# Unit 1: *EARTH SCIENCE*

## Earth System Science

***What is Earth system science?*** Technological advances, such as satellite photos, and environmental incidents, such as atmospheric pollution, have encouraged scientists and others to view Earth as a system of interconnected and interacting parts, instead of a collection of unrelated parts. This view of Earth as a system is a type of **model** (a representation of something which cannot be observed directly). A **system** is a region that can be studied separately. Because Earth exchanges little matter with its surroundings, it's an essentially **closed system** where little matter enters or leaves, though energy does.

***What are the Earth system's four spheres?*** The Earth system includes four spheres that all affect one another: the atmosphere, the geosphere, the hydrosphere and the biosphere. The **atmosphere** is the gaseous envelope surrounding Earth. The **geosphere** consists of all the physical features on Earth except water. Earth's water makes up the **hydrosphere**. Living things, including plants, animals and people, make up the **biosphere**. The spheres interact and change constantly.

***What are cycles and how do they work?*** The water cycle, the carbon cycle, and the energy cycle all involve interactions among the four spheres of Earth. All water on Earth is continually moving through the **water cycle**, which includes evaporation, transpiration (or evapotranspiration), and precipitation. A biogeochemical cycle involves the movement of an element, such as carbon, through the four spheres of the Earth system (as in the **carbon cycle**). The Earth system has three energy sources: **solar** energy (from the Sun) , **geothermal** energy (from Earth's internal heat) and **tidal** energy from the Moon's pull on Earth's oceans.

## The Nature of Science

***What is the purpose of science?*** The central purpose of scientific inquiry is to understand natural phenomena, solve problems, develop a body of knowledge about the world, and to develop and apply technology.

### III. Scientific Methodology

**Fact:** In science, an observation that has been repeatedly confirmed.
**Law:** A descriptive generalization about how some aspect of the natural world behaves under stated circumstances.
**Hypothesis:** A testable statement about the natural world that can be used to build more complex inferences and explanations.
**Theory:** In science, a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses, that makes valid predictions, and for which no contrary evidence exists

A. Science is a creative process, involving <u>many different methods</u>, but all share certain characteristics
B. Science is a human endeavor and is thus <u>imperfect</u>. Scientists struggle to eliminate bias and to be <u>skeptical</u> and conservative in their interpretations and explanations
C. **Empirical**
   1. data is <u>based on observations</u> and the body of previously-established **facts**
   2. Facts are culled from **primary sources** (original research), not **secondary sources** (other

sources which analyze or restate original primary research).

2. data must be **valid**
    a. **Internal Validity** – relates to the design and methods of the research. Data must be unbiased, accurate, precise, complete and consistent. Variables must be controlled so that findings are not affected by factors other than those thought to have caused them. Ex: **double-blind study** with **placebo**
    b. **External Validity** - the extent to which you can generalize your findings to a larger group or other contexts. Ex: lab research may not faithfully represent what might happen in the real world.

D. **Hypotheses** (proposed, tentative explanations) must be based on observation and must be testable, either by experimentation or through further observation of Nature. They are NOT merely "educated guesses"

E. Testing of hypotheses can involve experimentation or further observation

F. Analysis of **evidence** (observations and facts which support a conclusion) and testing, and the conclusions based on that analysis, may lead to rejection or revision of a hypothesis, or to its greater acceptance

G. Reporting of results
1. submittal of research to a **professional journal -** different from magazines and books, in that they filter and analyze articles through the process of peer review.
2. **Peer review -** the editors of a journal ask a team of experts in the field to review each submittal for validity and quality before publishing.
    a. review team may send the work back unpublished, with suggestions for improvement.
    b. if a paper is published, other scientists read and discuss it. If there is interest, some may try to duplicate the results. They may design a new experiment or search for additional evidence based on the paper. They may publish their own papers, supporting, disproving or modifying the original hypothesis. When similar investigations give different results, the challenge is to judge whether the differences are trivial or significant, and it often takes further studies to decide.
    c. Example: evolution of our understanding about the formation of the Moon – several hypotheses were disproved and rejected while others were modified and accepted by the scientific community
    d. example of no peer review: cold fusion
        1. 1989 media announcement: cheap power (heat) generated in a "glass of water"
        2. no peer review
        3. results could not be duplicated
        4. reputations ruined and the cold fusion concept still invokes negative connotations
        5. ironically, many scientists are working on the problem and think it has a future but the technology is quirky – they are fighting lots of skepticism
3. scientists speak and meet at conferences and participate in professional organizations to share information and to set and maintain high standards in the profession
4. One research project alone is not conclusive. The results must be duplicated and confirmed. It usually takes years of work by many teams before any research is generally accepted by the scientific community. Lay people often misinterpret media reports of early research.

