

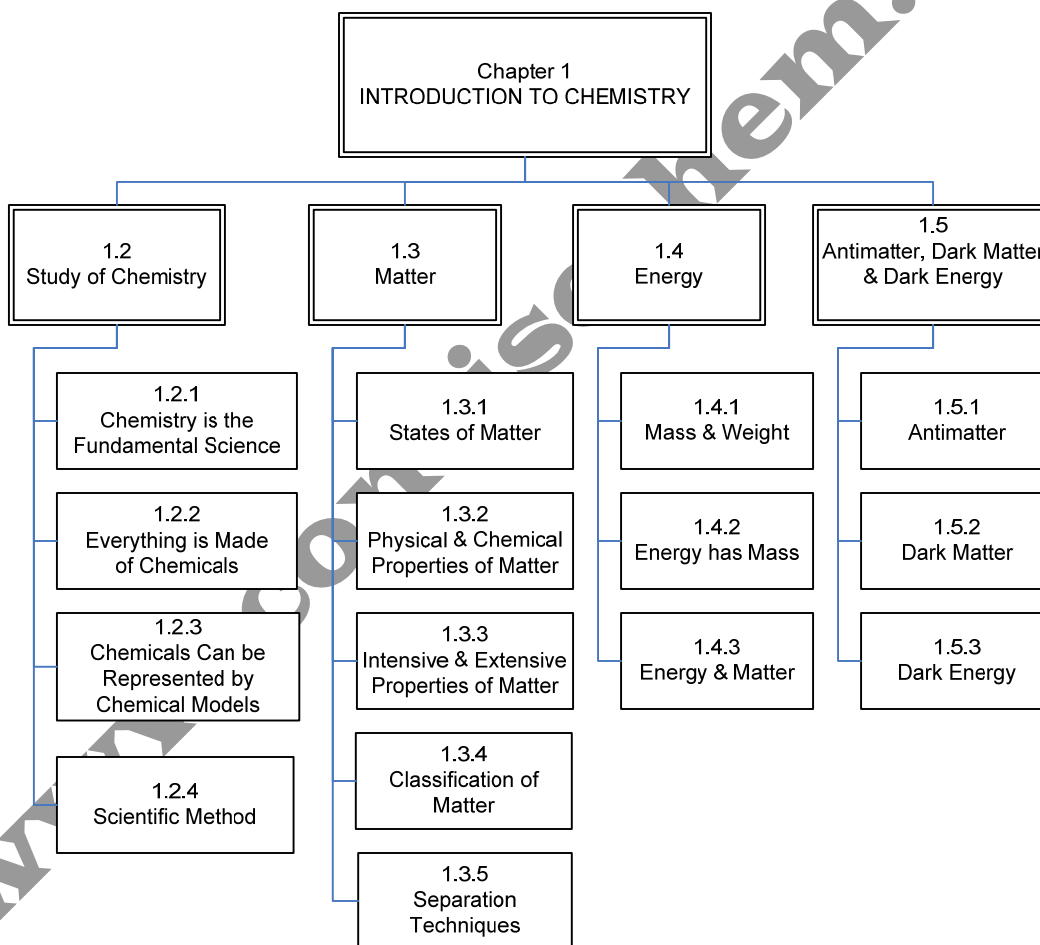
Chapter 1

Introduction to Chemistry

Chemistry is the central science.

- It's the foundation upon which all other sciences are based; embraces all other sciences.
- It's the study of properties and changes of matter, and its interactions with energy.
- Beauty of chemistry lies in its ability to simplify a seemingly terrifyingly complex universe, where everything is constantly changing on one time scale or another, into few fundamental principles that enable us to understand, appreciate and change our world.

1.1 Chapter Concept Map



1.2 Study of Chemistry

Chemistry is the *study of matter and changes that it undergoes*. It is the study of elements, the compounds that they form and reactions that they undergo. Chemistry enables us to comprehend how the world works so that we can appreciate its beauty, modify aspects of it and create new materials.

Inquisitive Chemist 1.1: Additional resources on chemistry.

Learning chemistry requires knowledge of many new terms, principles and their applications. "Inquisitive Chemist" boxes provide additional resources that will complement the material in text and aid your understanding of chemistry. Resources below were carefully selected, and will serve as a great tool to improve your understanding, grades and interest in chemistry.

- **Publisher websites** (excellent resources with lots of information & practice questions)

Atkins. Jones. *Chemical Principles: The Quest for Insight*. 2nd Ed. Freeman.

<http://www.whfreeman.com/chemicalprinciples/index.htm>

Averill. Eldredge. *Chemistry: Principles, Patterns and Applications*. 1st ed. Benjamin Cummings.

http://wps.aw.com/bc_averill_principles_1/0.11869.3126955-.00.html

Brady. Senese. *Chemistry: Matter and Its Changes*. 4th Ed. Wiley.

<http://bcs.wiley.com/he-bcs/Books?action=index&itemId=0471215171&bcsId=2049>

Brown. LeMay. Bursten. Burdge. *Chemistry: Central Science*. 9th Ed. Prentice Hall.

http://wps.prenhall.com/esm_brown_chemistry_9/0.4647.169060-.00.html

Chang. *Chemistry*. 7th Ed. McGraw Hill.

http://highered.mcgraw-hill.com/sites/0073656011/student_view0/

<http://www.mhhe.com/physsci/chemistry/chang7/esp/tools/equations/equations.htm> (all equations)

Chang. *General Chemistry: The Essential Concepts*. 3rd Ed. McGraw Hill.

http://highered.mcgraw-hill.com/sites/0072410671/student_view0/index.html

Chang. *Essential Chemistry*. 2nd Ed. McGraw Hill.

<http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/flash.mhtml>

Corwin. *Introductory Chemistry*. 4th Ed. Prentice Hall.

http://wps.prenhall.com/esm_corwin_chemistry_4/0.8579.1065587-.00.html

Ebbing. Gammon. *General Chemistry*. 8th Ed. Houghton Mifflin.

http://college.hmco.com/chemistry/general/ebbing/general_chem/8e/students/index.html

Ebbing. Gammon. Ragsdale. *Essentials of General Chemistry*. 1st & 2nd Ed. Houghton Mifflin.

<http://college.hmco.com/chemistry/general/ebbing/essentials/1e/students/index.html>

<http://college.hmco.com/chemistry/general/ebbing/essentials/2e/students/index.html>

Eubanks. Middlecamp. Pienta. Heltzel Weaver. *Chemistry in Context*. 5th Ed. McGraw Hill.

<http://chemincontext.eppg.com/>

Gilbert. *Chemistry: The Science in Context*. W. W. Norton & Company.

