Lesson 1
Scientific Method, Measurement, and Units

Introduction: Connecting Your Learning

The laws of physics affect everything in life. Many take this introductory course as a college/university requirement, to earn credits in science, or as a curious student for personal improvement. This course focuses on the laws, principles, and properties that underlie the fundamentals of physics. Lesson 1 introduces the nature of science, the scientific method, scientific measurement, and systems of units. The scientific method is presented to provide a framework for understanding the nature of scientific inquiry. The relationship between science and technology is discussed, and an introduction to scientific literature is presented.

Readings, Resources, and Assignments	
Required Textbook Readings	*Newtonian Physics* Chapter 0, pp. 19-38

Check Prior Knowledge

Check your prior knowledge by answering the following true/false questions. If physics is a new experience, you may not know the answers due to a lack of exposure to the information or the skills necessary to figure out the answer (i.e., maybe a mathematics skill is required). That is perfectly understandable, and this is why students take classes. You should think about each question in terms of what new knowledge or skills are required to answer the question. This is also a good time to start writing down any unfamiliar words to look up. It is convenient and often tempting to just gloss over unknown words, but that is not a good habit!

If the answer is false, what change would make the statement true? The answers for all practice activities are located at the end of the lesson.

1. A scientific theory and a scientific hypothesis are really the same thing.
2. A scientific hypothesis must be testable.
3. One very important job of a scientist is to prove scientific theories correct.
4. Scientific measurements are usually exact.
5. Qualitative data represents measurements with at least three significant digits.
6. The first step in the scientific method is usually an observation.
7. A meter and a yard are approximately equal (less than 6 inches difference).
8. The unit of measure of work is Newtons.

9. A nano is the metric prefix equal to 1/1,000,000,000 or 10^{-9}.

10. The unit of metric unit of measure for temperature is Fahrenheit.

Remember, the purpose for checking for prior knowledge is not to see how many correct answers you can accumulate (due to knowing or guessing), but instead, it is intended for you to start attaching prior knowledge to the new knowledge you are striving to acquire. In the next section of this lesson, read the objectives and start thinking about what method might work best to achieve the objectives. Some examples for this lesson might include, but are certainly not limited to:

- Making a timeline
- Making a table
- Drawing a graph
- Making a concept map

What other approaches to learning work well for you?

Focusing Your Learning

A note concerning the Textbook:

The textbooks used in this course are open resource texts that can be found at The Light and Matter Series. The books are free to download. Throughout the course, you will be directed to specific content located in the book, which is also included as a PDF in the lesson. You may want to download the entire book from the link provided, or you even have the option to buy a printed copy of the book.

The textbooks used in this course cover the critical concepts needed to understand physics, and they complement each online lesson. All assigned readings are pertinent to the content of this course.

Lesson Objectives

By the end of this lesson, you should be able to:

1. Apply the process of the scientific method using proper scientific terminology in the context of conducting scientific experiments.

2. Compare and contrast the current systems of units and measurements used in modern science and make simple conversions between USCS and metric units.

Approaching the Objectives

This lesson is comprised of three sections:

Section 1: The Nature of Scientific Inquiry and the Scientific Method

Section 2: Communication in Science Using Mathematics

Section 3: Units of Measurement in the Sciences

Section 1: The Nature of Scientific Inquiry and the Scientific Method

Begin by reading Chapter 0, Section 0.1 to 0.4, pp. 19 to 27 in the *Newtonian Physics* textbook.

Observations and Inferences

Observations involve using your senses (i.e., sight, hearing, touch, etc.) to gather information about the outside world. Observations fall into two categories: *qualitative* and *quantitative*. Qualitative observations do not involve numbers. For example, if you say that a car is fast, you are making a qualitative observation. Of course, fast is a relative term. Fast compared to what? Fast compared to a snail or a jet airplane? Often, qualitative observations do not provide sufficient information to be useful. Quantitative observations, on the other hand, involve attaching a numerical measurement to the observation. For example, the car's speed was measured at 87.4 miles per hour is a quantitative observation. Observations can be *direct* or *indirect*. If an instrument such as an electron microscope is used to observe something too small for the eye to see, then the observation is indirect. Measurements are a form of observation made with an instrument. If a quantity is measured with a ruler, for example, that is a measurement as well as a direct observation.

