Quick Reference Guide

1. General Scientific Terminology

Two important things to remember:

1. Science cannot prove anything with absolute certainty. The "truths" in science consist of statements of what is most likely to be true based on current knowledge.
2. A scientific statement must be capable of being disproven. If there is no conceivable evidence which would prove a statement false, it is not a scientific statement.

The following distinctions are useful for discussing various scientific processes.

Science can look at phenomena which are:

Historical: concerning a phenomena or object which no longer exists, such as the investigation of extinct animals or the origin of the universe.

Current: concerning a phenomena or object which is still in existence.

A scientific investigation can be:

Experimental: based on direct manipulation of the independent variables.

Observational: based on selecting existing cases with different values for the independent variables.

Notice that an investigation of historical phenomena must be based only on observational techniques, while an investigation of current phenomena can be either experimental or observational.

In a particular scientific investigation, you should be able to pick out the following items:

Hypothesis: a scientific statement which will be supported or contradicted by the investigation. The hypothesis is used to make predictions which are tested by the investigation.

Prediction: a specific consequence of a hypothesis which can be tested by an investigation.

Independent variables: conditions which are intentionally changed in the investigation, either by direct manipulation or by choosing a sample.

Dependent variables: conditions which are measured or determined in the investigation for the purpose of testing the hypothesis.

Controlled variables: conditions which are measured or determined in the investigation for the purpose of insuring that they do not change within the scope of the investigation.

Assumptions: principles and phenomena which are assumed to be true for the investigation but are not verified. This can include variables which are assumed to be unchanged, but which are not checked. An incorrect assumption will invalidate the investigation.

Result or **Conclusion**: a statement of the outcome of the investigation. The hypothesis can be supported, contradicted, or the results can be inconclusive.

Points to remember:

Any of the variables may be measured in an investigation. Do not assume that measuring a variable means that it is a dependent variable.

The distinction between a hypothesis and a prediction is not absolute. The hypothesis is usually a general statement from which many predictions can be made, while a prediction is a special case which can be tested by a single investigation.

Errors in experiments are often classified in the following two categories:

Random errors - errors in measurement that vary randomly from one measurement to the next. These can be due either to the person making the measurement or to variations in the equipment. Making many measurements and averaging the results will reduce the effect of random error.

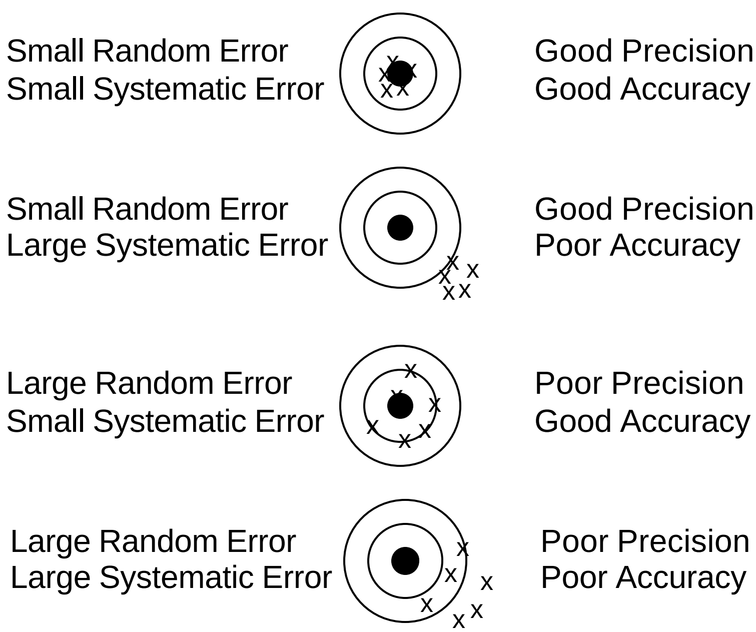
Systematic errors - errors that have a consistent bias. They can occur due to mistakes in setting up or making the measurement or to equipment not being calibrated properly. Averaging will not reduce the effect of these errors.