H. A **scientific theory** is an overarching explanation of observations and facts that makes valid predictions, and for which not a single exception has been found
1. Because theories provide explanations, they represent the highest level of scientific understanding
2. Theories often model complex processes which are not directly observable in themselves. Examples: electricity theory, germ theory, atomic theory.

3. The greater the number of severe tests a theory has passed, the greater its degree of confirmation and the more reasonable it is to accept it. However, to confirm is not the same as to prove logically or mathematically. No scientific theory can be proved with absolute certainty.
4. If there is more than one valid explanation to a current problem, they are called "multiple hypotheses," not theories. Once a theory has gained general acceptance in the scientific community, it becomes the single best explanation. Thus, there is normally only one theory to explain particular phenomena. Other explanations being tested would be called hypotheses at best.
5. Common lay definition of theory is very different: *"just one of many speculative ideas"*

I. Some scientific knowledge is very old and yet still valid. But major shifts regularly occur in the scientific view of how the world works. Scientific knowledge is subject to modification as new information challenges prevailing theories and as new theories lead to looking at old observations in a new way. No matter how well one theory fits observations, a new theory might fit them just as well or better.

**What's the difference between observation and inference?** Scientific inquiry involves observation, measurement, classification and inference.

***Observation*** is the interaction of one or more of the five senses with the environment or surroundings. We make observations when we use our senses or instruments to describe something. Ex: *The sky is blue. - or - The water is* $54^0$. However, our powers of observation are limited by our senses. For example, most people cannot tell the exact air temperature just by feeling it. Therefore, we often use *instruments* to extend our powers of observation, like when we use a thermometer to measure the air temperature precisely. So measurements made using instruments are observations too.

***Measurement*** is where we make precise (exact) observations using numbers. When we make a measurement, we are comparing something to a known standard such as a ruler, a counterweight (triple beam balance), or the volume of a graduated cylinder. We use instruments to extend our senses and improve our measurements. Instruments make our senses more powerful and precise.

***Classification*** is the grouping of objects or events based on common observable properties or characteristics. Classification makes our data easier to study and analyze, by organizing our observations in a meaningful way.

***Inference*** is the interpretation, explanation, conclusion, or prediction that is based on observations. An inference is not an observation, but an interpretation, which may be incorrect. Ex: *This soil was deposited by a glacier. - or - It will rain tonight.*

**Why is science important?**

What do *you* think?

## HOW IS SCIENCE RELATED TO OTHER FIELDS AND DISCIPLINES?

Common themes connect mathematics, science, and technology. Although fields include many different specialties, it is also important to see the "big picture," such as recognizing the commonalities that exist among different systems, or how parts of a system interrelate and combine to perform specific functions.

**Engineering design** is an iterative (repetitive / trial-and-error) process involving modeling and optimization (finding the best solution within given constraints). This process is used to develop technological solutions to problems within given constraints.

**Information technology** is used to retrieve, process, and communicate information as a tool to enhance learning. For example, meteorologists analyze weather maps to predict future weather events. Students might use library or electronic references to obtain information to support a laboratory conclusion.

The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science, technology, society, consumer decision making, design, and inquiry into phenomena. For example, local officials might analyze the issues related to local energy needs and develop a viable energy generation plan for the community. Politicians might investigate the political, economic, and environmental impacts of the global distribution and use of mineral resources and fossil fuels. And we all need to consider the environmental and social implications of various solutions to environmental problems.

Solving interdisciplinary problems involves a variety of skills and strategies, including effective work habits; gathering and processing information; generating and analyzing ideas; realizing ideas; making connections among the common themes of mathematics, science, and technology; and presenting results. For example, emergency management officials collect, collate, and process data concerning potential natural disasters (tornadoes, thunderstorms, blizzards, earthquakes, tsunamis, floods, volcanic eruptions, etc.) in an area and develop an emergency action plans. They might use a topographic map to determine the safest and most efficient route for rescue purposes.