An *inference* is different from an observation. Inferences usually follow from an observation. For example, an observer might see that the ground is wet. That observer may *infer* that it rained the night before. It would be incorrect to assume that it rained because the observer may not have seen it rain. He or she inferred that it rained based on the observation of the wet ground. Scientists must not confuse observations and inferences.

The next step following a scientific observation or scientific question is to propose a plausible explanation or answer to the question.

Hypotheses

An educated guess in answer to a scientific question is called a hypothesis. The key to proposing a valid hypothesis is to ensure that the hypothesis is *testable*. Not all proposed explanations or educated guesses fit into this category. If the hypothesis cannot be tested or there is no way to prove it wrong, then the hypothesis is not a valid scientific hypothesis. If a hypothesis is testable, it must be possible to design an experiment that is capable of showing that the hypothesis is false. This is known as *falsifiability*. The hypothesis may, in fact, not be false; that is perfectly acceptable. However, the hypothesis must be able to stand up to an experiment designed to prove the hypothesis false. A hypothesis can never be proven true; consequently, there is always a chance that an experiment can be devised to show the hypothesis to be incorrect. After the hypothesis is proposed and deemed falsifiable, the next step in the process is to design and perform the experiment and gather data.

Experimental Design

Experiments are designed to test hypotheses. One type of experiment is referred to as a *controlled* experiment. Normally, two variables are selected. One variable is manipulated or changed, and the resultant response of the second variable is observed or measured. The manipulated variable is referred to as the *independent variable* (this is discussed in more detail below). The variable that responds or changes due to manipulating the independent variable is referred to as the *dependent variable*. From a graphical perspective, in the normal x-y coordinate system where x refers to the horizontal axis and y refers to the vertical axis, the independent variable is plotted on the x-axis, and the dependent variable is plotted on the y-axis. The other factors that may influence the resultant variable are kept constant. These are referred to as *controlled variables*. A group of many experiments that produce similar findings can be pieced together to form a scientific law or principle.

Data

Any observations or measurements collected are called data. Data can be qualitative or quantitative, as discussed above. Scientists usually organize data into tables, which can be used to produce graphs. Data displayed in graphs often make it easier to spot trends or relationships between the variables or quantities being observed.

Results

Each experiment should produce results of some kind. The results may be what were expected, or they may be completely the opposite. Many important scientific discoveries have come about from unexpected results.

Conclusions

In the context of the scientific method, the *conclusion* forms the acceptance or the rejection of the hypothesis. This is sometimes referred to as *evidence*. It is important to remember that evidence is not the same as proof. If competent and well-respected experimenters assemble enough evidence, this evidence may be formulated into a law or principle that describes how nature is behaving. If the hypothesis is rejected, then the choice may be to formulate a new hypothesis that is testable and falsifiable and design a new experiment. No matter how much positive evidence is gathered, there is never enough to claim that the hypothesis has been proven true. However, even a small amount of evidence can show a hypothesis to be false.

Laws and Principles

A scientific law or principle is a summary of many experimental results. An abundance of evidence exists to support a scientific law or principle that explains how nature is behaving. Laws and principles attempt to explain how something works or how nature behaves the way it does. For example, Newton's Laws of Motion (studied in the next lesson) allow you to predict the motion of an object if the force on the object is known. Laws and principles predict how and not why.

Theories

A scientific theory is a large collection of scientific laws and principles that attempt to explain why nature behaves the way it does. Theories are like facts, laws, and principles in that they are subject to change. Theories are not absolute. Theories can never be proven right, only wrong. A prime example of a theory in physical science is the atomic theory. This is a large collection of facts and principles that, when pieced together, inform scientists why matter behaves or exhibits the characteristics that it does. The atomic theory as known today is very different from the atomic theory only 50 years ago. New information is continuously being gathered by research scientists to upgrade and refine theories.