Note that the "confidence limits" on a measurement can only reflect the effect of random errors, and cannot take systematic errors into account.

Terms that are closely connected with these are precision and accuracy. An accurate measurement is one that is close to a known, or "actual" value. A precise measurement is one that is repeatable. The terms precision and accuracy are most likely to be used to refer to a single measurement or a single instrument, whereas random and systematic errors are generally used to discuss an overall experiment.

In general then, a precise measurement implies small random errors and an accurate measurement implies small systematic errors.

These terms are illustrated below.



To repeat a very important point - **repeating measurements and averaging will reduce the effect of random errors but not of systematic errors**.

Scientific notation is a very convenient way of writing large and small numbers. It represents these numbers as the product of a "reasonable" number and a power of 10.

Examples:

2.74×10^{8} is equal to 274,000,000

1.94×10^{-11} is equal to 0.0000000000194

We will refer to the number on the left (such as 2.74 in the first line above) as the decimal part. The power of ten (such as 8 in the first line above) is called the exponent.

Many calculators have the capability of working directly with scientific notation.

This notation takes advantage of the fact that only a limited number of digits in a real world measurement are "significant". For example, if we measure a distance of 270 million miles, we probably cannot determine it to the nearest mile, or even to the nearest hundred miles. The digits in which we have some reasonable confidence are called "significant figures". When writing something in scientific notation, only the significant figures are displayed.

Exponents

An exponent or power, such as 3^4, means to multiply the number by itself the number of times given in the exponent.

$3^4 = 3 \times 3 \times 3 \times 3 = 81.$

Powers of ten are particularly easy. 10^n is equal to a one followed by n zeroes, i.e.,

$10^0 = 1$

$10^1 = 10$

$10^2 = 100$

$10^3 = 1000$

etc.

A negative exponent, such as 3^{-4}, means to multiply the number by itself the number of times given in the exponent, then divide the result into 1 (take the reciprocal).

$$3^{-4} = \frac{1}{3 \times 3 \times 3 \times 3} = \frac{1}{81}$$

Again, negative powers of 10 are easy. 10^{-n} is equal to 1 followed by n zeros, divided into 1,

$10^{-1} = 0.1$

$10^{-2} = 0.01$

$10^{-3} = 0.001$

$10^{-4} = 0.0001$

etc.

Basic Rules for Scientific Notation

The principles of exponents lead to simple rules for converting numbers in scientific notation, or, to and from scientific notation. The number remains the same if you:

1. Add a number to the exponent (making it larger), and move the decimal point the same number of places to the left (making it smaller).
2. Subtract a number from the exponent (making it smaller), and move the decimal point the same number of places to the right (making it larger).

In general, keep in mind,

Positive exponents mean large numbers.
Negative exponents mean small numbers.

The normal convention is to write the number as a number between 1 and 10, multiplied by the appropriate power of 10.

Examples

$654 = 65.4 \times 10^{1} = 6.54 \times 10^{2} = 0.654 \times 10^{3} = 0.0654 \times 10^{4} = 6540 \times 10^{-1}$

$0.0021 = 0.021 \times 10^{-1} = 0.21 \times 10^{-2} = 2.1 \times 10^{-3} = 21 \times 10^{-4} = 0.00021 \times 10^{1}$

Arithmetic with Numbers in Scientific Notation

To add or subtract numbers in scientific notation, first convert them so that both have the same exponent of 10, then add or subtract the decimal parts.

To multiply or divide numbers in scientific notation, multiply or divide the decimal parts and add (for multiplication) or subtract (for division) the exponents. Notice that this just follows the normal rules for dealing with exponents.

Significant figures can be used as a way of indicating the accuracy of a number or measurement. In order to do this, we indicate specific digits for only those positions in a number which we think we know with some degree of accuracy.

How many significant digits in a number?