In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs. For example, we can debate the effect of human activities on Earth systems as they relate to quality of life (global warming, land use, preservation of natural resources, pollution).

## THE POWER OF TECHNOLOGY

Information technology can have positive and negative impacts on society, depending upon how it is used. For example, early warning systems can protect society and the environment from natural disasters such as hurricanes, tornadoes, earthquakes, tsunamis, floods, and volcanoes. But knowledge of the impacts and limitations of information systems is essential to their effective and ethical use. For example, printed or electronic materials sometimes miscommunicate information (present it inaccurately or incompletely) or perpetuate misconceptions of current commonly accepted scientific knowledge. This can lead to poor decisions (“garbage in = garbage out”).

### How are philosophy and religion different from science?

A. **Philosophy** is broadly defined as the pursuit of <u>wisdom</u> by intellectual means and moral self-discipline. It can also be defined as the system of <u>personal values</u> by which one lives
   1. comprises logic, ethics, aesthetics, metaphysics, and epistemology (the nature of knowledge)
   2. includes the investigation of causes and laws underlying reality, including the critique and analysis of fundamental <u>beliefs</u> as they come to be conceptualized and formulated
   3. based on <u>logical reasoning alone</u> rather than empirical methods
   4. Thus, philosophy is different in that it is the pursuit of <u>wisdom</u>, by considering many disci-

plines (including science but also beliefs and ethics), and by logical reasoning alone

B. **Religion** is the belief in and acceptance of a supernatural power or powers as a controlling influence for the good in one's life
   1. based on revealed truth (revealed by the supernatural through spiritual leaders)
   2. encompasses a large variety of personal or institutionalized systems
   3. involves principles, values, causes and rituals pursued with zeal and conscientious devotion
   4. Thus religion is different in that it is based on revealed truth, encompasses a variety of beliefs in a supernatural creator or governor, and is a controlling influence on one’s life

C. **Science** is an empirical and rational approach to understanding Nature and solving problems
   1. accepts that the world can be understood through observation and by applying reason and logic; that there are fundamental rules which apply to matter and energy, space and time, which make the world understandable.
   2. accepts that empirical reality exists, regardless of, and unaffected by, our thoughts and beliefs.
   3. based on empirical observation (observable and experimental fact / evidence)
   4. explanations must provide testable predictions and must not be contradicted by evidence

D. Philosophy, religion and science are different disciplines, based on different assumptions, and having different goals. But they are not mutually exclusive (to accept one does not require you to reject another)
   1. It is appropriate to educate oneself about and utilize any or all of these disciplines
   2. All are equally valid in constructing one’s personal life view
   3. People differ in the extent to which they are influenced by any or all three
   4. There are many scientists who practice various religions. Conversely, many religious people accept scientific explanations of the natural world
   5. Some matters (ex: religion, ethics and morality) cannot be examined usefully in a scientific way.
   6. Just as one must study and reflect on religious texts to correctly learn and practice a religion, if one is to correctly understand or practice science, it is important to understand, and adhere to, its specific empirical and rational rigors. Regardless of our beliefs or philosophies, understanding how philosophy and religion are different from science enables us to be good scientists, by avoiding philosophical and religious bias in our observations, hypotheses and theories

## PATTERNS OF CHANGE

***Change*** is the occurrence of an event, when the properties of matter or a system are altered. It is a natural state of the environment. We describe or graph a change using a ***frame of reference*** such as time (how a change occurs over days or years) or space (how a change occurs over a distance). When a change occurs, energy flows from one part of the environment (which loses energy) to another (which gains energy) across an ***interface*** (boundary) between different materials or systems.

It's often important to examine the ***rate of change***, or the speed with which a change occurs over a period of time. We can describe the rate of change mathematically (ESRT p.1) where Rate = change in Y / time. Or, we can describe the rate of change graphically. The rate of change is fast if it takes less time (a steeper slope on the graph) and the rate of change is slow if it takes more time (a gentle slope). Sometimes it is difficult to observe or measure the rates of some Earth changes, such as the formations of mountain ranges, which can take many millions of years.