<http://www2.wwnorton.com/college/chemistry/gilbert/home.htm>

Hein. Arena. *Foundations of College Chemistry*. 11th & 12th Ed. Wiley.
<http://he-cda.wiley.com/WileyCDA/HigherEdTitle/productCd-0471328189.html>
<http://bcs.wiley.com/he-bcs/Books?action=index&itemId=0471741531&bcsId=3484>

Hill. Kolb. *Chemistry for Changing Times*. 10th Ed. Prentice Hall.
http://wps.prenhall.com/esm_hillkolb_chemistry_10

Hill. Petrucci. *General Chemistry: An Integrated Approach*. 3rd Ed. Prentice Hall.
<http://cwx.prenhall.com/bookbind/pubbooks/hillchem3/>

Hill. Petrucci. McCreary. Perry. *General Chemistry*. 4th Ed. Prentice Hall.
http://wps.prenhall.com/esm_hillpetrucci_genchem_4/0.8603.1078773-.00.html

Kelter. Mosher. Scott. *Chemistry: The Practical Science*. 1st Ed. Houghton Mifflin.
http://college.hmco.com/chemistry/general/kelter/chemistry/1e/student_home.html

McMurry. Castellion. *General, Organic and Biological Chemistry*. 4th Ed. Prentice Hall.
http://wps.prenhall.com/esm_mcmurry_fundamentals_4

McMurry. Fay. *Chemistry*. 4th Ed. Prentice Hall.
http://wps.prenhall.com/esm_mcmurry_chemistry_4/0.7623.616516-.00.html

Olmsted. Williams. *Chemistry*. 4th Ed. Wiley.
<http://bcs.wiley.com/he-bcs/Books?action=index&itemId=0471478113&bcsId=2246>

Petrucci. Harwood. Herring. *General Chemistry: Principles & Modern Applications*. 8th Ed. Prentice Hall.
<http://cwx.prenhall.com/petrucci/>

Silberberg. *Chemistry: The Molecular Nature of Matter and Change*. 3rd Ed. McGraw Hill.
http://highered.mcgraw-hill.com/sites/0072396814/student_view0/index.html

Snyder. *The Extraordinary Chemistry of Ordinary Things*. 4th Ed. Wiley.
<http://bcs.wiley.com/he-bcs/Books?action=index&itemId=0471415758&bcsId=1319>

Stanitski. Eubanks. Middlecamp. Pienta. Stratton. *Chemistry in Context*. 4th Ed. McGraw Hill.
http://highered.mcgraw-hill.com/sites/0072410159/student_view0/index.html

Tro. *Introductory Chemistry*. Prentice Hall.
http://wps.prenhall.com/esm_tro_trointro_1

Zumdahl. Zumdahl. *Chemistry*. 6th & 7th Ed. Houghton Mifflin.
<http://college.hmco.com/chemistry/general/zumdahl/chemistry/6e/students/index.html>
http://college.hmco.com/chemistry/zumdahl/chemistry/7e/student_home.html

- **Glossaries of chemistry terms**

<http://www.chemistry-dictionary.com/> (online chemistry dictionary)

http://en.wikipedia.org/wiki/Main_Page (Wikipedia)

<http://www.m-w.com/> (Merriam Webster dictionary)

<http://www.answers.com/> (Answers.com)

<http://www.iupac.org/publications/compendium/index.html> (IUPAC)

<http://www.chemguide.co.uk/index.html#top> (Chemguide)

<http://chemistry.about.com/od/chemistryatoz/a/aencyclopedia.htm> (About.com)

<http://www.chemicool.com/dictionary.html> (Chemicool.com)

<http://www.alcyone.com/max/physics/laws/> (definitions of chemistry laws)

<http://www.diracdelta.co.uk/> (science & engineering definitions)

Oxford Dictionary of Chemistry. Oxford University Press: New York, 2000.

McGraw-Hill Concise Encyclopedia of Chemistry. McGraw Hill: New York, 2002.

Considine. *Van Nostrand Reinhold Encyclopedia of Chemistry*. Van Nostrand Reinhold: New York, 1984)

CRC Handbook of Chemistry & Physics. CRC Press: New York, 2006. (reference book)

Dean Lange's *Handbook of Chemistry*. McGraw Hill: New York, 1992. (reference book)

- **Videos, lectures and tutorials; sample problems and quizzes**

<http://www.learner.org/resources/series61.html> (26 half-hour videos on chemistry by Annenberg)

<http://www.chemcollective.org/tutorials.php> (video tutorials by Carnegie Mellon)

<http://www.chemguide.co.uk/> (searchable chemistry information)

http://preparatorychemistry.com/Bishop_Chemistry_First.htm (Bishop)

<http://antoine.frostburg.edu/chem/senese/101/index.shtml> (Senese)

<http://textbookrevolution.org/chemistry> (link to some free chemistry books)

<http://www.liv.ac.uk/Chemistry/Links/links.html> (Oxford)

<http://scienceworld.wolfram.com/chemistry/> (Wolfram)

<http://www.renegadecchemistry.com/> (Westside High School)

<http://www.learnchem.net/> (learnchem.net)

http://nobel.scas.bcit.ca/chem3303/units_toc.htm# (Fong)

<http://www.chem.purdue.edu/gchelp/> (Purdue University)

<http://employees.oneonta.edu/kotzjc/GenChem.html> (Kotz)

http://www.tutor-homework.com/notes_exams_quizzes.html (chem tutor)

<http://www.sciencegeek.net/Chemistry/Powerpoints.shtml> (sciencegeek.com)

<http://www.chemtutor.com/> (chemtutor.com)

<http://www.chem.ox.ac.uk/vrchemistry/> (virtual chemistry)

<http://www.fordhamprep.org/gcurran/sho/sho/worksheets/workshindex.htm> (Fordham Prep)

<http://www.agt.net/public/alariv/nelson.htm> (Nelson page)

<http://bcs.whfreeman.com/acsgenchem/> (general chemistry project of ACS)

<http://www.chem4kids.com/> (chemistry in basic terms)

<http://www.chemsoc.org/networks/learnnet/index.htm> (learning resources by RSC)

<http://www.ch.cam.ac.uk/c2k/#area> (chemistry portal with website links)

<http://www.martindalecenter.com/GradChemistry.html> (chemistry portal with website links)

Munowitz. *Principles of Chemistry*. Norton: New York, 2000.

Pauling. *General Chemistry*. Dover Publications: New York, 1970.

- **History of chemistry; famous chemists; chemical experiments**

<http://www.chemheritage.org/explore/explore.html> (explore history of chemistry)

<http://www.chemsoc.org/timeline/pages/timeline.html> (timeline of discoveries in chemistry)

<http://chemistry.about.com/cs/history/a/aa020204a.htm> (timeline of chemistry)

<http://www.3rd1000.com/history/contents.htm> (historical perspective)

<http://www.chem.qmul.ac.uk/rschg/biog.html> (biographies of famous chemists)

<http://www.liv.ac.uk/Chemistry/Links/refbiog.html> (biographies of famous chemists)

http://nobelprize.org/nobel_prizes/chemistry/laureates/ (Nobel laureates in chemistry)

<http://web.lemoyne.edu/~giunta/paperabc.html> (selected classic papers on chemistry)

<http://www.columbia.edu/itc/chemistry/c2507/chemhist.html> (history of chemistry)

Partington. *A Short History of Chemistry*. Dover Publications: New York, 1989.

Ford. *Chemical Magic*. Dover Publications: New York, 1993.

Brent. *The Golden Book of Chemistry Experiments*. Golden Press: New York, 1960.