After developing a theory, it is essential to be able to communicate the findings and details of the theory to other scientists and society in general. One of the languages used to communicate scientific information is mathematics. Mathematics is often more concise, explicit, and compact than other forms of language. Of course, other forms of language are usually used in conjunction with mathematics to make the presentation easier to read or understand. Two primary forms of communicating scientific information are equations and graphs.

Section 2: Communication in Science using Mathematics

Variables and Constants

One purpose for performing an experiment, besides testing a hypothesis, is to search for *cause* and *effect* relationships. The idea is to find out if changing one specific quantity will cause another quantity to also undergo a change. The symbols that represent these quantities are called variables. One variable is manipulated (independent variable) in order to see if this causes a change (effect) in another variable. Quantities that do not change are referred to as constants. It is sometimes convenient to represent these quantities with shorthand symbols and produce equations that stipulate one set of quantities is equal to another set of quantities.

Proportions

Proportions describe how one quantity responds to another quantity. A *direct proportion* occurs when the increase in one quantity causes an increase in another quantity, or a decrease in one quantity causes a decrease in another quantity.

An inverse or indirect proportion arises when an increase in one quantity causes a decrease in another quantity or vice versa. Proportions can be made into equations if a constant of proportionality is added.

For example, the acceleration of an object is directly proportional to the net force acting on the object. This is written: **a α F**. The acceleration of an object is inversely proportional to its mass: **a α 1/m**. **Note:** The "α" is the Greek letter alpha and can be read as "is proportional to."

Equations and Formulas

When the proportionalities are combined, the result may be an equation. For example, the acceleration (a) on an object is equal to the net force on the object divided by the object's mass. **It is okay if you don't know what these quantities actually mean right now.**

These symbols can be used to generate an equation: a = F/m

Equations are symbolic representations for the relationships between quantities that the scientist understands. Some people call these relationships *formulas* as well. The distinction is sometimes made that a formula is a set of symbols that may or may not be understood by the person using the formula, but it can be used to generate answers anyway.

Ratios

Different quantities are often divided by one another to form a *ratio*. Ratios sometimes form another useful quantity that can be used to describe matter or other physical relationships. For example, when the mass of an object (the amount of matter) is divided by the volume of the object, the ratio is referred to as *density*. Density is a very useful description of matter because it does not depend on the quantity of matter being described. One brick has the same density as 1,000 bricks made of the same material, whereas the masses and the volumes of these two quantities of bricks are very different.

Graphs

Graphs are a visual representation of how one variable responds to another variable. There are many different ways to draw graphs. The three most common types of graphs used in science are line graphs, bar graphs, and pie graphs.

Line graphs:

Line graphs are most often used to demonstrate how one variable changes with respect to another variable. Line graphs show continuous change. For example, a line graph would be a good way to show how the position of a moving object changed with respect to time.

Pie graphs:

Pie graphs (or pie charts) show how each part of the data set data relates to the whole data set. For example, a pie chart would be a good way to display the various compounds (i.e., nitrogen, oxygen, argon, etc.) that make up the total composition of the atmosphere.

Bar graphs:

Bar graphs are useful to show changes in variables that are not continuous and to illustrate trends in data over long periods of time.

Perform an Internet search and locate examples of each type of graph.

Section 3: Units of Measurement in the Sciences

Begin by reading Chapter 0, Section 0.5 to 0.8, pp. 28 to 33 in the *Newtonian Physics* textbook. The SI system is the system of units used by scientists to communicate scientific information worldwide and in all scientific journals and magazines. The SI system is one of two commonly used metric systems utilized in science for everyday work. The SI system is sometimes referred to as the "MKS" system. The letters refer to M-meters, K-kilograms and S-seconds (length, mass, and time). In some branches of science (e.g., chemistry), meters (about one yard) and kilograms (about the weight of a golf ball made of brass) are cumbersome quantities to deal with in some laboratory applications. Therefore, it is common to use one-hundredth of a meter (centimeter) and one-thousandth of a kilogram (gram) instead. This alternate system is still metric in nature and is referred to as the "CGS" system.