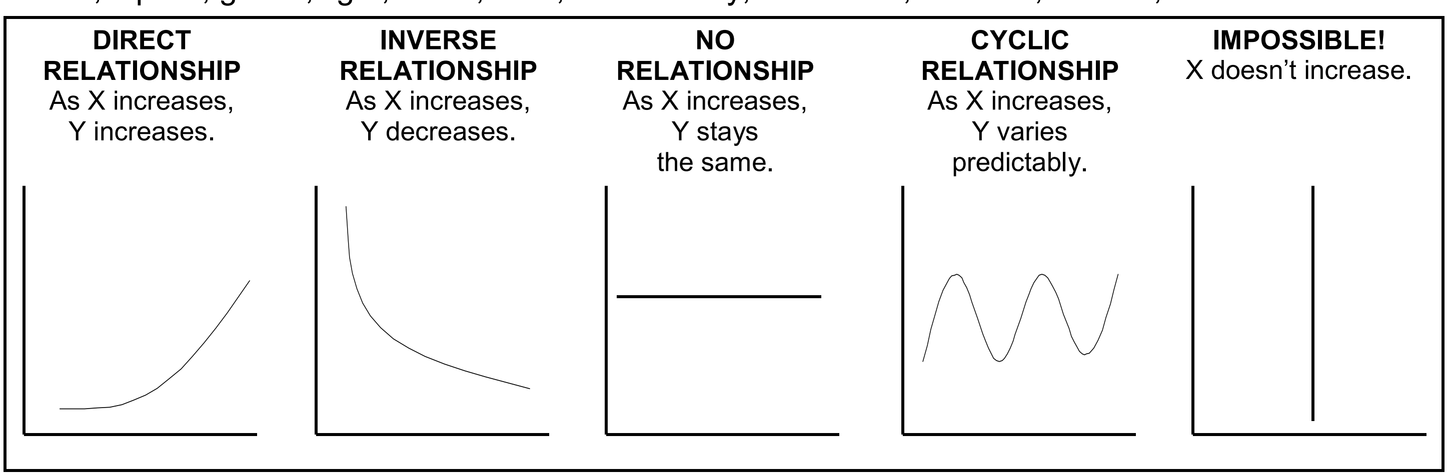
***Cyclic*** changes repeat again and again in a regular interval of time, making them predictable. Most changes in Nature are cyclic. Noncyclic changes do not repeat in any pattern.

**Identifying patterns of change is necessary for making predictions about the future.** Scientists often use graphs to help them organize, visualize and see patterns in their data.

For example, we can graph and interpret the nature of cyclic changes such as sunspots, tides, and atmospheric carbon dioxide. Based on present data of plate movement, we can determine past and future positions of land masses. Using weather data, we can identify the interface between air masses, such as cold fronts, warm fronts, and stationary fronts.

The environment is in a state of ***equilibrium***, or balance. Equilibrium is a state of stability due either to a lack of change (static equilibrium) or a balance between opposing forces (dynamic equilibrium). Static equilibrium appears as a horizontal line on a graph, and dynamic equilibrium appears as a cyclic relationship. For example, the orbits of planets and satellites result from the dynamic equilibrium between gravity and inertia.

The balance of Nature can be altered easily on a small scale. Human technology enables us to disrupt the equilibrium of large portions of the environment. For example, the dynamic equilibrium of Nature can be unbalanced by the introduction of pollutants into the environment. ***Pollution*** is any substance, organism, or form of energy that in high enough concentrations, adversely affects humans and their environment. A pollutant can be natural or manmade. Forms of pollution include solids, liquids, gases, light, noise, heat, radioactivity, chemicals, bacteria, viruses, dust and smoke.



varies with such factors as the seasons or the time of day. Since pollutants are often carried from one location to another by winds or water currents, the concentrations of pollutants will usually be greater downwind or downstream from the source of pollution. Precipitation tends to bring air pollutants to the ground, which cleans the air, but pollutes water and soil, and injures organisms.