1. Any non-zero digit is significant.
2. Since a zero is frequently a place-holder, it is not considered to be significant unless it is unneeded as a place-holder. In a number like 1200, we cannot determine the number of significant digits, since the 00 must be there as place holders. It is best to write numbers like this in scientific notation ($1.20 \quad 10^3$) when using significant figures. The leading zeroes in a fraction are never significant (if in doubt, rewrite it in scientific notation). Zeroes between other digits are always significant.

1.20×10^3	has 3 significant figures
0.004	has 1 significant figure
123.40	has 5 significant figures
5001	has 4 significant figures

Arithmetic with significant figures

After an arithmetic operation, the answer should be rounded off to the correct number of significant figures.

When multiplying or dividing, the answer has the number of significant digits equal to the least number of significant digits in any of the initial numbers.

$16.342 \times 1.23 = 20.1$ since 1.23 has only 3 significant figures.

When adding or subtracting, the answer is only accurate to the smallest position for which each of the numbers has a significant digit.

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 1.34
- .01875
 1.32
    ↑
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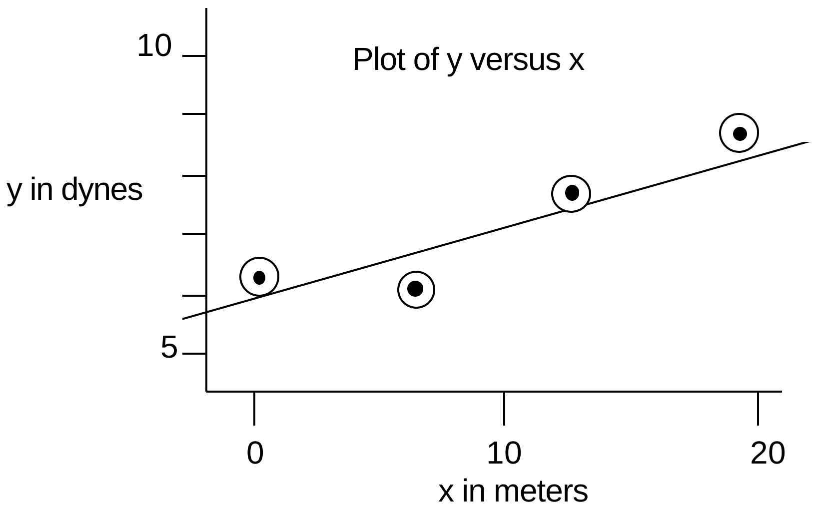
This is the smallest column which is significant since it is the last column in which both number have a significant figure.

5. Graphs



Graphs should have:

- A title - which describes the graph.
- Labels for the axes, including units.
- If more that one set of data is represented, a legend which indicates the symbols used for each.
- A consistent scale should be used on each axis. If the scale is not linear (such as a log scale) this should be clearly indicated by the labeling.
- A scale that increases upward on the Y-axis and to the right on the X-axis.

Normal practice is to plot the independent variable on the horizontal axis (*abscissa*), and the dependent variable on the vertical axis (*ordinate*).

A good practice is to indicate the data points with small dots (the ones above are large for emphasis), then circle them so that you can find them even if they are obscured by the line.

In general, you should not "connect the dots." The graph usually represents what we believe to be some relatively smooth relationship between the variables. For this reason, we often draw either a straight line or a smooth curve through the data points. This line need not pass through any data points. It should represent a "best fit" (by eyeball) to the data.

Very important issues when making any measurement:

- Check to see if the instrument reads zero when you expect zero. In many cases, you will need to make a "zero" measurement that you will subtract from the experimental measurements.
- Does the measurement make sense? For example, if you are measuring the diameter of a common pencil and get greater than 1 cm, something is wrong!

A common practice is to estimate to 1/10 of the smallest division of the scale. This then become the least significant figure.