In the United States, the metric systems (i.e., MKS and CGS) are not commonly used in non-scientific applications. For example, a likely temperature on a hot summer day in Lake Havasu City, Arizona might be 120°F. However, in most other places in the world, this temperature would be read as 49°C. A scientist would report this same temperature as 322 Kelvin (K) in a scientific article he or she might be writing. When a person goes to the meat market to buy a prime rib for a holiday feast, the butcher might weigh the meat at 18 pounds; this would be about 8.2 kg in other parts of the world.

In science, the metric system (SI system) is used to communicate data and measurements to other scientists. The metric system is the system in use around the world.

There are seven fundamental dimensions (or measurements) that can be used to describe observations in nature. These dimensions are mass, length, time, temperature, quantity of material (i.e., number of things), electric current, and luminosity (brightness). In order for these qualitative descriptors to have meaning, they must be accompanied by a system of units that quantifies the description. For example, mass can be generally defined as the amount of matter present in a sample. In order for this concept to be useful, you must first define a standard mass and measure the objects relative to that standard mass. The unit chosen for mass is the kilogram (kg). In more familiar terms for some, one kilogram is about 2.2 pounds (Note: Pounds are a unit of force, not mass, in this country.) The actual unit for mass in the USCS system is the slug, which is rarely ever used. There are many systems of units; however, the three primary unit systems are the International System (SI), a scaled down version of the SI system (CGS), and the USCS System. The table below shows the standard units for each of the seven dimensions in the three unit systems.

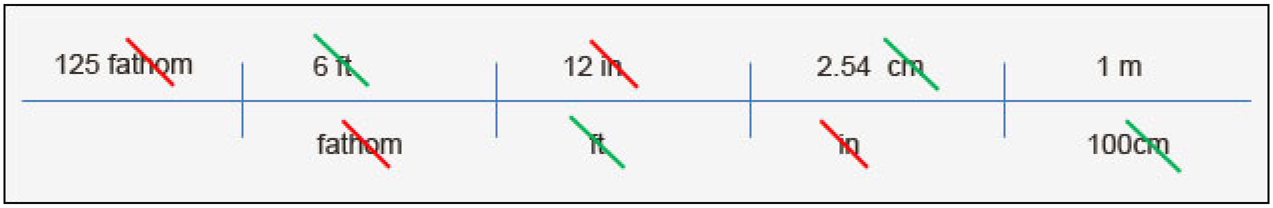
Measurement	SI Standard Unit
Mass	Gram (g)
Length	Meter (m)
Time	Second (s)
Temperature	Kelvin (K)
Force	Newton (N)
Energy	Joules (J)
Electric current	Ampere (A)
Electric potential	Volts (V)
Resistance	Ohms (Ω)
Power	Watts (W)
Frequency	Hertz (Hz)

It is important to be able to convert from one system of units to another. For example, a car's velocity may be expressed in miles per hour, but you are asked to calculate the acceleration in meters/second^2. You will need to know how to convert between miles and meters as well as hours and seconds. The method used is called the factor-label method. You will be introduced to this method in the following section.

The Math

Begin by reading Chapter 0, Section 0.9 to 0.10, pp. 34 to 38 in the *Newtonian Physics* textbook. This can be found in the appendix, located after the lessons.

Throughout this course, you will be required to use metric prefixes as well as convert between prefixes. Metric prefixes provide a value for units. The above standard units can be expressed using metric prefixes. For example, a nanosecond and the kilometer are both common units used in physics. The prefix decreases the number of zeroes used to express a number. The prefixes you will need to know are provided here.



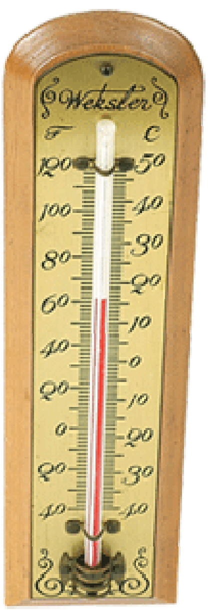
Metric prefixes are also used to convert between units, for example converting from a centimeter to a kilometer.