- **Chemical journals, newspapers and news websites**

<http://www.chemweb.com/journals> (collection of journals with free abstracts)

<http://pubs.acs.org/journals/query/subscriberSearch.jsp> (ACS Publications)

<http://www.ncbi.nlm.nih.gov/entrez/query.fcgi> (PubMed)
<http://www.sciencedirect.com/> (Elsevier Science Direct Publishing)
<http://www.rsc.org/Publishing/Journals/Index.asp> (RSC Publishing)
<http://jchemed.chem.wisc.edu/> (Journal of Chemical Education; monthly)
<http://www.rsc.org/Education/CERP/index.asp> (Chemistry Education Research and Practice)
<http://www.sciam.com/> (Scientific American; monthly)
<http://discovermagazine.com/> (Discover, monthly)
<http://www.rsc.org/chemistryworld/> (Chemistry World; monthly)
<http://www.popsci.com> (Popular science; monthly)
<http://www.ehponline.org/> (Environmental Health Perspectives; monthly)
<http://pubs.acs.org/journals/esthag/> (Environmental Science & Technology; biweekly)
<http://pubs.acs.org/cen/index.html> (Chemical & Engineering News; weekly)
<http://www.sciencemag.org/> (Science; weekly)
<http://www.sciencenews.org/> (Science News; weekly)
<http://www.nature.com> (Nature; weekly)
<http://chemweek.com/> (Chemical Week; weekly)
<http://www.newscientist.com> (New Scientists; weekly)
<http://www.americanscientist.org/> (American Scientist; bimonthly)
<http://businessweek.com/> (Business Week; weekly)
<http://www.msnbc.msn.com/id/3032542/site/newsweek/> (Newsweek; weekly)
<http://www.time.com/time/> (Time; weekly)
<http://www.usnews.com/> (US News & World Report; weekly)
<http://www.nytimes.com/pages/science/index.html> (NY Times; daily)
<http://www.washingtonpost.com/> (Washington Post; daily)
<http://www.latimes.com/news/science/?track=mainnav-science> (LA Times; daily)
<http://www.ft.com> (Financial Times; daily)
<http://www.sciencedaily.com/> (Science Daily)
<http://www.nationalacademies.org/> (National Academy of Sciences)
<http://www.bbc.co.uk/sn/> (BBC)

- **General chemistry; general interest**

<http://books.nap.edu/> (National Academies Press; lots of free books to view)
http://college.hmco.com/chemistry/intro/zumdahl/intro_chemistry/6e/assets/students/careers.html
 (Houghton Mifflin site for chemical careers)
<http://pubs.acs.org/cen/whatstuff/stuff.html> (what's that stuff)
<http://www.chemistryguide.org/index.php> (extensive chemistry portal with website links)
<http://www.rsc.org/Chemsoc/index.asp> (Chemical Society portal with links)
<http://www.chemweb.com/> (chemistry portal)
<http://www.liv.ac.uk/Chemistry/Links/links.html> (chemistry portal with website links)
<http://www.levity.com/alchemy/> (alchemy website)
<http://www.learner.org/> (science resources and videos by Annenberg media)
<http://environmentalhealthnews.org/> (environmental; health)
<http://www.howstuffworks.com/> (technical information on diverse topics)
<http://science.nasa.gov/> (NASA)
<http://www.cs.cmu.edu/%7Emwm/sci.html> (science centers world-wide)
<http://www.library.ucsb.edu/subjects/chem/chemuniv.html> (academic chem. depts. in the world)
<http://www.chemistry-conferences.com/> (schedule of worldwide chemical conferences)
 Cobb and Fetterolf. *The Joy of Chemistry*. Prometheus Books: New York, 2005.
 Pollack. *Uncertain Science, Uncertain World*. Cambridge University Press: Cambridge, 2003.
 Munowitz. *Knowing: The Nature of Physical Law*. Oxford University Press: New York, 2005.
 Cole. *Mind Over Matter*. Harvest Books: Orlando, 2003.

1.2.1 Chemistry is the Fundamental Science

- Chemistry interacts and supports all other sciences; its scope spans from the theoretical sciences, such as theoretical physics, to life sciences, such as biology.
- There are no hard border lines between sciences, and chemistry connects them all.
- In essence, chemistry is the founding block on which all other sciences build, and it's the application tool that allows us to manipulate atoms to form chemicals that we want.

1.2.2 Everything is Made of Chemicals

- Everything you touch, smell, taste, consume, and see is made of chemicals (e.g., clothes you wear, book you're touching, water we drink, air we breathe, etc.).
- Everything we do involves chemicals: our body is a big beaker of chemical reactions (e.g. breathing is an exchange of gases; metabolism of food is a chemical process, etc.)

Sample Problem 1.1: Can you name something that is not made from chemicals?

You'd be quite stumped if I asked you to name anything that is not made of chemicals or something that is not a chemical reaction. Can you?

Some chemicals are natural (i.e., occur in nature) and some are synthetic (i.e., man-made). Many think of natural chemicals as good and synthetic as bad, which has led to **chemophobia**, the *fear of chemicals*.

- **Natural chemicals**, such as oxygen we breathe and water we drink are good, but how about poison ivy and poison from the black widow spider? They are natural, but extremely poisonous.
- **Synthetic chemicals**, such as asbestos and some pesticides are bad, but how about the medicine that you take for your flu or the artificial sweetener that you consume in your diet drinks?
- Avoid generalizations about chemicals – we can only say that some are good and some bad, regardless of whether they are natural or synthetic. And even if they are poisonous, we can still use them without dire consequences if the dose is below the toxic threshold.

Inquisitive Chemist 1.2: Dose makes the poison.

Botox[®] is a chemical derived from the poison produced by Clostridium, bacteria so deadly that infected people usually die immediately (Botulism) because it destroys the communication between nerves and skeletal muscles. However, as you know, Botox has been approved by the US Food and Drug Administration (FDA) for “temporary relief” of wrinkles and has been used successfully for many years, especially by movie stars. To get more information from Allergan Inc., the company that makes the drug, go to www.botox.com.

Chemists have been especially concerned about the negative perception of chemicals by the public, and have taken many initiatives to try to change public's view.

- American Chemistry Council (ACC), a consortium of chemical companies, had entailed in 2006 on a mass public campaign entitled “Essential₂[®]” to educate the public that we should not fear chemicals because they are essential to safety, health, innovation, environment, economy, etc.; they are “essential₂living”. More can be explored at ACC's website.

Inquisitive Chemist 1.3: Information on chemicals.**American Chemistry Council (ACC):** www.americanchemistry.com

The trade association representing US chemical companies, including significant business groups.

American Chemical Society (ACS): www.acs.org

Primary professional organization for chemists and related occupations in US.

International Union of Pure and Applied Chemistry (IUPAC): <http://www.iupac.org/>

Scientific, international, non-governmental and objective body that serves to advance the worldwide aspects of the chemical sciences.

Royal Society of Chemistry: www.rsc.org

The largest organization in Europe for advancing the chemical sciences.

US Food and Drug Administration (FDA): www.fda.gov

Agency responsible for ensuring the safety and effectiveness of all drugs, biologics, vaccines, medical devices, food and cosmetics.

US Environmental Protection Agency (EPA): www.epa.gov

The mission of EPA is to protect human health and the environment. It enforces environmental laws, provides chemical information to the public and provides guidance to policy makers.

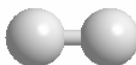

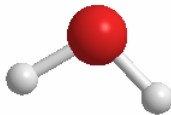
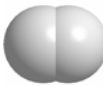


US Consumer Product Safety Commission (CPSC): www.cpsc.gov

Agency that works to reduce the risk of injuries and deaths from consumer products.