## FRAMES OF REFERENCE AND SCALE

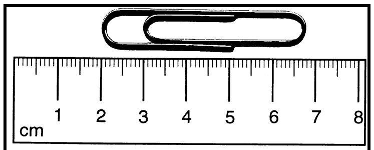
The grouping of magnitudes of size, time, frequency, and pressures or other units of measurement into a series of relative order provides a useful way to deal with the immense ranges of, and changes in, scale that are often encountered. For example, we might arrange in order the distances between the various planets and Sun, or between the Sun and other stars. Or it might be helpful to create a graphical representation on paper of the relative lengths of time of different periods of Earth history.

## MEASUREMENT

Scientific measurements have both numbers and units. Ex: 3.4g
There are two systems of measurement: English and Metric (International System of Units, SI)

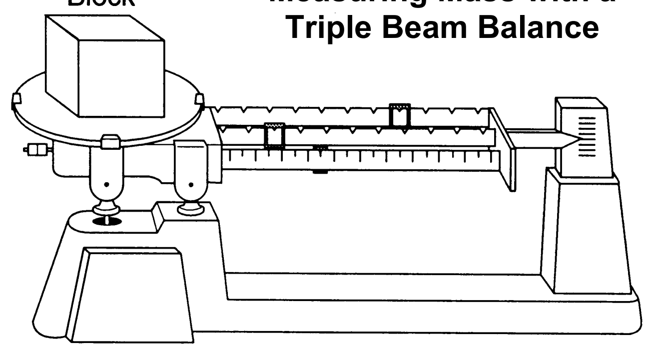
Basic units of measurement are single units by themselves.

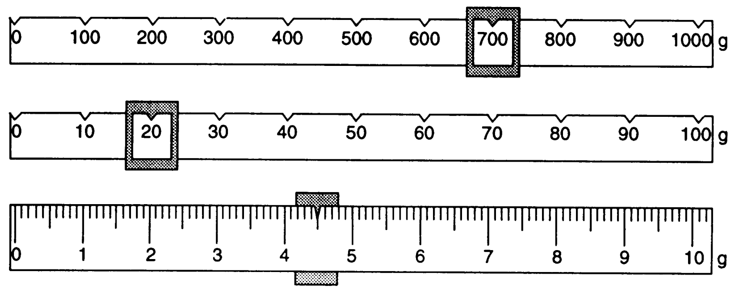
- **Length** is the shortest distance between two points, measured in cm, meters, km., feet or miles (there's a ruler in ESRT p.1)
- **Mass** is the amount of matter in an object, measured in grams or kg.
- **Time** can be either a period or an instant. A period of time is the duration of an event (how long something takes to happen). An instant is the exact point at which an event occurs. Measured in s, min, hrs, days, months, years.
- **Temperature** is a measure of the average amount of heat energy in an object. Measured in degrees Celsius, Fahrenheit or Kelvin (ESRT p. 13)




*If this diagram were on a test, many students would say the length of the paper clip was 6.8cm. Of course it's really 4.8cm (don't forget to subtract 2cm in this case).*

## Measuring Mass with a Triple Beam Balance




*Triple beam balances use three beams, each with a sliding counterweight, to measure mass in grams. The 100's place and 10's place weights must "click" into place before an accurate reading is made. The 1/10's weight is totally free-sliding. Here, the mass is 700 + 20 + 4.5 = 724.5g.*

Derived units are combinations of units, multiplied or divided by each other.

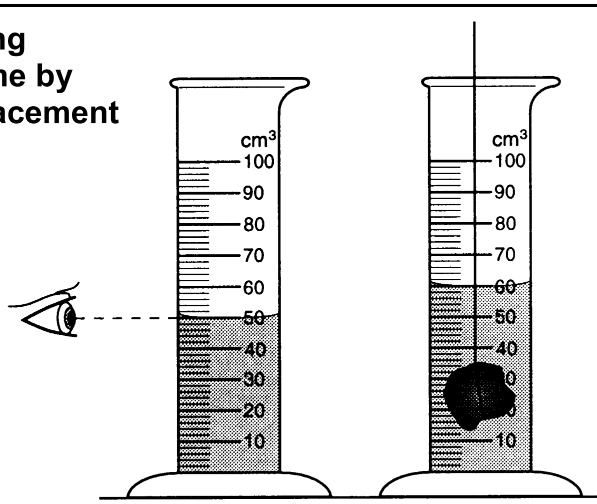
**Volume** is the amount of space an object occupies, measured in $cm^3$ ( = ml) or l.

