

SUBAREA I.

FOUNDATIONS OF SCIENTIFIC INQUIRY

Competency 1.0 Understand the relationships and common themes that connect mathematics, science, and technology.

The union of science, technology, and mathematics has shaped the world we live in today. Science describes the world. It attempts to explain all aspects of how nature works, from our own bodies to the tiny particles making up the world, from the entire earth to the universe beyond. Science lets us know in advance what will happen when a cell splits or when two chemicals react. Yet, science is ever-evolving. Throughout history, people have developed and validated many different ideas about the processes of the universe. Frequently, the development of new technology used in conducting experiments allows for new information and theories to emerge.

Technology makes use of scientific knowledge to solve real-world problems. For example, science is used to study the flow of electrons, but technology is required to channel the flow of electrons to create a supercomputer. **Basic research** generally refers to investigation of fundamental scientific principles. **Applied research** is oriented toward making use of basic research in technology development. Applied research is dependent on basic research, and both are necessary for technology advancement. Mathematics, in turn provides the language that allows this knowledge to be communicated. It allows the creation models for scientists to use in explaining natural phenomena and is also the language of technology and computers.

The economy today is dependent upon the existence of technology. The job market changes as new technologies develop. For example, with the advent of computers, many trained workers in information science and technology are needed, moving our economy from a manufacturing-based economy to a knowledge-based economy. Industrial labs are being redefined or eliminated, creating a convergence between scientific disciplines and engineering and providing for new entrepreneur opportunities.

At the same time, advances in scientific knowledge and technology often present ethical dilemmas for society. Industrialization brought about the consumption of great amounts of energy, for example. This, in turn, created environmental problems, lead to wars, and a depletion of natural resources. Scientific knowledge tells us there is oil is shale that we have not accessed yet. Technology developments will allow us to reach the oil and power our economy. At the same time, new technologies will emerge providing for alternative power supplies like wind farms or soy fuels. New types of skills will be needed to support these new technologies and the job market; education and our society will shift in response.

The need for technology development drives science, and in turn discoveries in science influence society and allow new technologies to be developed. The first personal computers were mass-marketed by IBM and Apple in the late 1970s. The IBM 5100 had 16K of memory, a five-inch screen, and cost nearly \$11,000 in 1975! A mere twenty-five years later, computers are everywhere and used for everything, with gigabytes of memory and monitors larger than some televisions. Why did computers develop so quickly? It was the interconnection between science, technology, and society.

Competency 2.0 Understand the historical and contemporary contexts of the study of chemistry

Development of Modern Chemistry

Chemistry emerged from two ancient roots: craft traditions and philosophy. The oldest ceramic crafts (pottery) known are from roughly 10,000 BC in Japan. Metallurgical crafts in Eurasia and Africa began to develop by trial and error around 4000-2500 BC resulting in the production of copper, bronze, iron, and steel tools. Other craft traditions in brewing, tanning, and dyeing led to many useful empirical ways to manipulate matter.

Ancient philosophers in Greece, India, China, and Japan speculated that all matter was composed of four or five elements. The Greeks thought that the four elements were fire, air, earth, and water. Indian philosophers and the Greek, Aristotle, also thought a fifth element — "aether" or "quintessence" — filled all of empty space. The Greek philosopher Democritus thought that matter was composed of indivisible and indestructible atoms. These concepts are now known as classical elements and classical atomic theory.

Before the emergence of the scientific method, attempts to understand matter relied on alchemy: a mixture of mysticism, best guesses, and supernatural explanations. The goals of alchemy included the transmutation of other metals into gold and the synthesis of an elixir to cure all diseases. Ancient Egyptian alchemists developed cement and glass. Chinese alchemists developed gunpowder in the 800s AD.

During the height of European alchemy in the 1300s, the philosopher, **William of Occam**, proposed the idea that when trying to explain a process or develop a theory, the simplest explanation with the fewest variables is the best one. This is known as **Occam's Razor**. European alchemy slowly developed into modern chemistry during the 1600s and 1700s. This began to occur after **Francis Bacon** and **René Descartes** described the scientific method in the early 1600s.

Robert Boyle was educated in alchemy in the mid-1600s, but he published a book called *The Sceptical Chemist* that attacked alchemy and advocated using the scientific method. He is sometimes called the founder of modern chemistry because of his emphasis on proving a theory before accepting it, but the birth of modern chemistry is usually attributed to Lavoisier. Boyle rejected the four classical elements and proposed the modern definition of an element. Boyle's law states that the volume of a gas is proportional to the reciprocal of pressure.

Blaise Pascal, in the mid-1600s, determined the relationship between **pressure** and the height of a liquid in a **barometer**. He also helped to establish the scientific method. The SI unit of pressure is named after him.

Isaac Newton studied the nature of **light**, the laws of **gravity**, and the **laws of motion** around 1700. The SI unit of force is named after him.

Daniel Bernoulli proposed the **kinetic molecular theory** for gases in the early 1700s to explain the nature of heat and Boyle's Law. At that time, heat was thought to be related to the release of a substance called *phlogiston* from combustible materials.

James Watt created an efficient **steam engine** during the 1760s through 1780s. Later chemists and physicists would develop the theory behind this empirical engineering accomplishment. The SI unit of power is named after him.

Joseph Priestley studied various gases in the 1770s. He was the first to produce and drink **carbonated water**, and he was the first to isolate **oxygen** from air. Priestley thought oxygen was air with its normal phlogiston removed, so it could burn more fuel and accept more phlogiston than natural air.

Antoine Lavoisier is called the **father of modern chemistry** because he performed **quantitative, controlled experiments**. He carefully weighed material before and after combustion to determine that burning objects gain weight. Lavoisier formulated the rule that **chemical reactions do not alter total mass**, after finding that reactions in a closed container did not cause the total weight to change. This disproved the phlogiston theory, and he named Priestley's substance oxygen. He demonstrated that air and water were not elements. Lavoisier defined an element as a substance that could not be broken down further. He published the first modern chemistry textbook, *Elementary Treatise of Chemistry*. Lavoisier was executed in the Reign of Terror at the height of the French Revolution.

Gas Laws Developed in the 1700s and 1800s

These contributions were built on the foundation developed by Boyle in the 1600s. **Jacques Charles** developed **Charles' law** in the late 1700s. This law states that gas volume is proportional to absolute temperature.

William Henry developed a law that stated that gas solubility in a liquid is proportional to the pressure of gas over the liquid. This is known as **Henry's Law**.

Joseph Louis Gay-Lussac developed a gas law stating that gas pressure is directly proportional to absolute temperature. He also determined that two volumes of hydrogen react with one of oxygen to produce water and that other reactions occurred with similar simple ratios. These observations led him to develop the **Law of Combining Volumes**.

Amedeo Avogadro developed the hypothesis that **equal volumes of different gases contain equal numbers of molecules** if the gases are at the same temperature and pressure. The proportionality between volume and number of moles is called **Avogadro's Law**, and the number of molecules in a mole is called **Avogadro's Number**. Both were posthumously named in his honor.

Thomas Graham developed **Graham's Law** of effusion and diffusion in the 1830s. He is called the father of **colloid chemistry**.

Electricity and Magnetism in the 1700s and 1800s

Benjamin Franklin studied electricity in the mid-1700s. He developed the concept of **positive and negative electrical charges**. His most famous experiment showed that lightning is an electrical process.

Luigi Galvani discovered **bioelectricity**. In the late 1700s, he noticed that the legs of dead frogs twitched when they came into contact with an electrical source.

In the late 1700s, **Charles-Augustin de Coulomb** derived mathematical **equations for attraction and repulsion** between electrically charged objects.

Alessandro Volta built the first **battery** in the 1800s, permitting future research and applications to have a source of continuous electrical current available. The SI unit of electric potential difference is named after him.

André-Marie Ampère created a mathematical theory in the 1820s for magnetic fields and electric currents. The SI unit of electrical current is named after him.

Michael Faraday is best known for his work in the 1820s and 1830s establishing that a moving magnetic field induces an electric potential. He built the first **dynamo** for electricity generation. He also discovered benzene, invented oxidation numbers, and popularized the terms **electrode**, **anode**, and **cathode**. The SI unit of electrical capacitance is named in his honor.

James Clerk Maxwell derived the **Maxwell Equations** in 1864. These expressions completely describe **electric and magnetic fields** and their interaction with matter. Also see Ludwig Boltzmann below for Maxwell's contribution to thermodynamics.

Nineteenth century chemistry: caloric theory and thermodynamics

Lavoisier proposed in the late 18th century that the heat generated by combustion was due to a weightless material substance called **caloric** that flowed from one place to another and was never destroyed.

In 1798, **Benjamin Thomson**, also known as **Count Rumford**, measured the heat produced when cannon were bored underwater and concluded that caloric was not a conserved substance because heat could continue to be generated indefinitely by this process.

Sadi Carnot, in the 1820s, used caloric theory to develop theories for the **heat engine** to explain the engine already developed by Watt. Heat engines perform mechanical work by expanding and contracting a piston at two different temperatures.

Also in the 1820s, Robert **Brown** observed dust particles and particles in pollen grains moving in a random motion. This was later called **Brownian motion**.

Germain Henri Hess developed **Hess' Law** in 1840 after studying the heat taken up by or emitted from reactions was composed of several steps.

James Prescott Joule determined the equivalence of heat energy to mechanical work in the 1840s by carefully measuring the heat produced by friction. Joule attacked the caloric theory and played a major role in the acceptance of **kinetic molecular theory**. The SI unit of energy is named after him.

William Thomson, 1st Baron of Kelvin, also called **Lord Kelvin**, theorized the existence of **absolute temperature** in the 1840s and proposed the temperature scale that is named after him. He failed in an attempt to reconcile caloric theory with Joule's discovery, and caloric theory began to fall out of favor.

Hermann von Helmholtz, in the 1840s, proposed that **energy is conserved** during physical and chemical processes, not heat as proposed in caloric theory.

Rudolf **Clausius** introduced the concept of **entropy** in the 1860s.

In the 1870s, **Ludwig Boltzmann** generalized earlier work by Maxwell solving the **velocity or energy distribution among gas molecules**. The final diagram in shows the Maxwell-Boltzmann distribution for kinetic energy at two temperatures. Maxwell's contribution to electromagnetism is described above.

In the 1870s, **Johannes van der Waals**, was the first to consider **intermolecular attractive forces** in modeling the behavior of liquids and non-ideal gases.

Francois Marie Raoult studied colligative properties in the 1870s. He developed **Raoult's Law** relating solute and solvent mole fraction to vapor pressure lowering.

Jacobus van 't Hoff was the first to fully describe **stereoisomerism** in the 1870s. He later studied **colligative properties** and the impact of temperature on equilibria.

Josiah Willard Gibbs studied thermodynamics and statistical mechanics in the 1870s. He formulated the concept, now known as **Gibbs free energy**, which determines whether or not a chemical process will spontaneously occur at constant pressure.

Henri Louis **Le Chatelier** studied how chemical **equilibrium** is affected by a change in conditions in the 1880s, now defined as **Le Chatelier's Principle**.

In the 1880s, **Svante Arrhenius** developed the idea of **activation energy**. He also described the dissociation of salts, including **acids and bases**, into ions. Before then, salts in solution were thought to exist as intact molecules, and ions were mostly thought to exist as electrolysis products. Arrhenius also predicted that CO₂ emissions would lead to global warming.