Use of Scales and Rulers

For the most accurate measurements, *do not use the end of the ruler*. Why? It may be worn, and it is hard to use even if not worn. Measure using the difference between two marks on the ruler, such as by starting with the "1" mark. This technique is commonly used by fine cabinetmakers and machinists. In fact, the best rulers do not start with zero at the end, but with a marked zero located a short distance from the end.

When you use this method *don't forget to subtract the numbers*.

7. Units

Science uses measurements to investigate the natural world and to make predictions about it. Many of those measurements are made in terms of some established unit, such as inches, centimeters, or liters.

When two quantities are added or subtracted, they must have the same units. It makes no sense to add inches to gallons.

When calculations such as multiplication and division are done with quantities involving units, we can carry through the same calculation on the units as on the number themselves. This will give the correct units for the result. If we want to find the speed that we are traveling, we can divide the distance traveled by the time. This means that the units of speed are distance/time. In other words, we divide miles traveled by hours traveled to get miles per hour or mi/hr. Notice that the word “per” is equivalent to division of the units. This is generally true.

If we have two different units that measure the same quantity, we can convert between the two by multiplying or dividing by a conversion factor. A common difficulty is determining whether to multiply or divide by the factor. Here is a systematic way to figure this out starting with a simple equality between units (which is usually given in a table of conversions).

Let’s convert 34.0 cm into inches.

1. Start with the cm - inches relationship: 1 inch = 2.54 cm

2. By dividing both sides of the equation by the quantity on one side of the equation, convert this to a ratio equal to 1, with units included.

$$\frac{1 \text{ inch}}{2.54 \text{ cm}} = 1 \quad \text{or} \quad \frac{2.54 \text{ cm}}{1 \text{ inch}} = 1$$

(Divide both sides by 2.54 cm to get the left equation. Divide both sides by 1 inch to get the right equation.)

3. Multiply the original number by whichever expression gives the correct final units. (Following the principle that “multiplying by one will not change the value of an expression.”)

$$34.0 \, \cancel{\text{cm}} \times \frac{1 \text{ inch}}{2.54 \, \cancel{\text{cm}}} = 13.4 \text{ inches}$$

8. Metric System

Length			Volume:		
1 km	=	1000 m	1 l	=	1000 ml
1 cm	=	0.01 m	1 ml	=	1000 µl
1 mm	=	0.001 m			
1 µm	=	0.000001 m	**Weight**		
1 nm	=	0.000000001 m	1 kg	=	1000 g
			1 g	=	1000 mg
			1 mg	=	1000 µg

Conversions

Length			Volume		
1 yd	=	0.9144 m	1 l	=	1.057 qt
1 m	=	39.37 in	1 qt	=	0.9463 l
1 in	=	2.54 cm			

Weight/Mass (only on Earth - see section on weight and mass)

1 lb	=	0.454 kg
1 lb	=	454 g
1 kg	=	2.2 lb
1 g	=	0.0022 lb
1 kg	=	9.80 N

Key

Metric			English		
km	=	kilometer	yd	=	yard
m	=	meter	in	=	inch
cm	=	centimeter			
mm	=	millimeter	qt	=	quart
µm	=	micrometer			
nm	=	nanometer	lb	=	pound
l	=	liter			
ml	=	ml			
µl	=	microliter			
kg	=	kilogram			
g	=	gram			
mg	=	milligram			
µg	=	microgram			
N	=	newton			

9. Weight and Mass

The terms weight and mass are often used interchangeably, but they refer to different characteristics of objects.

Mass is a measure of how much material is present. Strictly speaking it measures the difficulty of accelerating the object, called the inertia.

Weight is a measure of how hard the gravitational attraction of the Earth is pulling on the object. It is measured by the force acting on the object.

The same object will have the same mass at different locations, but its weight will depend on which (if any) planet that it sits on.

The confusion occurs because on the surface of the earth a certain amount of mass will always have the same weight, and vice-versa. We commonly use pounds and kilograms to refer to either.