**Density** is mass per unit volume, measured in g/mL or g/$cm^3$

**Gradient** is the change in some field value over a distance. Ex: ft/mi, $^0$/m.

**Velocity** is speed (a distance travelled per unit of time), measured in m/sec, mi/hr.

**Finding Volume by Displacement**




*Finding volume using the "displacement" method. The graduated cylinder on the left contains 50ml of water. When the mineral sample is lowered into the cylinder, it reads 60ml. The volume of the mineral sample is therefore 10ml. (60ml - 50ml = 10ml).*

**Unit Prefixes**

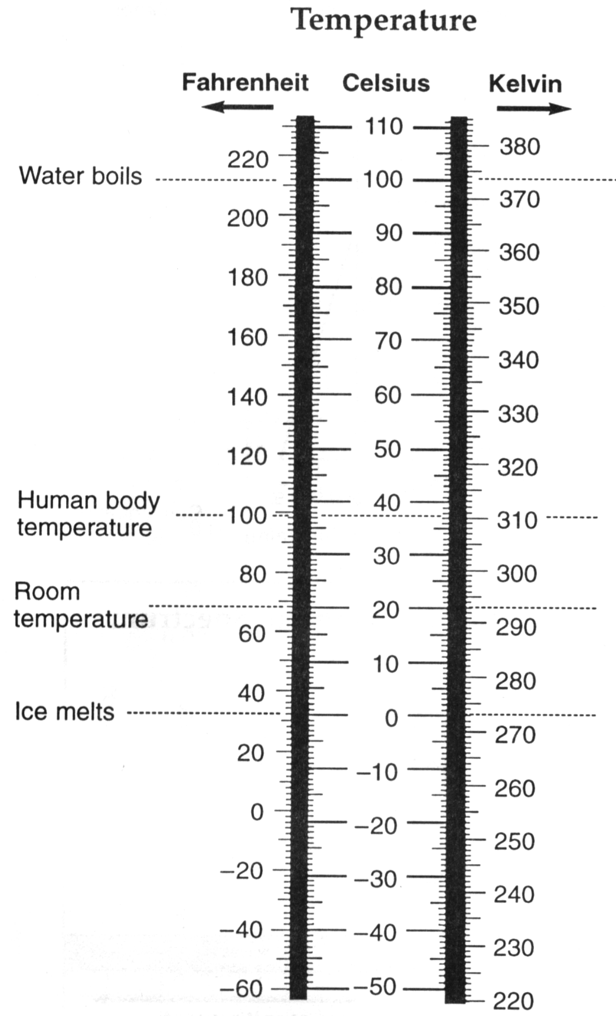
milli 0.0_ (hundredth)
centi 0._ (tenth)
kilo 1000.0 (thousand)

**Scientific notation** (powers of ten) is a "shorthand" for writing very large or very small numbers.

*A.B x 10 $^{n}$*, where A.B is a number between 1 and 10 but not 10; n is the exponent (power of 10).

1. $2.6 \times 10^{3}$ =
2. $1.79 \times 10^{2}$ =
3. $9.45 \times 10^{4}$ =
4. $3.8 \times 10^{-1}$ =
5. $5.1 \times 10^{-3}$ =
6. $6.4 \times 10^{-2}$ =
7. 0.1 =
8. 0.001 =
9. 0.01 =
10. 0.24 =
11. 0.68 =
12. 10 =
13. 100 =
14. 1000 =
15. 148 =
16. 6370 =

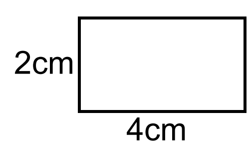
**Temperature Conversion**



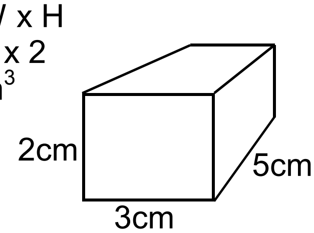

*To convert units of temperature, we use the above scale from the ESRT p.13. From the scale, you can see that an average room temperature of $68^{0}$F equals $20^{0}$C or $293^{0}$ Kelvin.*

