EFB 462/662 Animal Physiology: Environmental & Ecological
Units and dimensions

Measurements are only sensible when accompanied by a unit: a standard which relates a magnitude to a property. One has to be a bit fussy about units: one foot describes a much different length than one meter, or one kilometer. Consequently, scientists have set up standard systems of units to ensure consistency and intelligibility of measurements. Unfortunately, the agreed upon systems differ from discipline to discipline. Physiology is especially problematic, with odd "traditional" units that are not always consistent or easily related to other standard unit systems.

The Systeme-Internationale (SI) is now the standard system for units, used by all the sciences. Unfortunately, physiology has not quite caught up, and you will see in your textbook many odd units. Schmidt-Nielsen often tries to use convert measurements to SI units, but is not consistent. Making sense of these units is made easier by understanding the relationships between units, dimensions, and how to convert between different unit systems.

Unit systems are based upon *dimensions*, which describe fundamental properties of matter and energy. These are length [L], mass [M], time [T] and temperature [Θ]. Each dimension is described with a standard unit, which is the meter, kilogram, second and Kelvin, respectively. This is why SI units are described as a m-kg-s system, as opposed to the older cm-g-s system found in older chemistry and physics textbooks. Many compound units can be built from combinations of these fundamental units and dimensions. Speed, for example, has dimensions of $[L]\ [T]^{-1}$, which in SI units is expressed as $m\ s^{-1}$. Other more complicated units can also be derived from their dimensions. Force, for example is accelerated mass. The dimensions of force are therefore $[M]\ [L]\ [T]^{-2}$ and will have units of $kg\ m\ s^{-2}$. Some standard units are given simpler names: the SI unit of force is the Newton, for example. Other units are easily derivable from these. Work, for example, is force acting over a distance, which will have dimensions of $\{[M]\ [L]\ [T]^{-2}$ (force) * [L] (distance)} or $\{[M]\ [L]^2\ [T]^{-2}\}$. The units of work are $kg\ m^2\ s^{-2}$.

Note that dimensions and units can both be treated as quantities that can be multiplied or divided. Units and dimensions can never be added or subtracted, however. This property makes it easy to convert from one unit system to another. Suppose, for example, one wishes to convert a length in inches to meters. We know there are 25.4 millimeters to the inch. A conversion factor is easily derived by setting up an equation consisting of units:

$$\frac{m}{in} = \frac{25.4mm}{in} \times \frac{1m}{1000mm} = 0.0254$$

A measurement in inches can then be converted to meters simply by multiplying the inches by 0.0254.

One can also derive more complicated conversion factors from simpler conversions. Any pressure, for example, is an applied force per area. The English unit for pressure is pounds per square inch, while the SI unit is the pascal, or newton per square meter. The conversion factor for pressure can be derived from the two simpler conversions for force and length. There are 0.22481 lbs per newton, and 39.37 inches per meter? The conversion for pressure is therefore:

$$\frac{Pa}{lbs / inch^2} = \frac{1N}{0.22481lb} \times \left[\frac{39.37in}{1m}\right]^2 = 6984$$

Thus, every pound per square inch corresponds to 6,984 pascals.

Dimensions can sometimes also reveal interesting consistencies between seemingly different physical properties. For example, the dimensions of pressure are $[M]\ [L]^{-2}\ [T]^{-2}$. The dimensions of stress in a bent bone, meanwhile, are the same. Stress is, therefore, a kind of pressure. We will see other parallels as the course proceeds.

Note also that dimensions and units are written not as fractions but as products of exponential quantities. This seems fussy, but there is good reason for this. Speed, for example, is a ratio of a length traveled and a time required to travel it. The SI unit of speed is therefore meters per second. We could write this unit in abbreviated form as a ratio, m/s. SI dictates another form, though, as the multiple of one unit and the inverse of another. So, the compound unit m/s could also be written as m * (1/s). Since an inverse of something is equivalent to raising it to the power of -1, we can write the unit of velocity as m s^{-1}.

This might seem the ultimate in obfuscation: what's wrong with a simple ratio, like m/s? