Introduction to the Scientific Method

The scientific method is the process by which scientists, collectively and over time, endeavor to construct an accurate (that is, reliable, consistent and non-arbitrary) representation of the world.

Recognizing that personal and cultural beliefs influence both our perceptions and our interpretations of natural phenomena, we aim through the use of standard procedures and criteria to minimize those influences when developing a theory. As a famous scientist once said, "Smart people (like smart lawyers) can come up with very good explanations for mistaken points of view." In summary, the scientific method attempts to minimize the influence of bias or prejudice in the experimenter when testing an hypothesis or a theory.

I. The scientific method has four steps

1. Observation and description of a phenomenon or group of phenomena.

2. Formulation of an hypothesis to explain the phenomena. In physics, the hypothesis often takes the form of a causal mechanism or a mathematical relation.

3. Use of the hypothesis to predict the existence of other phenomena, or to predict quantitatively the results of new observations.

4. Performance of experimental tests of the predictions by several independent experimenters and properly performed experiments.

If the experiments bear out the hypothesis it may come to be regarded as a theory or law of nature (more on the concepts of hypothesis, model, theory and law below). If the experiments do not bear out the hypothesis, it must be rejected or modified. What is key in the description of the scientific method just given is the predictive power (the ability to get more out of the theory than you put in; see Barrow, 1991) of the hypothesis or theory, as tested by experiment. It is often said in science that theories can never be proved, only disproved. There is always the possibility that a new observation or a new experiment will conflict with a long-standing theory.

II. Testing hypotheses

As just stated, experimental tests may lead either to the confirmation of the hypothesis, or to the ruling out of the hypothesis. The scientific method requires that an hypothesis be ruled out or modified if its predictions are clearly and repeatedly incompatible with experimental tests. Further, no matter how elegant a theory is, its predictions must agree with experimental results if we are to believe that it is a valid description of nature. In physics, as in every experimental science, "experiment is supreme" and experimental verification of hypothetical predictions is absolutely necessary. Experiments may test the theory directly (for example, the observation of a new particle) or may test for consequences derived from the theory using mathematics and logic (the rate of a radioactive decay process requiring the existence of the new particle). Note that the necessity of experiment also implies that a theory must be testable. Theories which cannot be tested, because, for instance, they have no observable ramifications (such as, a particle whose characteristics make it unobservable), do not qualify as scientific theories.

If the predictions of a long-standing theory are found to be in disagreement with new experimental results, the theory may be discarded as a description of reality, but it may continue to be applicable within a limited range of measurable parameters. For example, the laws of classical mechanics (Newton's Laws) are valid only when the velocities of interest are much smaller than the speed of light (that is, in algebraic form, when $v/c \ll 1$). Since this is the domain of a large portion of human experience, the laws of classical mechanics are widely, usefully and correctly applied in a large range of technological and scientific problems. Yet in nature we observe a domain in which v/c is not small. The motions of objects in this domain, as well as motion in the "classical" domain, are accurately described through the equations of Einstein's theory of relativity. We believe, due to experimental tests, that relativistic theory provides a more general, and therefore more accurate, description of the principles governing our universe, than the earlier "classical" theory. Further, we find that the relativistic equations reduce to the classical equations in the limit $v/c \ll 1$. Similarly, classical physics is valid only at distances much larger than atomic scales ($x \gg 10^{-8}$ m). A description which is valid at all length scales is given by the equations of quantum mechanics.

We are all familiar with theories which had to be discarded in the face of experimental evidence. In the field of astronomy, the earth-centered description of the planetary orbits was overthrown by the Copernican system, in which the sun was placed at the center of a series of concentric, circular planetary orbits. Later, this theory was modified, as measurements of the planets motions were found to be compatible with elliptical, not circular, orbits, and still later planetary motion was found to be derivable from Newton's laws.

Error in experiments have several sources. First, there is error intrinsic to instruments of measurement. Because this type of error has equal probability of producing a measurement higher or lower numerically than the "true" value, it is called random error. Second, there is non-random or systematic error, due to factors which bias the result in one direction. No measurement, and therefore no experiment, can be perfectly precise. At the same time, in science we have standard ways of estimating and in some cases reducing errors. Thus it is important to determine the accuracy of a particular measurement and, when stating quantitative results, to quote the measurement error. A measurement without a quoted error is meaningless. The comparison between experiment and theory is made within the context of experimental errors. Scientists ask, how many standard deviations are the results from the theoretical prediction? Have all sources of systematic and random errors been properly estimated? This is discussed in more detail in the appendix on *Error Analysis* and in Statistics Lab 1.

III. Common Mistakes in Applying the Scientific Method

As stated earlier, the scientific method attempts to minimize the influence of the scientist's bias on the outcome of an experiment. That is, when testing an hypothesis or a theory, the scientist may have a preference for one outcome or another, and it is important that this preference not bias the results or their interpretation. The most fundamental error is to mistake the hypothesis for an explanation of a phenomenon, without performing experimental tests. Sometimes "common sense" and "logic" tempt us into believing that no test is needed. There are numerous examples of this, dating from the Greek philosophers to the present day.

Another common mistake is to ignore or rule out data which do not support the hypothesis. Ideally, the experimenter is open to the possibility that the hypothesis is correct or incorrect. Sometimes, however, a scientist may have a strong belief that the hypothesis is true (or false), or feels internal or external pressure to get a specific result. In that case, there may be a psychological tendency to find "something wrong", such as systematic effects, with data which do not support the scientist's expectations, while data which do agree with those expectations may not be checked as carefully. The lesson is that all data must be handled in the same way.

Another common mistake arises from the failure to estimate quantitatively systematic errors (and all errors). There are many examples of discoveries which were missed by experimenters whose data contained a new phenomenon, but who explained it away as a systematic background. Conversely, there are many examples of alleged "new discoveries" which later proved to be due to systematic errors not accounted for by the "discoverers."

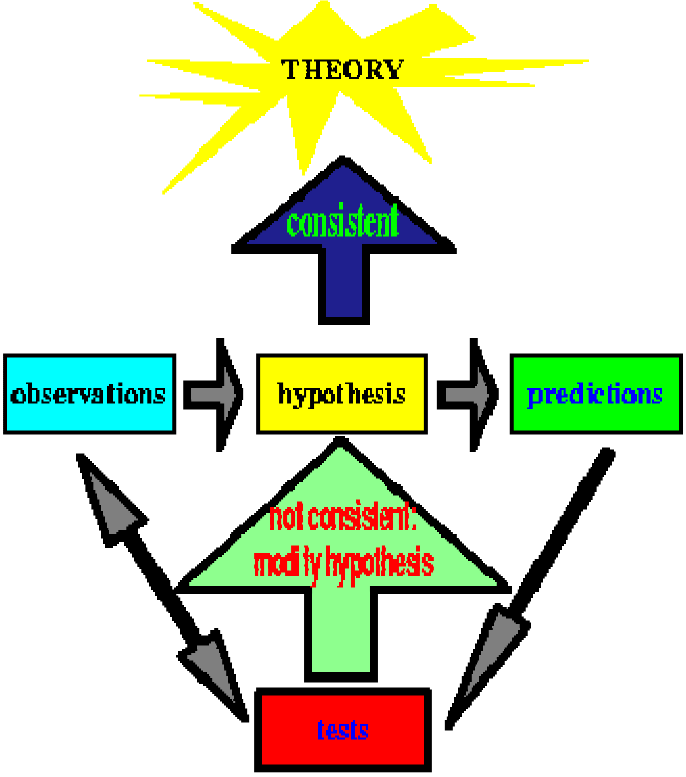
In a field where there is active experimentation and open communication among members of the scientific community, the biases of individuals or groups may cancel out, because experimental tests are repeated by different scientists who may have different biases. In addition, different types of experimental setups have different sources of systematic errors. Over a period spanning a variety of experimental tests (usually at least several years), a consensus develops in the community as to which experimental results have stood the test of time.

IV. Hypotheses, Models, Theories and Laws

In physics and other science disciplines, the words "hypothesis," "model," "theory" and "law" have different connotations in relation to the stage of acceptance or knowledge about a group of phenomena.