Here are the "correct" weight and mass units in the metric and English systems:

	Metric (SI)	English
Mass	kilogram	slug
Weight (force)	newton	pound

Note that the kilogram is a mass unit and the pound is a unit of weight or force.

On Earth, 1 kilogram of mass weighs 2.2 pounds and 9.8 newtons. (We will ignore the slug in this course.) At other locations the conversion will be different.

We are often interested in the rate that something is happening. One of the most important to most of us is our salary, expressed in such terms as dollars per hour or dollars per year.

An interesting observation is that people often have no difficulty with calculations involving their salary but a much greater difficulty with other types of rates, even though the principles are the same!

In general, a rate is in the form of:

$$rate = \frac{something}{time}$$

Examples in terms of general quantities:

$$speed = \frac{distance}{time} \qquad salary = \frac{money}{time} \qquad power = \frac{energy}{time}$$

Here are some possible units for these three examples:

$$speed = \frac{meters}{second} \qquad salary = \frac{dollars}{year} \qquad power(watts) = \frac{joules}{second}$$

When dealing with rates you will often need to find one of the three quantities (rate, something, or time) from the other two. This always requires either multiplying or dividing the two given quantities.

To work these the easy way, use the units to tell you what to do. Example: how long does it take to travel 100 miles at 50 mph? 50 mph is 50 miles/hour (per is always division). I need hours in the answer, and the only way to get that from the two numbers is to divide 50 miles/hour into 100 miles to get 2 hours.

This works with any simple rate problem, as long as you know what units you need in the answer.

Science 1101-1102 Quick Reference	**11. Proportionality**

Proportional relationships are common in our everyday experience. We know, for example, that the cost of a bag of apples or a piece of meat will be proportional to its weight. If our car maintains a steady speed, the distance traveled will be proportional to the amount of driving time. And if we earn an hourly wage, the amount of money we receive is proportional to the number of hours we work.

Proportionality means that two quantities have a **fixed ratio** to each other and is expressed in a mathematical statement using the symbol $\propto$.

Directly Proportional

Let's look at proportionality using a simple example. If you have a job at a local market, the amount of money you have earned (d) is directly proportional to the number of hours you worked (h), or:

$$d \propto h \,.$$

This proportionality, by itself, does not tell you how much money you have earned in a given period of time (such as 6 hours). For this, you must know the ratio of d to h. That ratio is a constant that can be represented in a general equation by the letter k.

$$d = kh$$

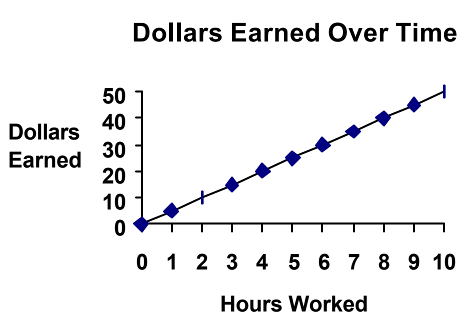
In our example, if you earn five dollars an hour, then the amount of money you earn in six hours can be represented as:

$$d = 5h$$
$$d = 5\,(6)$$
$$d = 30.$$

Note that the value of d will always be five times the value of h, so the ratio of d to h is 5.

If you graph the relationship between two proportional variables, the result is a **straight line** with a slope equal to k. (Remember that the slope of a line is the number of units it moves vertically for each unit it moves horizontally.) The graph below is for the equation d = 5h.

The type of relationship depicted here is a direct one, and we say that the amount of money earned is **directly proportional** to the number of hours worked.