1.2.3 Chemicals Can be Represented by Chemical ModelsChemists try to understand and explain the **macroscopic** (*large scale*) world in terms of **microscopic** (*atomic, molecular scale*) composition and reactions.

- Chemists have devised a number of different ways of representing atoms and molecules.
- To understand chemistry, you must be able to read and write these models of the molecular world.

Table 1.1: Chemical Models

Chemical Model	Hydrogen	Oxygen	Water
Molecular formula	H ₂	O ₂	H ₂ O
Structural formula	H-H	O=O	H-O-H
Ball & stick model			
Space filling model			

In molecular formulas, the subscript tells number of atoms to the left of it. If there isn't a subscript, it means that there is one atom. For example, water has two atoms of H and one atom of O.

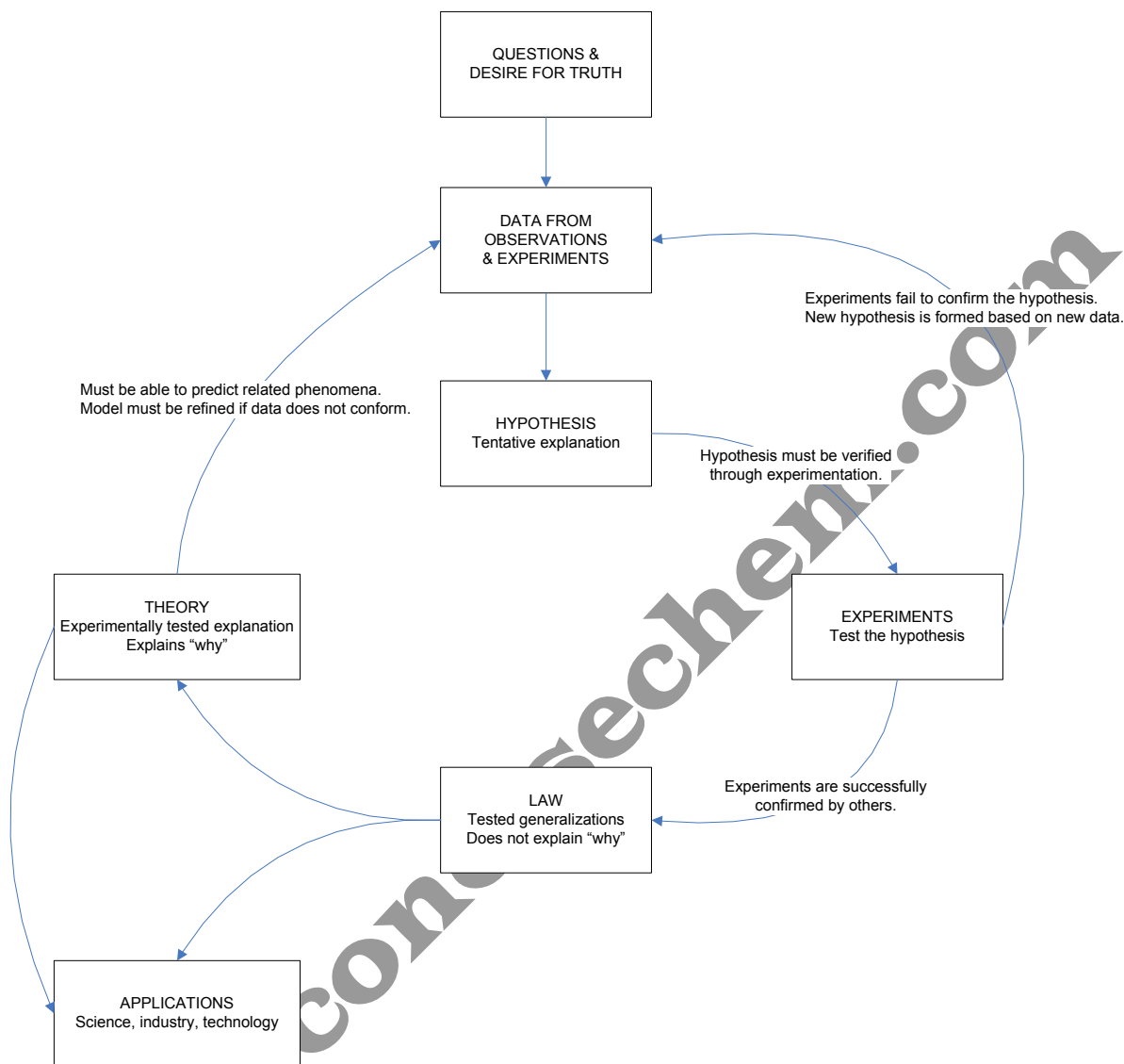
1.2.4 Scientific Method

Scientific method provides guidance for the practice of science. The scientific method is summarized by the sequence of steps in Figure 1.1.

- After observing a number of facts, either through the pursuit of one's own research interests or by simply learning about findings of others, a scientist forms a general idea to correlate the observed facts. This idea is called a **hypothesis** (*tentative explanation of observed data*).
- The hypothesis has to be subjected to further test through **experiments**. If experiments fail to confirm the hypothesis, the scientist must revise to hypothesis to reflect the new data. If the experiments confirm the hypothesis, other scientists perform the experiments as well to confirm the findings.
- These successful findings are usually combined in a **scientific law (law)**, which *summarizes the observed experimental facts*. For example, Charles's Law states that the volume (V) of a gas \uparrow directly with an \uparrow in temperature (T). Note that a law makes no attempt to explain "why" that happens.
- An explanation of the relationship between T & V is given by the kinetic **theory** of gases, which *not only explains the observations, but also correctly predicts many other properties* of gases.

Hypothesis is a tentative explanation. **Laws** are tested generalizations. **Theory** is a verified hypothesis compounded of facts, laws and deductive arguments (inferences).

The paradox of science is that every answer to a question results into new questions. The more we learn, the more we realize how little we know. What this means is that some of the biggest questions still remain to be asked in our never ending quest for understanding "everything."

Figure 1.1: Scientific Method

Scientific method is quite dynamic because you can never prove a theory for sure; one can only take the theory to be true until new findings disprove it.

- As is often the case, just when we think that our models have finally put everything together, some scientist comes along with a new insight and completely changes the current models and our world.

Scientific discoveries fall into three general categories¹:

1. Charge: scientist solves a known problem (e.g., develop a drug to lower cholesterol).
2. Challenge: scientist provides a new concept or theory to explain unexplained facts and observations (e.g., Einstein explained the constant speed of light with special relativity). Challenge requires originality in perception of the problem, as well as coming up with a solution.

¹ Adapted from "The Cha-Cha-Cha Theory of Scientific Discovery" by Koshland. *Science*. Vol 317. August 2007.

3. Chance: discovery by scientist is serendipitous (e.g., discovery of Viagra). Even a chance discovery doesn't happen entirely by chance; one has to be very knowledgeable about the area of research, and be able to recognize the importance of the discovery.

Discoveries in all fields of science can be quite challenging, so a high level of knowledge, curiosity and commitment are a prerequisite. A scientist should also have an unwavering desire for truth and should never allow for misconceptions to interfere with the interpretation of results. Peer review makes sure of that by providing the additional set of eyes to prevent hasty conclusions at first sight of encouraging results.