In 1905, **Albert Einstein** created a **mathematical model of Brownian motion** based on the impact of water molecules on suspended particles. Kinetic molecular theory could now be observed under the microscope. Einstein's more famous later work on **relativity** may be applied to chemistry by correlating the energy change of a chemical reaction with extremely small changes in the total mass of reactants and products.

Nineteenth and Twentieth Century: Atomic Theory

See Competency 0007 for the contributions to atomic theory of John **Dalton**, J. J. **Thomson**, Max **Planck**, Ernest **Rutherford**, Niels **Bohr**, Louis **de Broglie**, Werner **Heisenberg**, and Erwin **Schrödinger**.

Wolfgang **Pauli** helped to develop quantum mechanics in the 1920s by forming the concept of spin and the **exclusion principle**.

Friedrich **Hund** determined a set of **rules to determine the ground state** of a multi-electron atom in the 1920s (**Hund's Rule**).

Discovery and synthesis: nineteenth century

Humphry Davy used Volta's battery in the early 1800s for **electrolysis of salt solutions**. He separated several molecules into pure elements using electrolysis to generate non-spontaneous reactions. **Jöns Jakob Berzelius** isolated several elements, but he is best known for inventing modern **chemical notation** by using one or two letters to represent elements in the early 1800s.

Friedrich Wöhler isolated several elements, but he is best known for the chemical synthesis of an **organic compound** in 1828, using the carbon atom in silver cyanide. Before Wöhler, many had believed that a transcendent "life-force" was needed to make the molecules of life.

Justus von Liebig studied the chemicals involved in agriculture in the 1840s. He has been called the **father of agricultural chemistry**.

Louis Pasteur studied **chirality** in the 1840s by separating a mixture of two chiral molecules. He is better known in biology for discovering the germ theory of disease.

Henry Bessemer, in the 1850s, developed the **Bessemer Process** for mass producing steel by blowing air through molten iron to oxidize impurities.

Friedrich August Kekulé von Stradonitz studied the chemistry of carbon in the 1850s and 1860s. He proposed the **ring structure of benzene** and the tetravalent nature of carbon.

Anders Jonas Ångström was one of the founders of the science of spectroscopy. In the 1860s, he found hydrogen and other **elements in the spectrum of the sun**. A non-SI unit of length equal to 0.1 nm is named for him.

Alfred Nobel invented the explosive **dynamite** in the 1860s and continued to develop other explosives. In his will he used his fortune to establish the **Nobel Prizes**.

Dmitri Mendeleev developed the first modern **periodic table** in 1869.

Discovery and synthesis: turn of the 20th century

William Ramsay and **Lord Rayleigh** (John William Strutt) isolated the **noble gases**.

Wilhelm Konrad Röntgen discovered **x-rays**.

Antoine Henri Becquerel discovered **radioactivity** using uranium salts.

Marie Curie discovered the property of radioactivity and determined that it was a **property of atoms** that did not depend on which molecule contained the element.

Pierre and Marie Curie utilized the properties of radioactivity to **isolate radium** and other radioactive elements. Marie Curie was the first woman to receive a Nobel Prize and the first person to receive two. Her story continues to be inspiring. See <http://nobelprize.org/physics/articles/curie/index.html> for a biography.

Frederick Soddy and **William Ramsay** discovered that radioactive decay can produce helium (**alpha particles**).

Fritz Haber developed the process for synthesizing ammonia from hydrogen and nitrogen using an iron **catalyst (Haber Process)**. Ammonia is still produced by this method to make fertilizers, textiles, and other products.

Robert Andrew Millikan determined the **charge of an electron** using an oil-drop experiment.

Discovery and synthesis: 20th century

Gilbert Newton Lewis described **covalent bonds** as sharing electrons in the 1910s and the **electron pair donor/acceptor theory of acids and bases** in the 1920s. Lewis dot structures and Lewis acids are named after him.