An hypothesis is a limited statement regarding cause and effect in specific situations; it also refers to our state of knowledge before experimental work has been performed and perhaps even before new phenomena have been predicted. To take an example from daily life, suppose you discover that your car will not start. You may say, "My car does not start because the battery is low." This is your first hypothesis. You may then check whether the lights were left on, or if the engine makes a particular sound when you turn the ignition key. You might actually check the voltage across the terminals of the battery. If you discover that the battery is not low, you might attempt another hypothesis ("The starter is broken"; "This is really not my car.")

The word model is reserved for situations when it is known that the hypothesis has at least limited validity. A often-cited example of this is the Bohr model of the atom, in which, in an analogy to the solar system, the electrons are described has moving in circular orbits around the nucleus. This is not an accurate depiction of what an atom "looks like," but the model succeeds in mathematically representing the energies (but not the correct angular momenta) of the quantum states of the electron in the simplest case, the hydrogen atom. Another example is Hook's Law (which should be called Hook's principle, or Hook's model), which states that the force exerted by a mass attached to a spring is proportional to the amount the spring is stretched. We know that this principle is only valid for small amounts of stretching. The "law" fails when the spring is stretched beyond its elastic limit (it can break). This principle, however, leads to the prediction of simple harmonic motion, and, as a model of the behavior of a spring, has been versatile in an extremely broad range of applications.



A scientific theory or law represents an hypothesis, or a group of related hypotheses, which has been confirmed through repeated experimental tests. Theories in physics are often formulated in terms of a few concepts and equations, which are identified with "laws of nature," suggesting their universal applicability. Accepted scientific theories and laws become part of our understanding of the universe and the basis for exploring less well-understood areas of knowledge. Theories are not easily discarded; new discoveries are first assumed to fit into the existing theoretical framework. It is only when, after repeated experimental tests, the new phenomenon cannot be accommodated that scientists seriously question the theory and attempt to modify it. The validity that we attach to scientific theories as representing realities of the physical world is to be contrasted with the facile invalidation implied by the expression, "It's only a theory." For example, it is unlikely that a person will step off a tall building on the assumption that they will not fall, because "Gravity is only a theory."

Changes in scientific thought and theories occur, of course, sometimes revolutionizing our view of the world (Kuhn, 1962). Again, the key force for change is the scientific method, and its emphasis on experiment.

The scientific method has 5 steps: To help you remember the steps of the scientific method, think of the word "POHEC".

Problem
Observation
Hypothesis
Experiment
Conclusion

1. State the problem
2. Make Observations
3. Form a Hypothesis
4. Do the Experiment
5. Draw a conclusion.

V. Are there circumstances in which the Scientific Method is not applicable?

While the scientific method is necessary in developing scientific knowledge, it is also useful in everyday problem-solving. What do you do when your telephone doesn't work? Is the problem in the hand set, the cabling inside your house, the hookup outside, or in the workings of the phone company? The process you might go through to solve this problem could involve scientific thinking, and the results might contradict your initial expectations.

Like any good scientist, you may question the range of situations (outside of science) in which the scientific method may be applied. From what has been stated above, we determine that the scientific method works best in situations where one can isolate the phenomenon of interest, by eliminating or accounting for extraneous factors, and where one can repeatedly test the system under study after making limited, controlled changes in it.

There are, of course, circumstances when one cannot isolate the phenomena or when one cannot repeat the measurement over and over again. In such cases the results may depend in part on the history of a situation. This often occurs in social interactions between people. For example, when a lawyer makes arguments in front of a jury in court, she or he cannot try other approaches by repeating the trial over and over again in front of the same jury. In a new trial, the jury composition will be different. Even the same jury hearing a new set of arguments cannot be expected to forget what they heard before.

VI. Conclusion

The scientific method is intricately associated with science, the process of human inquiry that pervades the modern era on many levels. While the method appears simple and logical in description, there is perhaps no more complex question than that of knowing how we come to know things. In this introduction, we have emphasized that the scientific method distinguishes science from other forms of explanation because of its requirement of systematic experimentation. We have also tried to point out some of the criteria and practices developed by scientists to reduce the influence of individual or social bias on scientific findings. Further investigations of the scientific method and other aspects of scientific practice may be found in the references listed below.

The Systeme International [S I]

Le Systeme international d'Unites officially came into being in October 1960 and has been officially recognised and adopted by nearly all countries, though the amount of actual usage varies considerably. It is based upon 7 principal units, 1 in each of 7 different categories -

Category	***Name***	***Abbrev.***
Length	metre	m

Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Definitions of these basic units are given. Each of these units may take a prefix. From these basic units many other units are derived and named.

Definitions of the Seven Basic S I Units

metre [m]

The metre is the basic unit of length. It is the distance light travels, in a vacuum, in 1/299792458*th* of a second.

kilogram [kg]

The kilogram is the basic unit of mass. It is the mass of an international prototype in the form of a platinum-iridium cylinder kept at Sevres in France. *It is now the only basic unit still defined in terms of a material object, and also the only one with a prefix[kilo] already in place.*

second [s]

The second is the basic unit of time. It is the length of time taken for 9192631770 periods of vibration of the caesium-133 atom to occur.

ampere [A]

The ampere is the basic unit of electric current. It is that current which produces a specified force between two parallel wires which are 1 metre apart in a vacuum.*It is named after the French physicist Andre Ampere (1775-1836).*

kelvin [K]

The kelvin is the basic unit of temperature. It is 1/273.16*th* of the thermodynamic temperature of the triple point of water. *It is named after the Scottish mathematician and physicist William Thomson 1st Lord Kelvin (1824-1907).*

mole [mol]

The mole is the basic unit of substance. It is the amount of substance that contains as many elementary units as there are atoms in 0.012 kg of carbon-12.

candela [cd]

The candela is the basic unit of luminous intensity. It is the intensity of a source of light of a specified frequency, which gives a specified amount of power in a given direction.

Derived Units of the S I

From the 7 basic units of the SI other units are derived for a variety of purposes. Only a few of are explained here as examples, there are many more.

farad [F]

The farad is the SI unit of the capacitance of an electrical system, that is, its capacity to store electricity. It is a rather large unit as defined and is more often used as a microfarad. *It is named after the English chemist and physicist Michael Faraday (1791-1867).*

hertz [Hz]

The hertz is the SI unit of the frequency of a periodic phenomenon. One hertz indicates that 1 cycle of the phenomenon occurs every **second**. For most work much higher frequencies are needed such as the kilohertz [kHz] and megahertz [MHz]. *It is named after the German physicist Heinrich Rudolph Hertz (1857-94).*

joule [J]

The joule is the SI unit of work or energy. One joule is the amount of work done when an applied force of 1 **newton** moves through a distance of 1 **metre** in the direction of the force.*It is named after the English physicist James Prescott Joule (1818-89).*

newton [N]

The newton is the SI unit of force. One newton is the force required to give a mass of 1 **kilogram** an acceleration of 1 **metre** per **second** per **second.** *It is named after the English mathematician and physicist Sir Isaac Newton (1642-1727).*

ohm [Ω]

The ohm is the SI unit of resistance of an electrical conductor. Its symbol, is the capital Greek letter 'omega'. *It is named after the German physicist Georg Simon Ohm (1789-1854).*

pascal [Pa]

The pascal is the SI unit of pressure. One pascal is the pressure generated by a force of 1 **newton** acting on an area of 1 square **metre**. It is a rather small unit as defined and is more often used as a kilopascal [kPa]. *It is named after the French mathematician, physicist and philosopher Blaise Pascal (1623-62).*

volt [V]

The volt is the SI unit of electric potential. One volt is the difference of potential between two points of an electical conductor when a current of 1 **ampere** flowing between those points dissipates a power of 1 **watt**. *It is named after the Italian physicist Count Alessandro Giuseppe Anastasio Volta (1745-1827).*

watt [W]

The watt is used to measure power or the rate of doing work. One watt is a power of 1 **joule** per **second**. *It is named after the Scottish engineer James Watt (1736-1819).*

The Prefixes of the S I

The S I allows the sizes of units to be made bigger or smaller by the use of appropriate prefixes. For example, the electrical unit of a watt is not a big unit even in terms of ordinary household use, so it is generally used in terms of 1000 watts at a time. The prefix for 1000 is *kilo* so we use kilowatts[kW] as our unit of measurement. For makers of electricity, or bigger users such as industry, it is common to use megawatts[MW] or even gigawatts[GW]. The full range of prefixes with their [symbols or abbreviations] and their multiplying factors *which are also given in other forms* is

yotta	[Y]	1 000 000 000 000 000 000 000 000	= 10^24
zetta	[Z]	1 000 000 000 000 000 000 000	= 10^21
exa	[E]	1 000 000 000 000 000 000	= 10^18
peta	[P]	1 000 000 000 000 000	= 10^15
tera	[T]	1 000 000 000 000	= 10^12
giga	[G]	1 000 000 000	*(a thousand millions = a billion)*
mega	[M]	1 000 000	*(a million)*
kilo	[k]	1 000	*(a thousand)*
hecto	[h]	100	*(a hundred)*
deca	[da]	10	*(ten)*
		1	
deci	[d]	0.1	*(a tenth)*
centi	[c]	0.01	*(a hundredth)*
milli	[m]	0.001	*(a thousandth)*
micro	[µ]	0.000 001	*(a millionth)*

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nano  [n] 0.000 000 001                   (a thousand millionth)
pico  [p] 0.000 000 000 001                   = 10^-12
femto [f] 0.000 000 000 000 001                       = 10^-15
atto  [a] 0.000 000 000 000 000 001           = 10^-18
zepto [z] 0.000 000 000 000 000 000 001               = 10^-21
yocto [y] 0.000 000 000 000 000 000 000 001   = 10^-24
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[µ] the symbol used for **micro** is the Greek letter known as 'mu'
Nearly all of the SI prefixes are multiples (kilo to yotta) or sub-multiples (milli to yocto) of 1000.
However, these are inconvenient for many purposes and so **hecto**, **deca**, **deci**, and **centi** are also used.
deca also appears as **deka [da]** or **[dk]** in the USA and Contintental Europe. So much for standards!

Conventions of Usage in the S I

There are various rules laid down for the use of the SI and its units as well as some observations to be made that will help in its correct use.

- Any unit may take only ONE prefix. For example 'millimillimetre' is incorrect and should be written as 'micrometre'.
- Most prefixes which make a unit bigger are written in capital letters (M G T etc.), but when they make a unit smaller then lower case (m n p etc.) is used. Exceptions to this are the kilo [k] to avoid any possible confusion with kelvin [K]; hecto [h]; and deca [da] or [dk]
- It will be noted that many units are eponymous, that is they are named after persons. This is always someone who was prominent in the early work done within the field in which the unit is used. Such a unit is written all in lower case (newton, volt, pascal etc.) when named in full, but starting with a capital letter (N V Pa etc.) when abbreviated. An exception to this rule is the litre which, if written as a lower case 'l' could be mistaken for a '1' (one) and so a capital 'L' is allowed as an alternative. It is intended that a single letter will be decided upon some time in the future when it becomes clear which letter is being favoured most in use.
- Units written in abbreviated form are NEVER pluralised. So 'm' could always be either 'metre' or 'metres'. 'ms' would represent 'millisecond'.
- An abbreviation (such as J N g Pa etc.) is NEVER followed by a full-stop unless it is the end of a sentence.
- To make numbers easier to read they may be divided into groups of 3 separated by spaces (or half-spaces) but NOT commas.
- The SI preferred way of showing a decimal fraction is to use a comma (123**,**456) to separate the whole number from its fractional part. The practice of using a point, as is common in English-speaking countries, is acceptable providing only that the point is placed ON the line of the bottom edge of the numbers (123**.**456) and NOT in the middle.

A Brief History of Measurement

One of the earliest types of measurement concerned that of length. These measurements were usually based on parts of the body. A well documented example (the first) is the Egyptian cubit which was derived from the length of the arm from the elbow to the outstretched finger tips. By 2500 BC this had been standardised in a royal master cubit made of black marble (about 52 cm). This cubit was divided into 28 digits (roughly a finger width) which could be further divided into fractional parts, the smallest of these being only just over a millimetre.

In England units of measurement were not properly standardised until the 13th century, though variations (and abuses) continued until long after that. For example, there were three different gallons (ale, wine and corn) up until 1824 when the gallon was standardised.