Inquisitive Chemist 1.4: Quotes about science and scientific method.

“Happy is he who gets to know the reasons for things.” - *Virgil*

“The most incomprehensible thing about our universe is that it can be comprehended.” - *Albert Einstein*

“The joy of discovery is certainly the liveliest that the mind of man can ever feel.” - *Claude Bernard*

“Every experiment proves something. If it doesn't prove what you wanted it to prove, it proves something else.” - *Anonymous*

“Theory guides. Experiment decides.” - *Anonymous*

“It is a capital mistake to theorise before one has data. Insensibly one begins to twist facts to suit theories instead of theories to suit facts.” - *Sherlock Holmes*

“There ain't no rules around here! We're trying to accomplish something!” - *Thomas Edison*

Section Test

Questions

1. What is the difference between natural and synthetic chemicals? Which are toxic?
2. Which of the following describe a scientific theory: (a) tested, (b) explains observations, (c) known to be true, (d) repeatable?

Answers

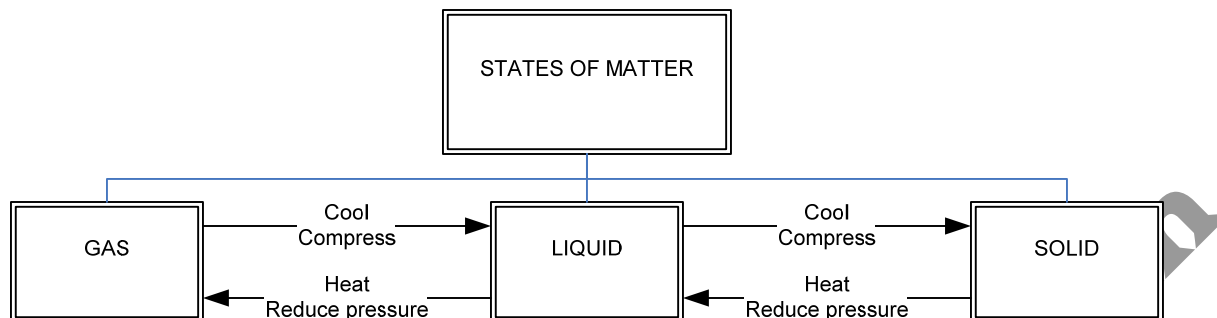
1. Natural chemicals occur in nature, whereas as synthetic chemicals are man-made. Toxicity is a property specific to a chemical, regardless of its origin. For example, alcohol (i.e., ethanol) is the same chemical (i.e., $\text{CH}_3\text{CH}_2\text{OH}$) regardless of whether it was made in nature by fermentation or synthesized in lab by a chemist.
2. A, b & d. Scientific theory is always vulnerable to change.

1.3 Matter

Matter is *anything that has mass and occupies space*. It is the physical material of the universe. Chemistry helps us understand how matter is put together and helps us understand their properties.

1.3.1 States of Matter

There are three states of matter (Figure 1.4): **gas**, **liquid** and **solid**.

Figure 1.2: The Three States of Matter

They can be described on macroscopic and molecular levels (Table 1.1). For the sake of our descriptions below, **definite** means shape/volume is *not defined by a container*, whereas as **indefinite** means that shape/volume is *defined by a container*. A **particle** refers to atoms and/or molecules.

Table 1.2: Macroscopic & Molecular Descriptions of States of Matter

Description	Gas	Liquid	Solid
Macroscopic	<ul style="list-style-type: none"> Indefinite volume Indefinite shape 	<ul style="list-style-type: none"> Definite volume Indefinite shape 	<ul style="list-style-type: none"> Definite volume Definite shape
Molecular	<ul style="list-style-type: none"> Particles are far apart with mostly empty space 	<ul style="list-style-type: none"> Particles are tightly packed but can move past each other 	<ul style="list-style-type: none"> Particles are tightly packed

Macroscopic View

- Gas will take the size and shape of any container. For example, when you light a match, the smoke expands throughout the room.
- Liquid will take the shape of the container but will not expand in volume. For example, when pouring a beer into a mug, it will take the shape of the beer mug but will not increase in volume (wouldn't that be nice).
- Solid has a definite volume and a definite shape. For example, a metal block will not change its shape nor volume regardless of the container it's in.

Molecular View

- Gases have indefinite volume and shape because the gas molecules are far apart with mostly empty space.
- Liquids can change their shape because particles can move past each other.
- Solids have definite volume and shape because their particles are tightly packed.

Inquisitive Chemist 1.6: "Fourth" and "fifth" states of matter.

You usually learn of only three states of matter because those are the only states of matter that are prevalent on our planet. However, two additional states of matter do exist under different conditions.

- **Plasmas (ionized gas)** are the “fourth” state of matter. Plasmas are formed at high temperatures when electrons are stripped from neutral atoms to form an ionized gas mixture consisting of ions, electrons, and neutral atoms. A plasma must have sufficient numbers of charged particles so that the gas, as a whole, exhibits a collective response to electric and magnetic fields. Plasmas are common in the universe; for instance, stars are predominantly plasma. Plasma densities and temperatures vary widely. More info on plasma applications can be found at www.plasmas.org.
- **Bose-Einstein Condensate (BEC)** state of matter was predicted by Satyendra Bose and Albert Einstein in 1920, but was not created until 1995 by scientists Cornell and Weiman. This state of matter is completely opposite of plasma (super hot and super excited atoms); the atoms in BEC are super-unexcited and super-cold atoms (170 billionth of a degree above absolute zero). Cooling rubidium atoms to that extreme caused the individual atoms to condense into a "super-atom" behaving as a single entity. Read more at <http://jilawww.colorado.edu/press/bose-ein.html>

1.3.2 Physical & Chemical Properties of Matter

We have all seen common salt (sodium chloride, NaCl). What does it look like? Well, depending on the type of salt that you use, for your shaker or grinder, you might picture the table salt in fine grains, or table salt in the form of larger crystals. In either case, salt is still salt. Both types will have same physical and chemical properties.

The *characteristics of different substances* are called **properties**.

- Properties relate to type of atoms present and arrangement of those atoms.

Matter has physical and chemical properties, and can undergo physical and chemical changes.

- **Physical properties** can be *observed without changing a substance into another substance*. If we were to compare the densities (mass/volume) of the two types of common salt (fine grains and larger crystals), we would notice that they are exactly same (2.17 g/cm^3). There are many other physical properties that can be measured (Table 1.2). **Physical changes** are *changes in matter that do not change the composition of a substance*. For example, freezing of water is a physical change.

Table 1.3: Examples of Physical Properties

Physical Property	Example/Definition
Mass	A nickel weighs about 5 grams
Temperature	A hot summer day has a temperature of 39°C
Boiling Point	Water boils at 100°C
Freezing Point	Water freezes at 0°C
Color^a	Sulfur is yellow
Hardness^b	Diamond is an exceptionally hard substance
Structure	Salt is crystalline
Heat Capacity	Water has a high heat capacity
Conductivity	Copper is a good conductor of electricity
Solubility	Sugar is very soluble in water
Malleability	Ease with which the a substance can be hammered into thin sheets
Ductility	Ease with which the substance can be drawn into a wire
Density	Density = mass \div volume; density of water is 1kg/L ;
Taste & Odor^d	Acetic acid is sour

Physical Property	Example/Definition
-------------------	--------------------

^a Often depends on its state of subdivision.