Johannes Nicolaus Brønsted and **Thomas Martin Lowry** simultaneously developed the **proton donor/acceptor theory of acids and bases** in the 1920s.

Irving Langmuir, in the 1920s, developed the science of **surface chemistry** to describe interactions at the interface of two phases. This field is important to heterogeneous catalysis.

Fritz London studied the electrical nature of chemical bonding in the 1920s. The weak intermolecular **London dispersion forces** are named after him.

In the 1930s, **Hans Wilhelm Geiger** developed the **Geiger counter** for measuring ionizing radiation.

Wallace Carothers and his team first synthesized **organic polymers** (including neoprene, polyester and nylon) in the 1930s.

In the 1930s, **Linus Pauling** published his results on the **nature of the covalent bond**. Pauling electronegativity is named after him. In the 1950s, Pauling determined the α -helical structure of proteins.

Lise Meitner and **Otto Hahn** discovered **nuclear fission** in the 1930s.

Glenn Theodore Seaborg created and isolated several elements larger than uranium in the 1940s. Seaborg reorganized the periodic table to its current form.

James Watson and **Francis Crick** determined the double helical structure of DNA in the 1950s.

Neil Bartlett produced **compounds containing noble gases** in the 1960s, proving that they are not completely chemically inert.

Harold Kroto, Richard Smalley, and Robert Curl discovered the **buckyball (C₆₀)** in the 1980s.

Competency 3.0 Understand the process of scientific inquiry and the role of observation and experimentation in explaining natural phenomena.

Modern science began around the late 16th century with a new way of thinking about the world. Few scientists will disagree with Carl Sagan's assertion that "science is a way of thinking much more than it is a body of knowledge" (Broca's Brain, 1979). Science is a process of inquiry and investigation. It is a way of thinking and acting, not just a body of knowledge to be acquired by memorizing facts and principles. This way of thinking, the scientific method, is based on the idea that scientists begin their investigations with observations. From these observations they develop a hypothesis, which is further developed into a prediction. The hypothesis is challenged through experimentation and further observations and is refined as necessary. Science has progressed in its understanding of nature through careful observation, a lively imagination, and increasingly sophisticated instrumentation. Science is distinguished from other fields of study in that it provides guidelines or methods for conducting research, and the research findings must be reproducible by other scientists in order for those findings to be validated.

It is important to recognize that scientific practice is not always this systematic. Discoveries have been made that are serendipitous and others have been predicted based on theory rather than observation of phenomena. Einstein's theory of relativity was developed not from the observation of data but with a kind of mathematical puzzle. Only later were experiments able to be conducted that validated his theory.

The scientific method is a logical set of steps that a scientist goes through to solve a problem. While an inquiry may start at any point in this method and may not involve all of the steps, the overall approach can be described as follows:

Making observations

Scientific questions frequently result from observation 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 may provide answers, or they may lead to one or more questions.. In chemistry, 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. Perhaps the question has already been answered, or another experimenter has found part of the solution. The scientist then may want to test or reproduce the answer found in the literature. Or, the research might lead to a new question.

Sometimes the same observations are made over and over again and are always the same. For example, one can observe that daylight lasts longer in summer than in winter. This observation never varies. Such observations are called **laws of nature**. For example, one of the most important laws in chemistry 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 chemistry in the early 19th century.

Developing a hypothesis

If the question has not yet 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 or a mathematical theory.

Conducting an 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, called the *independent variable*. The other variable, the dependent variable, shows the result of 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 to which the rats respond. All other factors, such as time, temperature, age, water, and other nutrients given to the rats are held constant.

Chemists sometimes do short experiments "just to see what happens" or to see what a certain reaction produces. 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 are 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 an important part of the scientific method. If data are not organized in a logical manner, incorrect conclusions can be drawn. Also, other scientists may not be able to follow or reproduce the results

Drawing conclusions

Finally, a scientist must draw conclusions from the experiment. A conclusion must address the hypothesis on which the experiment was based. The conclusions state whether or not the data support the hypothesis. If 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 and plan new experiments .