In the U S A the system of weights and measured first adopted was that of the English, though a few differences came in when decisions were made at the time of standardisation in 1836. For instance, the wine-gallon of 231 cubic inches was used instead of the English one (as defined in 1824) of about 277 cubic inches. The U S A also took as their standard of dry measure the old Winchester bushel of 2150.42 cubic inches, which gave a dry gallon of nearly 269 cubic inches.

Even as late as the middle of the 20th century there were some differences in UK and US measures which were nominally the same. The UK inch measured 2.53998 cm while the US inch was 2.540005 cm. Both were standardised at 2.54 cm in July 1959, though the U S continued to use 'their' value for several years in land surveying work - this too is slowly being metricated.

In France the metric system officially started in June 1799 with the declared intent of being 'For all people, for all time'. The unit of length was the metre which was defined as being one ten-millionth part of a quarter of the earth's circumference. The production of this standard required a very careful survey to be done which took several years. However, as more accurate instruments became available so the 'exactness' of the standard was called into question. Later efforts were directed at finding some absolute standard based on an observable physical phenomenon. Over two centuries this developed into the S I. So maybe their original slogan was more correct than anyone could have foreseen then.

Categories of Units

Length

The S I unit of length is the **meter**. To change any of these other units of length into their **equivalent values in meters** use the operation and conversion factor given. Those marked with # are **exact.** Other values are given to an appropriate degree of accuracy. *Where some uncertainty is indicated it means that a good idea of the size of the unit can be given but that a better value would depend upon knowing the period and/or culture in which the unit was being used.*

Note than in matters concerned with land measurements, for the most accurate work, it is necessary to establish whether the US survey measures are being used or not.

Area

The S I unit of area is the **square metre**. To change any of these other units of area into their **equivalent values in square metres** use the operation and conversion factor given. Those marked with # are **exact.** Other values are given to an appropriate degree of accuracy. *Where some uncertainty is indicated it means that a good idea of the size of the unit can be given but that a better value would depend upon knowing the period and/or culture in which the unit was being used.* Note than in matters concerned with land measurements, for the most accurate work, it is necessary to establish whether the US survey measures are being used or not.

Volume or Capacity

The S I unit of volume is the cubic metre. However, this seems to be much less used than the **litre** (1000 litres = 1 cubic metre).To change any of these other units of volume into their **equivalent values in litres** use the operation and conversion factor given. Those marked with # are **exact.** Other values are given to an appropriate degree of accuracy.

The **litre**. There can be some ambiguity about the size of the litre. When the metric system was introduced in the 1790's the litre was intended to match up with the volume occupied by 1 kilogram of pure water at a specified pressure and temperature. As the ability to measure things got better (by 100 years later) they found that there was a mismatch between the kilogram and the litre. As a result of this they had to redefine the litre (in 1901) as being 1.000028 cubic decimetres. Very handy!

This nonsense was stopped in 1964 when it was ruled that the word "litre" may be employed as a special name for the cubic decimetre, with the additional recommendation that for really accurate work, to avoid any possible confusion, the litre should not be used.

Here the **litre** is taken as being a cubic decimetre.

Mass (or Weight)

The S I unit of mass is the **kilogram**. To change any of these other units of mass into their **equivalent values in kilograms** use the operation and conversion factor given. Those marked with # are **exact.** Other values are given to an appropriate degree of accuracy.

Temperature

There have been five main temperature scales, each one being named after the person who invented it.

FAHRENHEIT (1686-1736) a German physicist, in about 1714 proposed the first practical scale. He called the freezing-point of water 32 degrees (so as to avoid negative temperatures) and the boiling-point 212 degrees.

REAUMUR (1673-1757) A French entomologist, proposed a similar scale in 1730, but set the freezing-point at 0 degrees and the boiling-point at 80 degrees. This was used quite a bit but is now obsolete.

CELSIUS (1701-1744) a Swedish astronomer, proposed the 100-degree scale (from 0 to 100) in 1742. This was widely adopted as the centigrade scale. But since grades and centigrades were also measures of angle, in 1947 it officially became the Celsius scale. Also, the S I system of units gives preference to naming units after people where possible.