**Finding the Area and Volume of a "Regular" or Rectangular Solid**

**Area** = L x W
= 4 x 2
= $8cm^{2}$




**Volume** = L x W x H
= 5 x 3 x 2
= $30cm^{3}$

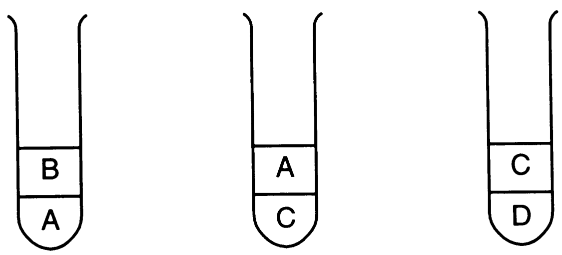


**Density** is a measure of the concentration or "packing" of the particles in an object. The formula (ESRT p.1) is mass/volume. Less dense materials will float on top of heavier, more dense materials. Density can be used to help identify pure substances like minerals (they have characteristic densities). Density is affected by temperature, pressure and phase (physical state). It is NOT affected by size or shape.

**Density Factoids:**

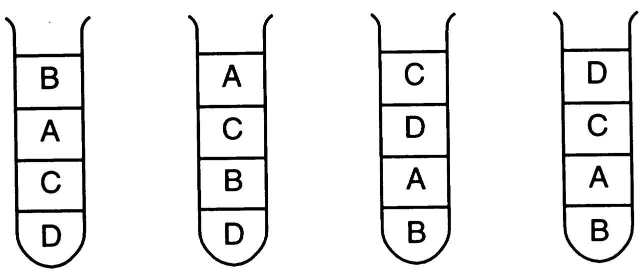
- **Size and Shape** of an object do not affect its density. If you break a pure material into many pieces, all the pieces will have exactly the same density.
- **Temperature:** As temperature increases, density decreases (inverse relationship).
- **Pressure:** As pressure increases, density increases (direct relationship).
- **Phase:** Solids are denser than liquids, which in turn are denser than gases. But water is unique: water is most dense as a liquid at $3.98^0$C, when its density = 1.0 g/cm$^3$ (ESRT p. 1).

Liquids A, B and C below are immiscible (like oil and water - they don't mix). The diagram shows that they also have different densities, so some will float on others.




B floats on A A floats on C C floats on D

Which of the diagrams below shows how these liquids would line up if they were all in the same test tube?



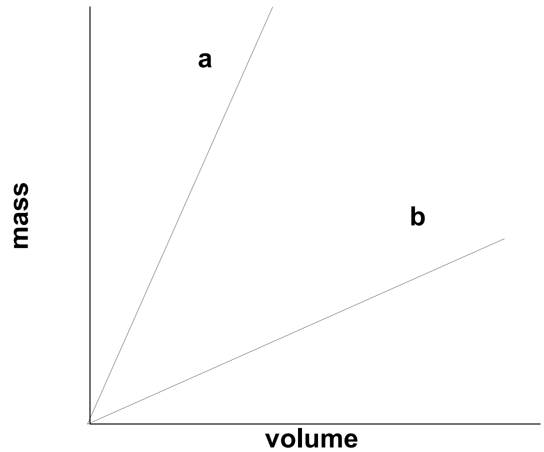

(1) (2) (3) (4)

Which of the following samples will float in water?

| Substance | Density (g/cm$^3$) |
|---|---|
| Sample A | 0.7 g/cm$^3$ |
| Sample B | 1.2 g/cm$^3$ |
| Sample C | 0.9 g/cm$^3$ |
| Sample D | 2.5 g/cm$^3$ |
| Water | 1.0 g/cm$^3$ |

Answer: ____________

## Densities of pure materials a and b




$$D = \frac{mass}{volume} = \frac{rise}{run} = slope$$

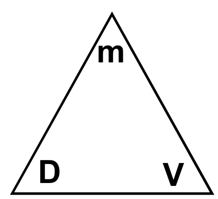
Graphs of density are straight lines, where the slope of the line = density. In this example, a is more dense than b. You can determine the density from the graph: pick a point on the line then divide Y by X or:

$$D = \frac{m}{V}$$

### The "Magic Triangle"

According to ESRT p. 1, the formula for density is D = m/V. But what if we're asked to solve for mass or volume? We could solve algebraically, or we can use the "magic triangle."