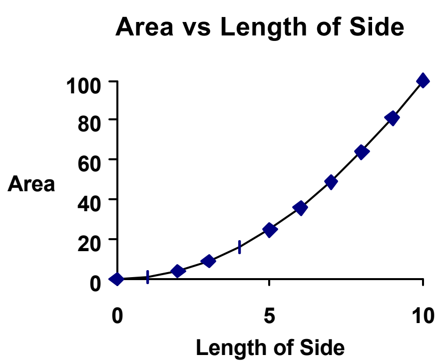
Directly Proportional to the Square

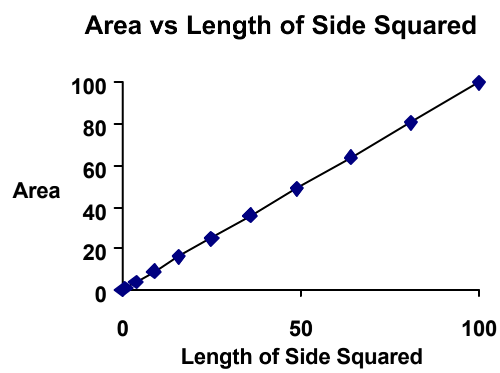
Sometimes proportionality is more complex. We know, for example, that if we increase the length of the side of a square, the area will increase. But the amount of increase is not a simple ratio, and plotting one against the other does not produce a straight line. To illustrate this, imagine a square with sides 1 cm long. The area is therefore 1 cm^2 and the ratio of side length to area is 1:1, or 1. If the length of the side were directly proportional to area, then all squares would have the same side length/area ratio of 1. But we know that if the sides are 2 cm long, the area is 4 cm^2, for a ratio of 1:2. And if the sides are 3 cm, the area is 9 cm^2 for a ratio of 1:3.

In this case, the area of the square is not proportional to the length of the side, but rather it is proportional to the square of the length of the side. Another way to say this, given the terms A for area and s for the length of a side, is:

$$A \propto s^2$$

We can also see this if we graph A against s and A against s^2. Only the latter forms a straight line. In this case, area is directly proportional to the square of s (or to s^2).





Inversely Proportional

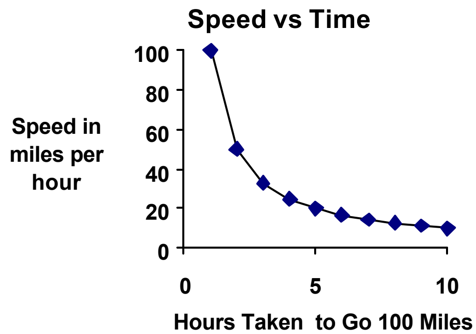
Another variation of proportional relationships is seen in that between speed and time. Speed is defined as the amount of distance covered in a given period of time, or:

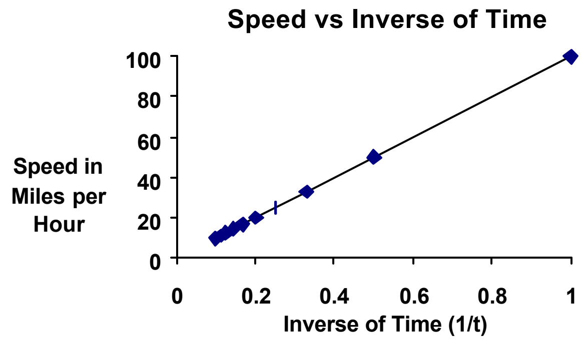
$$S = d/t.$$

Notice that, if the distance a vehicle travels is kept constant (say 100 miles), the speed at which it moves is proportional to 1/t, or to the **inverse** of the time taken to cover that distance. The smaller the time taken to go the distance, the faster the speed. Speed, then, is **inversely proportional** to time, or:

$$S \propto 1/t$$

A graph of time versus speed (top of next page) results in a curved line, indicating that the two are not directly proportional. On the other hand, plotting speed against the inverse of t (or 1/t) does produce a straight line. This means that speed is proportional to the inverse of time.





Note on the second graph that the points along the X-axis that are plotted are 1/t, not t. In other words, the value used for 2 hours is 1/2, or 0.5. Similarly, the value used for 3 hours is 1/3 (0.33), the value used for 4 hours is 1/4 (0.25) and so forth.