^b We say one substance is less hard than a second substance if it is scratched by the second substance

^c Density usually increases when going from gas to solid to liquid (more tightly packed), but there are a few exceptions. For example, ice has a greater density than liquid water.

^d Taste and odor are closely related with chemical nature of substances, and are often considered chemical properties even though we can get a chemical's characteristic taste or odor without chemically changing it.

- **Chemical properties** (Table 1.3) can only be *observed when a substance is changed into another substance*. **Chemical changes** are *changes in matter that change the composition of a substance*. For example, burning of a match is a chemical change. In the course of a chemical reaction, the reacting substances are converted into new substances.

Physical Change: $A + B \rightarrow A + B$ (components retain their chemical properties)

Chemical Change: $A + B \rightarrow C$ (new substance is formed)

Table 1.4: Examples of Chemical Properties

Substance	Example
Hydrogen	Burns explosively with oxygen to form water
Iron	React with oxygen to form iron oxide (rust)
TNT	Very explosive
Argon	Inert gas (does not react)

Sample Problem 1.4: We can use liquid nitrogen to freeze a flower. Is that physical or chemical change?

Physical change; the chemical nature of the flower has not changed. Watch the video at

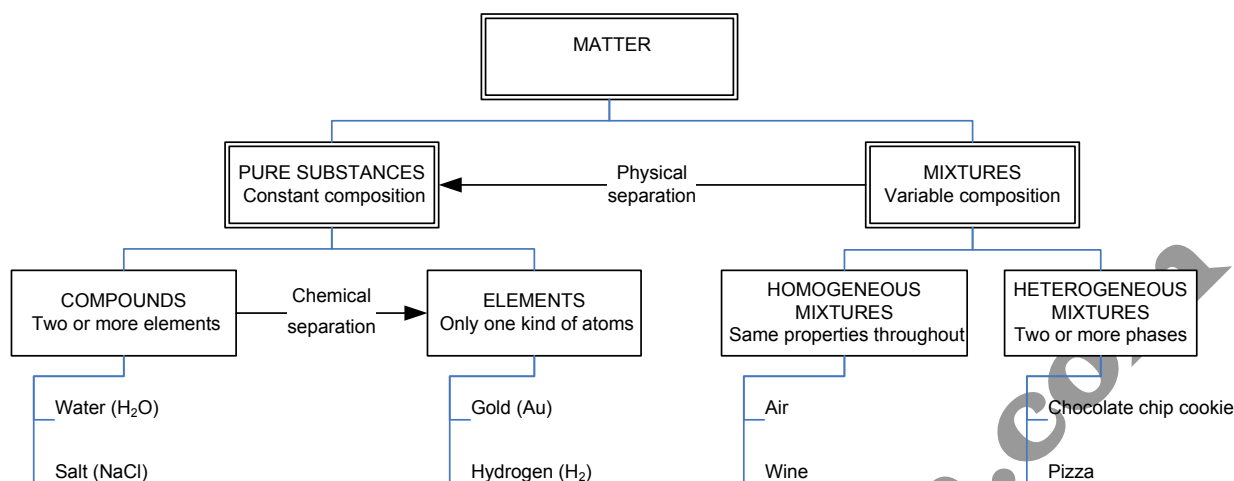
<http://www.youtube.com/watch?v=QaprCLxG5Tg>.

1.3.3 Intensive & Extensive Properties of Matter

- **Intensive properties** are *independent of the amount of the substance that is present*. Some examples are density and boiling point. For example, the density of liquid water is always 1 kg/L regardless of how much water you have ($d=m/V$, so when mass \uparrow , volume also \uparrow proportionally, keeping density constant).
- **Extensive properties** depend upon the amount of the substance present. Mass, volume and energy are extensive properties.

1.3.4 Classification of Matter

Follow [Figure 1.2](#) through the discussion below.

Figure 1.3: Classification of Matter

- **Atom** is the *smallest particle that is characteristic of a given element*. They are the building block of matter. If we split the atom any further, we lose the identity of that atom and end up with subatomic particles that are the same regardless from which atom they come from (e.g. protons from hydrogen are the same as those from helium).

Inquisitive Chemist 1.5: Are atoms real?

In 1981, Gerd Binnig and Heinrich Rohrer at the IBM Corporation discovered the scanning tunneling microscope (STM) that has achieved magnifications of up to 10 million, allowing chemists to look directly at individual atoms. They won a Nobel Prize in Physics in 1986. An extensive STM image gallery (including the initial atom manipulations by the IBM team) can be found at <http://www.almaden.ibm.com/vis/stm/gallery.html>.

- Each **element** is *made of the same kind of atoms*. It is a collection of one kind (type) of atoms and cannot be decomposed into simpler substance. The symbols on the periodic table (Figure 1.3) represent elements. There are 117 known elements. Only group 8 elements exist as single atoms; all other elements exist in more complex forms. Hydrogen and helium (the two lightest elements) are the most abundant elements in the universe accounting for about 97% of the universe. The human body and earth's crust have oxygen as the most abundant element. Only group 8 elements exist as single atoms. All other elements are found in more complex forms. The *existence of an element in more than one form* is called **allotropy**. Allotropes are made from the same atoms, but they are simply in a different form (arrangement) and thereby have different properties. This could be the result of differences in molecular structures ("normal" oxygen gas: O₂ and ozone: O₃), or the result of differences in packing of molecules in the solid (carbon: graphite, diamond, buckyball, nanotube). All allotropes of carbon can be viewed at http://en.wikipedia.org/wiki/Allotropes_of_carbon.

Figure 1.4: Periodic Table of Elements

1																	18	
1	1																2	
2	3	4															10	
3	11	12											13	14	15	16	17	18
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
6	55	56	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
7	87	88	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	118	

Lanthanides	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Actinides	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

- A **compound** is made of two or more different kinds of atoms. The smallest obtainable piece of a compound is called a **molecule**. For example, water (a compound) is made of many H₂O molecules. Each of these is made of two different types of atoms: hydrogen (H) atoms and oxygen (O) atom. Since a molecule is composed of two or more different kinds of atoms, we can break them chemically down into its constituent atoms. For example, water (liquid) can be broken down chemically (by electrolysis) into hydrogen (gas) and oxygen (gas). As seen with water, compounds have very different properties from their component elements. All compounds can be represented by **chemical formulas**, which show the constituent elements and the number of atoms of each constituent element. For example, water (H₂O) is made of 2 hydrogen atoms and 1 oxygen atom.
- Since all compounds are made of only one type of molecule, and all elements are made of only one type of atom, we can categorize compounds and elements as **pure substances** (commonly called simply **substances**) because they both have **constant composition**. For example, water, gold and hydrogen are pure substances because water (compound) is made of only H₂O molecules, gold is made of only Au atoms and hydrogen is made of only H₂ molecules.

Sample Problem 1.2: How about pure sugar dissolved in pure water, is it a pure substance?

No. Even though it is homogeneous, it does not have a fixed composition. Composition is not definite; it is widely variable depending on how much sugar we mix with water. Pure sugar dissolved in pure water is therefore a mixture.