First, re-write the formula as a triangle:



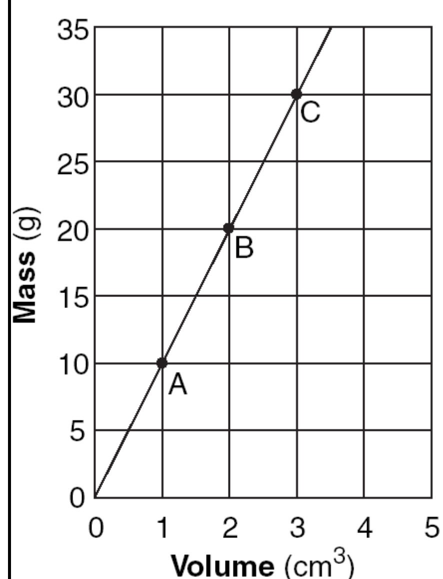

Now, to solve for any of the variables, you use your finger to cover the letter of the variable you're solving for; then the formula will appear.

For example, if you're solving for mass, cover the "m" with your finger. Now you can see the formula for mass is DV (D x V).

Let's say you're solving for volume. Cover the "V" and you'll see the formula for volume is:

$$V = \frac{m}{D}$$

What's the density of this material?




D = ____________________

Using the "Magic Triangle," you can see that:

$$m = DxV$$

$$V = \frac{m}{D}$$

$$D = \frac{m}{V}$$

**Examples:**

1. D = 2.5g/ml and m = 10g V = ?

2. D = 1.5g/ml and V = 10.0ml m = ?

***Error - Percent Deviation*** *from the accepted value* (or “percent of error”)

Most measurements contain some error due to human or instrument error. We use percent of error to check on the accuracy and precision of our measurements (ESRT p.1).

$$\text{Percent deviation from accepted value} = \frac{\text{difference from accepted value}}{\text{accepted value}} \times 100\%$$

We can calculate our error as a percentage of our measurement by comparing our measured values to a known, true or accepted value. For example, we might mass a known 100.0g weight on a balance to see if we get 100.0g.

Written a different way:

$$= \frac{\text{difference between the two values}}{\text{(accepted / known / actual / true) value}} \times 100\%$$

If we mass a 100.0g weight on our balance and it measures 99.0g, then the error is

$$= \frac{100.0\text{g} - 99.0\text{g}}{100.0\text{g}} \times 100\%$$

$$= \frac{1.0}{100.0} \times 100\%$$

$$= 0.01 \times 100\%$$

$= 1\%$ (we always round error to the nearest percent)

**Examples:**

1. A student masses a mineral sample to be 24.0g. But the sample is known to be 25.0g. What’s the percent deviation?

2. The teacher (!) calculates the density to be 2.9g/ml, when the actual density is 2.7g.ml. What’s the percent of error?

# DENSITY Calculations Name ______________

Draw Magic Triangle HERE

**Directions: use the Magic Triangle to solve the following problems.**

1. What's the density of a rock that has a mass of 35 grams and a volume of 7.0 cubic centimeters?

2. What's the density of an object with a volume of 3.0 milliliters and a mass of 12 grams?

3. What's the density of a rectangular solid whose dimensions are 5.0cm by 4.0cm by 3.0cm and whose mass is 120 grams?

4. A student puts a mineral in a graduated cylinder and the water level rises 5ml. The student masses the sample at 125.5g. What is the mineral's density?

5. A student fills a graduated cylinder to the 35ml line. A mineral is placed into the cylinder and the water level rises to the 42ml line. If the mass of the mineral is 88.2g, what is it's density?

6. What is the mass of a 4.0ml sample whose density is 6.1g/ml?

7. V = 4.0cm$^3$, D = 2.7g/cm$^3$ m = ?

8. What is the volume of a 77.4g object with a density of 8.6g/ml?

9. D= 5.4g/ml, m = 10.8g V = ?

10. How dense is Mr. Ling?
    a) low density
    b) 2.9g/ml
    c) very dense
    d) huh?