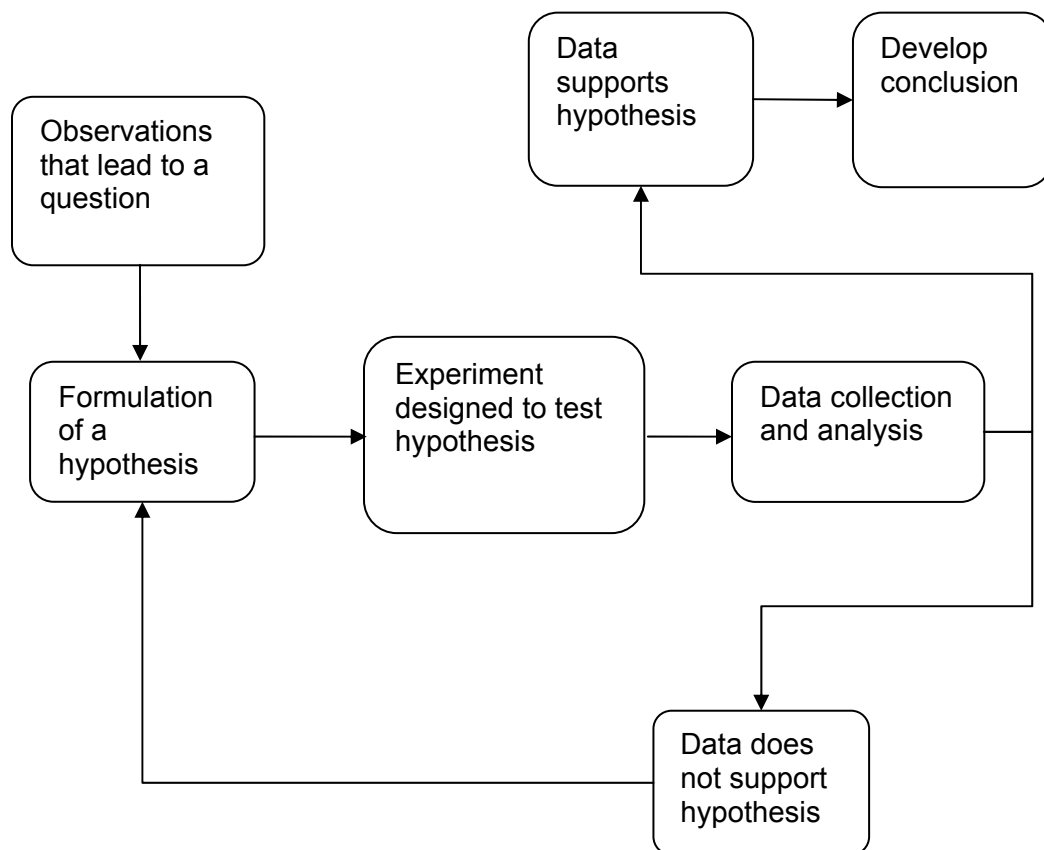
Developing a theory

When a hypothesis survives many experimental tests to determine its validity, the hypothesis may be developed 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 minor 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 example, in your chemistry course, you will develop a mental (and possibly a physical) model of the atom and its behavior. Outside of science, the word theory is often used to describe an unproven notion. 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 this requires is to demonstrate 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



The design of chemical experiments must include every step needed to obtain the desired data. In other words, the design must be **complete** and it must include all required **controls**.

Complete design

Familiarity with individual experiments and equipment will help you evaluate if anything is missing from the design. For data requiring a difference between two values, the experiment **must determine both values**. For data utilizing the ideal gas law, the experiment **must determine three of the values of P , V , n , or T** in order to determine the fourth, or one value and a ratio of the other two in order to determine the fourth. In general, whenever an equation is used to determine an unknown quantity, each of the other quantities in the equation must be measured or otherwise derived from the experiment.