- When two or more compounds are combined through a physical process (e.g. mixing them together) they form a **mixture**. For example, whiskey & coke drink is a mixture. The compounds in the mixtures retain their own chemical properties. Mixtures have

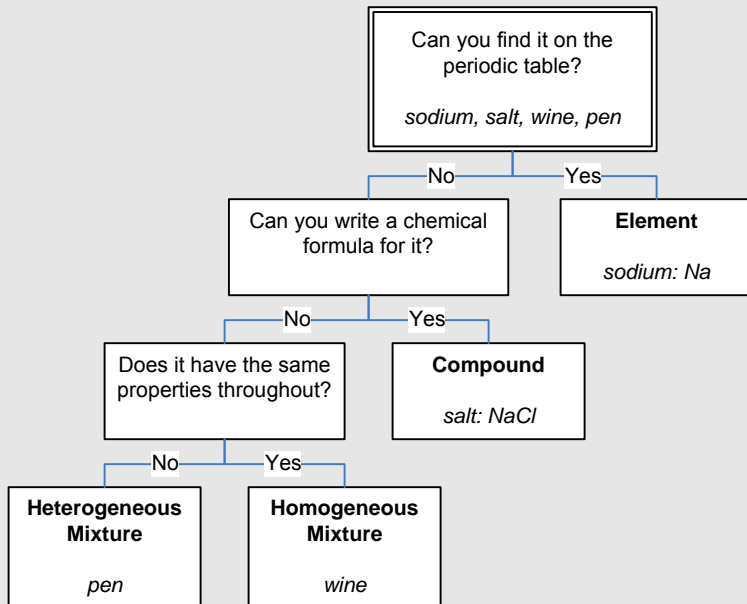
variable composition. For example, you can make a soft whiskey & coke which has few whiskey (ethanol; C_2H_6O) molecules or you can have a strong whiskey & coke that will have lots of ethanol molecules.

- **Homogeneous mixtures** are *mixtures that have the same properties throughout*. These usually don't have visible parts. For example, air is composed of many different molecules: nitrogen, oxygen, water, etc. However, these molecules are evenly distributed throughout the air. Regardless of whether you sit in the front of the room or back of the room, you're expected to breath in the same number of oxygen molecules. From the problem above, sugar dissolved in water is a mixture because the ratio of water to sugar can be changed, and is homogeneous because each component is uniformly dispersed throughout the solution.
- **Heterogeneous mixtures** are *mixtures that do not have the same properties throughout*. These usually have visible parts. An example would be a soup, made of water, salt, the recipe and noodles. Not only does the ratio of each constituent vary depending on who is making the soup (mixture), but also, the noodles are always found at the bottom (heterogeneous).

Sample Problem 1.3: Solving classification problems.

Now, let's put the above process into context with an example. Appropriately classify the following: sodium (Na), table salt (NaCl), wine and pen.

To answer any classification question simply follow the process map below.



1.3.5 Separation Techniques

Because each component of a mixture retains its own properties, we can distinguish between mixtures and pure substances by the mixtures ability to be separated by physical

methods (e.g., it is possible to separate a salt and water mixture by allowing the water to evaporate).

- It is important to note that in all these methods of separation are based on physical properties; the chemical properties of mixture constituents are not changed.
- Only chemical methods (chemical reactions) can change the chemical properties of compounds.

Important separation techniques (based on differences in physical properties) are listed below.

Evaporation

- Used to separate a solid from a solid/liquid mixture by heating the mixture until the liquid completely evaporates (e.g. mixture of water & salt).

Distillation

- Used to separate a liquid from a liquid/liquid mixture by separating the more **volatile** (evaporating readily) liquid from less volatile liquid.
- Because the constituents in the mixture have different boiling points, one of them will boil first and change into vapor, which will then be collected and isolated in pure form (e.g. mixture of ethanol & water obtained by fermentation of grapes)

Filtration

- Used to separate a mixture by dissolving one of the constituents, while leaving the other constituent undissolved.
- The entire mixture is then poured over the filter paper, leaving the undissolved constituent trapped in the filter paper (e.g. mixture of sand & water).

Chromatography

- Mixture is separated into the constituents based on the interactions (stickiness) of the constituents with the mobile (moving) and stationary (non-moving) phase.
- If it sticks well to the mobile phase, it will travel far. If it sticks well to the stationary phase, it will hardly move (e.g. separating ink into constituent colors).

Extraction

- Separation based on the differences of solubility between the constituents of the mixture.
- For example, to separate the sugar that is mixed with oil, one would add water, mix it all well, and then simply pour off the water (with the sugar dissolved in it) leaving the oil behind.

Section Test

Questions

1. You're given a mixture of sand, salt and water. How would you separate the three compounds?
2. What is the difference between chemical and physical properties? Give examples of each.
3. Which is heavier: 1g of rock or 1g of cotton? Which is heavier: 1mL of rock or 1 mL of cotton?

Answers

1. You can filter the three to first separate the sand, and then boil the water to separate water and salt.
2. Chemical properties describe changes in composition of a chemical (e.g., explosive, reactive) whereas physical properties are characteristics of a chemical that can be measured or observed without changing the composition (e.g., color, density).

3. Gram of anything is a gram. The second part of the question is a density question. We know that density of a rock is much higher than that of cotton, which means that the mass of a rock is much higher than that of cotton when we measure equal volumes of each.

1.4 Energy

Do you still remember the challenge posed earlier where you were asked to name something that is not made from chemicals (i.e. something that is not matter)? Well, if you were able to come up with something that wasn't matter (e.g., light), then you just named a form of energy. The universe as we know it is composed of matter and energy.

Change in matter always involves change in energy; hence chemistry is concerned with both matter and energy. The difference between the two is not as obvious as it might seem.

1.4.1 Mass & Weight

In common language, we use mass and weight interchangeably, but in the scientific language they are quite different.

- **Mass** is the *measure of the amount of material in an object*. It does not depend on the location of the object.
- It is different from **weight**, which is a *measure of gravitational force that a large body (e.g. earth) exerts on an object*, and does depend on the location.

Inquisitive Chemist 1.7: Weight on different planets.

Planet Mars is about 1/3 as dense as Earth, exerting about 1/3 of the gravity on an object. Hence, if your weight on Earth were 150 lbs, your weight on Mars would be ~ 38 lbs. To explore your weight on different planets, moons and stars, go to <http://www.exploratorium.edu/ronh/weight/>.

1.4.2 Energy has Mass

For many years, mass was used as the distinguishing characteristic between matter and energy. That is, until early in the 20th century, when Albert Einstein pointed out with his famous equation that **energy** (*potential for causing changes; ability to do work*) has mass as well. Einstein's equation showed that matter of mass m possesses an intrinsic rest mass energy given by mc^2 .

$E = mc^2$			
where			units
E	=	energy	J
m	=	mass	kg
c	=	speed of light in vacuum	$m \cdot s^{-1}$
	=	2.99792458×10^8	

The fact that energy has mass was later demonstrated with a showcase of bending light ray of a distant star as it passed close to the sun. If light has no mass, there should not have been any gravitational attraction of the light ray toward the sun.

1.4.3 Energy & Matter

Matter and energy are intimately related.

- We can see from Einstein's equation that it is possible to convert matter to energy (observed in reactions involving nuclei of atoms such as fusion and fission), and to convert energy to matter (observed in creation of elementary particles).
- It is important to note here the **law of conservation of mass**, which embodies in it the principles that *both matter and energy are conserved*. In essence, it says that the mass to be conserved includes both the mass of the matter in the **system** (portion of the universe that is singled out for study) and the mass of energy in the system.