KELVIN (1824-1907) a Scottish mathematician and physicist, worked with J P Joule - about

1862 - to produce an absolute scale of temperature based on laws of heat rather than the freezing/boiling-points of water. This work produced the idea of 'absolute zero', a temperature below which it was not possible to go. Its value is -273.15 degrees on the Celsius scale. **RANKINE** (1820-1872) a Scottish engineer and scientist, promoted the Kelvin scale in its Fahrenheit form, when the equivalent value of absolute zero is -459.67 degrees Fahrenheit. Nowadays, while scientists use the KELVIN scale, the CELSIUS scale is the preferred scale in our everyday lives. However, the Fahrenheit scale is still widely used and there frequently is a need to be able to change from one to the other.

Line density

Line density is a measure of mass per unit length. The S I compatible unit of line density is **kilograms/metre**. A major use of line density is in the textile industry to indicate the coarseness of a yarn or fibre. For that purpose the SI unit is rather large so the preferred unit there is the **tex**. (1 tex = 1 gram/kilometre) To change any of these other units of line density into their **equivalent values in kilograms/metre** use the operation and conversion factor given. Those marked with # are **exact.** Other values are given to an appropriate degree of

Density

Density is the shortened term generally used in place of the more accurate description *volumetric density*.It is a measure of mass per unit volume. The S I compatible unit of density is **kilograms/cubic metre**. However, this a rather large unit for most purposes (iron is over 7000, wood is about 600 and even cork is over 200). A much more useful size of unit is **kilograms/litre** (for which the previous values then become 7, 0.6 and 0.2 respectively). This unit also has the great advantage of being numerically unchanged for grams/cubic centimetre and tonnes/cubic metre (or megagrams/cubic metre). To change any of these other units of density into their **equivalent values in kilograms/litre** use the operation and conversion factor given. Those marked with # are **exact.** Other values are given to an appropriate degree of accuracy.

Energy or work

There is a lot of room for confusion in some of the units used here. The **calorie** can take 5 different values and, while these do not vary by very much, for accurate work it is necessary to specify which calorie is being used.

Unless a clear statement is made saying otherwise, assume the IT calorie is being used.
As a further complication, in working with food and expressing nutritional values, the unit of a Calorie *(capital C)* is often used to represent 1000 calories, and again it is necessary to specify which calorie is being used for that.
The **British thermal unit** (Btu) can also take different values and they are named in a similar way to the calorie, that is Btu (IT), (th), etc. Also note that the **therm** is 100 000 Btu so its exact size depends on which Btu is being used.
The S I unit of energy or work is the **joule**. To change any of these other units of energy or work into their **equivalent values in joules** use the operation and conversion factor given. Those marked with # are **exact.** Other values are given to an appropriate degree of accuracy.

Force

The S I unit of force is the **newton**. To change any of these other units of force into their **equivalent values in newtons** use the operation and conversion factor given. Those marked with # are **exact.** Other values are given to an appropriate degree of accuracy.

Power

Since power is a measure of the rate at which work is done, the underlying units are those of work or energy, and that section should be looked at for explanations concerning the **calorie** and **Btu**. In this section the (IT) values have been used.
In this section it is the **horsepower** which provides confusion. Just like the calorie, it can take 5 different values, and these are identified as necessary by the addition of (boiler), (electric), (metric), (UK) and (water). Unlike the calorie *(whose 5 values are reasonably close to each other)*, the horsepower has 4 which are close and 1 (boiler) which is considerably different - it is about 13 times bigger than the others - but it seems to be very little used.
The S I unit of power is the **watt**. To change any of these other units of energy or work into their **equivalent values in watts** use the operation and conversion factor given. Those marked with # are **exact.** Other values are given to an appropriate degree of accuracy.

Pressure or Stress

The S I unit of pressure is the **pascal**. The units of pressure are defined in the same way as those for stress - force/unit area. To change any of these other units of pressure (or stress) into their **equivalent values in pascals** use the operation and conversion factor given. Those marked with # are **exact.** Other values are given to an appropriate degree of accuracy.
Measures based on water assume a density of 1 kg/litre - a value which is rarely matched in the real world, though the error is small.

Speed

The S I compatible unit of speed is **metres/second**. To change any of these other units of speed into their **equivalent values in metres/second** use the operation and conversion factor given. Those marked with # are **exact.** Other values are given to an appropriate degree of accuracy.