Example: In a mercury manometer, the level of mercury in contact with a reaction vessel is 70.0 mm lower than the level exposed to the atmosphere. Use the following conversion factors:

$$760 \text{ mm Hg} = 1 \text{ atm} = 101.325 \text{ kPa}$$

What additional information is required to determine the pressure in the vessel in kPa?

Solution: The barometric pressure is needed to determine vessel pressure from an open-ended manometer. A manometer reading is always a **difference** between two pressures. One standard atmosphere is 760 mm mercury, but on a given day at a given location, the actual ambient pressure may vary. If the barometric pressure on the day of the experiment is 104 kPa, the pressure of the vessel is:

$$104 \text{ kPa} + 70.0 \text{ mm Hg} \times \frac{101.325 \text{ kPa}}{760 \text{ mm Hg}} = 113 \text{ kPa} .$$

Controls

Experimental **controls** prevent factors other than those under study from impacting the outcome of the experiment. A test sample in a controlled experiment is the unknown to be compared against one or more control samples. Control samples should be selected to be as identical to the test sample as possible in every way other than the one variable being tested.

A **negative control** is a control sample that is known to lack the effect. A **positive control** is known to contain the effect. Positive controls of varying strengths or concentrations are often used to generate a **calibration curve** (also called a **standard curve**).

For example, a scientist may wish to measure the level of arsenic in drinking water in a former mining area. A negative control would consist of water similar to that being tested that does not contain arsenic. This insures that there has been no cross-contamination during the experiment, and that the instruments are recording properly. Positive controls are also prepared consisting of water samples with increasing known concentrations of arsenic. The curve of concentration responses obtained is called a calibration curve, and is compared to past curves to ensure that the instrument is recording accurate and precise measurements across a wide concentration range.

When determining the concentration of a component in a mixture, an **internal standard** is a known concentration of a different substance that is added to the experimental sample. An **external standard** is a known concentration of the substance of interest. External standards are more commonly used. They are not added to the experimental sample; they are analyzed separately. These standards are frequently used to evaluate potential bias in the results, which may be caused by poor instrument calibration, interference from other compounds, or loss of the substance during sample pre-processing.

Example: A pure chemical in aqueous solution is known to absorb light at 615 nm. What controls would best be used with a spectrophotometer to determine the concentration of this chemical when it is present in a mixture with other solutes in an aqueous solution?

Solution: The other solutes may also absorb light at 615 nm. The best negative control would be an identical mixture with the chemical of interest entirely absent. Known concentrations of the chemical could then be added to the negative control to create positive controls (external standards) and develop a calibration curve of the spectrophotometer absorbance reading at 615 nm as a function of concentration. Replicate samples of each standard and of the unknown should be read.

Example: Ethanol is separated from a mixture of organic compounds by gas chromatography. The concentration of each component is proportional to its peak area. However, the chromatograph detector has a variable sensitivity from one run to the next. Is an internal standard required to determine the concentration of ethanol?

Solution: Yes. The variable detector sensitivity may only be accounted for by adding a known concentration of a chemical not found in the mixture as an internal standard to the experimental sample and control samples. The variable sensitivity of the detector will be accounted for by determining the ratio of the peak area for ethanol to the peak area of the added internal standard.

Replicate samples

Replicate samples characterize the degree decrease the impact of random error that is present. A mean may be taken of the results from replicate samples to obtain a best value, or replicate samples may be used in statistical testing to determine if one sample is likely part of the same population as another. If one replicate is obviously inconsistent with the results from other replicates samples, it may be discarded as an **outlier** and not counted as an observation when determining the mean. Discarding an outlier is equivalent to assuming the presence of a systematic error for that particular observation. In research, this must be done with great caution because some real-world behavior generates sporadically unusual results, and most natural populations contain occasional outliers.