Sample Problem 1.5: Einstein's relation between mass and energy: nuclear reaction.

When 1 kg of uranium 235 (^{235}U) undergoes nuclear fission, as in the detonation of an atomic bomb, $0.823 \times 10^{14}\text{J}$ of energy is liberated. How much has the mass of sample decreased?

Let's calculate the mass of uranium lost by the use of Einstein's equation

$$m = \frac{E}{c^2} = \frac{0.823 \times 10^{14}\text{J}}{(2.998 \times 10^8)^2 \text{m}^2\text{s}^{-2}} = 0.0916 \times 10^{-2}\text{kg} = 0.000916\text{kg}$$

Thus, the mass of ^{235}U has decreased by 0.0916%.

In the above example, a small amount of matter was converted to a large amount of energy. But that mass lost is relatively large compared to mass lost in non-nuclear reactions – reactions that we're concerned with in general chemistry.

Let's take a very explosive reaction and see how much mass is lost in the process.

Sample Problem 1.6: Einstein's relation between mass and energy: non-nuclear reaction.

When 1 kg of nitroglycerine explodes, $8.0 \times 10^6\text{J}$ of energy is liberated. How much has the mass of sample decreased?

Let's calculate the mass of nitroglycerine lost by the use of Einstein's equation

$$m = \frac{E}{c^2} = \frac{0.823 \times 10^6\text{J}}{(2.998 \times 10^8)^2 \text{m}^2\text{s}^{-2}} = 0.89 \times 10^{-10}\text{kg} = 0.00000000089\text{kg}$$

Thus, the mass of nitroglycerine has decreased by 0.0000000089%.

From the above example we see that the difference in mass of the product and reactants in non-nuclear reactions is negligible. In fact, it is so slight that you would never detect it with regular weight balances. For all practical purposes, we say that mass of matter is conserved in ordinary chemical reactions. Effectively, for ordinary chemical reactions we can ignore the energy part, and simply say that the *total mass of the products of chemical reaction is the same as the total mass of reactants*.

Mass of matter is conserved in ordinary chemical reactions.

Section Test**Questions**

1. Loss of mass is an important factor in: (a) nuclear reactions, (b) ordinary reactions, (c) both?

Answers

1. A - see sample problems 1.5 and 1.6.

1.5 Antimatter, Dark Matter & Dark Energy

You've probably heard of, if not even read, Dan Brown's bestselling *fiction* novel *Angels and Demons* in which he talks about a plot to destroy the Vatican using 1 gram of antimatter stolen from Switzerland's Conseil European pour la Recherche Nucleaire (CERN). Luckily, antimatter is not present in the universe; it has to be made. In decades of research at CERN, less than a billionth of a gram of antimatter was made, which would provide enough energy to simply light a bulb. Even if significant amount of antimatter could be produced, transporting it would be a really big problem. Since antimatter would disappear the moment it would come into contact with matter, it must be caught with devices that use electric and magnetic fields as trap walls (i.e., Penning traps). Shortly after its publication in 2000, followed by *The Da Vinci Code*, interest in CERN exploded and the center had to put up a website to respond to the tremendous inquiry about antimatter (see <http://livefromcern.web.cern.ch/livefromcern/antimatter/> for more information).

Current theory states that only 4% corresponds to the visible baryonic matter which constitutes stars, planets and living beings. What constitutes the rest?

1.5.1 Antimatter

- According to our current understanding, each of the atomic particles of matter has a twin, an **antiparticle**, which is *identical in mass to matter particle but exactly opposite in all other properties*. In the beginning of the universe, matter and antimatter probably existed in equal amounts, but minuscule asymmetry between the two allowed a small quantity of matter to escape and mark the beginning of the universe.
- **Antimatter** is *matter composed of antiparticles*. When matter and antimatter come into contact with each other, the two destroy each other to produce pure energy. Luckily, antimatter does not exist in nature except very briefly and in very small quantities as the result of radioactive decay or cosmic rays. If you want some, you have to make it in a laboratory such as CERN. And even then, it can be made only in minuscule amounts, which is much less than required to get any useful energy or make a bomb.

Inquisitive Chemist 1.8: Positron emission tomography (PET).

Antimatter is used in PET scanning to produce images for medical diagnosis. These images are simply captions of energy released when a **positron**, an *antiparticle of electron*, is annihilated by an electron in the body. The positron is introduced into the body by a radioactive atom. More information on PET scans and how they work can be found at www.petscaninfo.com.

Researchers have also discovered that **antiprotons** have potential for detecting and treating cancer. They are, however, much more difficult to create and control than positrons.

There is considerable speculation about the apparent asymmetry of matter and antimatter, and remains one of the great unsolved mysteries of the universe. Perhaps with time, experiments at CERN and other similar investigations will give more information on why the universe favors matter over antimatter, possible existence of antimatter in parallel universes, synthesis of antimatter and its containment (e.g. electric and magnetic fields as prison walls) and how we can use antimatter to fight cancer.

1.5.2 Dark Matter

Dark matter is not like regular matter and has never been observed, but its identification might be on the verge of success. Current theory states that about 22% of the universe consists of mysterious, dense (about 5 times as dense as regular matter) and invisible **dark matter** that *keeps the universe intact*. Without it, there wouldn't be enough mass in the universe to keep the galaxies from flying apart. In 2006, NASA scientists were able to detect the gravitational pull exerted by dark matter which has been predicted for so long (http://www.nasa.gov/home/hqnews/2006/aug/HQ_06297_CHANDRA_Dark_Matter.html). It is now believed that dark matter provides the "bones" around which all other cosmic structures have taken shape.

1.5.3 Dark Energy

Another dark mystery was discovered when scientists found surprisingly faint supernovas that suggested that universe is expanding faster, rather than slowing down because of gravity's relentless pull as everyone expected. The universe seems to be pushed by some *repulsive force, or antigravity*, which has been called **dark energy**. This energy is diffused throughout space and does not give off light. Current theory claims that about 74% of the universe consists of dark energy. More about dark matter and dark energy can be found at National Aeronautics and Space Administration's (NASA) *Imagine the Universe* website <http://imagine.gsfc.nasa.gov/docs/science/science.html>.

As you can see, some of the biggest questions about the universe remain unanswered: we don't know the true size of the universe and what it contains; we don't know if other universes exist; we don't know why the universe favors matter over antimatter, and we still don't understand how dark energy shapes universe's fate. These are all important and very exciting questions, especially since just one significant finding could lead to a whole new framework of physical laws. We'll have to leave that to the theoretical physicists, and as chemists, we'll now turn to learning about the elements of our world, which is just as exciting.

Section Test

Questions

1. What % of the universe consists of matter?
2. What's the difference between matter, antimatter and dark matter?

Answers

1. ~4%
2. Matter is ordinary matter as we know it (has mass and occupies volume). Antimatter has the same mass as matter, but is completely opposite of matter in all other properties; the two destroy each other when they come in contact. There is a miniscule amount of antimatter in the universe. Dark matter is dense and invisible; it

keeps the universe intact. Even though it's believed to constitute ~22% of the universe, it has never been observed; only its gravitational pull has been detected.

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