Metric conversions

The factor-label method is used to convert between prefixes or even between units of conversion. Common units of conversion are provided here.

Technique for Unit Conversion

Taking measurements and converting units is a skill that is useful in many applications of everyday life.



This thermometer shows two different temperature scales. The scale on the right is referred to as the Celsius scale or sometimes the Centigrade scale. This scale is based on the freezing and boiling points of pure water. The scale is conveniently divided into 100 divisions between these two defined temperatures. Around the same time that the Celsius scale was being developed, another scientist, Daniel Fahrenheit, wanted the zero point to be the coldest temperature he could obtain. This occurred when equal parts of salt were added to water. Other factors such as wanting to have 64 equal intervals between certain fixed points on the scale led to water boiling at about 212° on the Fahrenheit scale. After all of the calibrations and adjustments were performed, this resulted in the Fahrenheit degree being smaller than the Celsius degree by a factor of 100/180 or (5/9). This coupled with the 32° offset explained above leads to the equation that can be used to convert between the temperature scales.

$^{o}C = 5/9\ (^{o}F - 32)$ (Equation 1)

Check this by substituting 32 for ^{o}F. This yields: $^{o}C = 5/9\ (32 - 32) = 0$, which corresponds to what is expected. Likewise, substitute 212 for ^{o}F. This yields: $^{o}C = 5/9\ (212 - 32) = 5/9\ (180) = 100$. Therefore, when the temperature is $212^{o}F$, this corresponds to $100^{o}C$. Which is smaller, a degree Fahrenheit or a degree Celsius? A degree Fahrenheit is smaller by a factor of 5/9. Which represents a wider range in temperatures: $10^{o}F$ or $10^{o}C$? A 10° Celsius difference represents a wider range in temperatures.

Math Challenge: Use the above equation and solve for ^{o}F.

Hint: If $y = 5/9(x - 32)$ what does $x = ??$

Answer

$x = 9/5y + 32$ (Equation 1)

So...

°F = 9/5 °C + 32 (Equation 2)

Note the importance of the parentheses in the first equation. In Equation 1, subtract first and then multiply and divide. In Equation 2, multiply and divide first and then add. The order of operations makes a huge difference!

Activity: Complete the following conversions between metric prefixes and units. Answers can be found at the end of the lesson.

1.

1.5 mm to km

4.

1.43 in to cm

2.

3.7 ns to s

5.

25 km to miles

3.

.75 gm to cm

6.

58 miles/hour to km/s

A basic understanding of angles and degrees will be needed for this course. Physics expresses motions in two dimensions. These two dimensions relate to one another based on angles. You do not need to be able to solve problems using trigonometry; however, you should understand the basic premises of trigonometry and right angles.

View the video from Khan Academy on Basic Trigonometry

Summarizing Your Learning

This lesson provided basic tools (i.e., units, conversion factors, and basic mathematics terms) that are needed in most science classes. This skill is not only useful in science, but extends to other areas as well.

Practice Answers

Check Prior Knowledge

1. A scientific theory and a scientific hypothesis are really the same thing. False
2. A scientific hypothesis must be testable. True
3. One very important job of a scientist is to prove scientific theories correct. False
4. Scientific measurements are usually exact. False
5. Qualitative data represent measurements with at least 3 significant digits. False
6. The first step in the scientific method is usually an observation. True
7. A meter and a yard are approximately equal (less than 6 inches difference). True
8. The unit of measure of work is Newtons. False
9. A nano is the metric prefix equal to 1/1,000,000,000 or 10-9. True
10. The unit of metric unit of measure for temperature is Fahrenheit. False

Section 3: The Math

Complete the following conversions between metric prefixes and units.

1. 1.5 mm to Km = 1.5x10^-6Km
2. 3.7 ns to s = 3.7x10^-9s
3. .75 Gm to cm = 7.5x10^10cm
4. 1.43 in to cm = 3.6322 cm
5. 25 Km to miles = 15.534 miles
6. 58 miles/hour to Km/s = 0.026 Km/s