the electrical signal are usually entered into the oscilloscope via a coaxial cable or probes. A variety of transducers can be used with an oscilloscope that enable it to measure other stimuli including sound, pressure, heat, and light.

Voltmeter/Ohmmeter/Ammeter: A common electrical meter, typically known as a multimeter, is capable of measuring voltage, resistance, and current. Many of these devices can also measure capacitance (farads), frequency (hertz), duty cycle (a percentage), temperature (degrees), conductance (siemens), and inductance (henrys).

These meters function by utilizing the following familiar equations:

Across a resistor (Resistor R):

$$V_R = IR_R$$

Across a capacitor (Capacitor C):

$$V_C = IX_C$$

Across an inductor (Inductor L):

$$V_L = IX_L$$

Where V=voltage, I=current, R=resistance, X=reactance.

If any two factors in the equations are held constant or are known, the third factor can be determined and is displayed by the multimeter.

Signal Generator: A signal generator, also known as a test signal generator, function generator, tone generator, arbitrary waveform generator, or frequency generator, is a device that generates repeating electronic signals in either the analog or digital domains. They are generally used in designing, testing, troubleshooting, and repairing electronic devices.

A function generator produces simple repetitive waveforms by utilizing a circuit called an electronic oscillator or a digital signal processor to synthesize a waveform. Common waveforms are sine, sawtooth, step or pulse, square, and triangular. Arbitrary waveform generators are also available which allow a user to create waveforms of any type within the frequency, accuracy and output limits of the generator. Function generators are typically used in simple electronics repair and design where they are used to stimulate a circuit under test. A device such as an oscilloscope is then used to measure the circuit's output.

Spectrometer: A spectrometer is an optical instrument used to measure properties of light over a portion of the electromagnetic spectrum. Light intensity is the variable that is most commonly measured but wavelength and polarization state can also be determined. A spectrometer is used in spectroscopy for producing spectral lines and measuring their wavelengths and intensities. Spectrometers are capable of operating over a wide range of wavelengths, from short wave gamma and X-rays into the far infrared. In optics, a spectrograph separates incoming light according to its wavelength and records the resulting spectrum in some detector. In astronomy, spectrographs are widely used with telescopes.

Skill 1.4 Identify leading physicists and their contributions.

Archimedes

Archimedes was a Greek mathematician, physicist, engineer, astronomer, and philosopher. He is credited with many inventions and discoveries some of which are still in use today such as the Archimedes screw. He designed the compound pulley, a system of pulleys used to lift heavy loads such as ships.

Although Archimedes did not invent the lever, he gave the first rigorous explanation of the principles involved which are the transmission of force through a fulcrum and moving the effort applied through a greater distance than the object to be moved. His Law of the Lever states that magnitudes are in equilibrium at distances reciprocally proportional to their weights.

He also laid down the laws of flotation and described Archimedes' principle which states that a body immersed in a fluid experiences a buoyant force equal to the weight of the displaced fluid.

Niels Bohr
Bohr was a Danish physicist who made fundamental contributions to understanding atomic structure and quantum mechanics. Bohr is widely considered one of the greatest physicists of the twentieth century.
Bohr's model of the atom was the first to place electrons in discrete quantized orbits around the nucleus.

Bohr also helped determine that the chemical properties of an element are largely determined by the number of electrons in the outer orbits of the atom. The idea that an electron could drop from a higher-energy orbit to a lower one emitting a photon of discrete energy originated with Bohr and became the basis for future quantum theory.

He also contributed significantly to the Copenhagen interpretation of quantum mechanics. He received the Nobel Prize for Physics for this work in 1922.

Marie Curie
Curie was as a Polish-French physicist and chemist. She was a pioneer in radioactivity and the winner of two Nobel Prizes, one in Physics and the other in Chemistry. She was also the first woman to win the Nobel Prize.

Curie studied radioactive materials, particularly pitchblende, the ore from which uranium was extracted. The ore was more radioactive than the uranium extracted from it which led the Curies (Marie and her husband Pierre) to discover a substance far more radioactive then uranium. Over several years of laboratory work the Curies eventually isolated and identified two new radioactive chemical elements, polonium and radium. Curie refined the radium isolation process and continued intensive study of the nature of radioactivity.

Albert Einstein
Einstein was a German-born theoretical physicist who is widely considered one of the greatest physicists of all time. While best known for the theory of relativity, and specifically mass-energy equivalence, $E = mc^2$, he was awarded the 1921 Nobel Prize in Physics for his explanation of the photoelectric effect and "for his services to Theoretical Physics". In his paper on the photoelectric effect, Einstein extended Planck's hypothesis ($E = h\nu$) of discrete energy elements to his own hypothesis that electromagnetic energy is absorbed or emitted by matter in quanta and proposed a new law $E_{\max} = h\nu - P$ to account for the photoelectric effect.

He was known for many scientific investigations including the special theory of relativity which stemmed from an attempt to reconcile the laws of mechanics with the laws of the electromagnetic field. His general theory of relativity considered all observers to be equivalent, not only those moving at a uniform speed. In general relativity, gravity is no longer a force, as it is in Newton's law of gravity, but is a consequence of the curvature of space-time.

Other areas of physics in which Einstein made significant contributions,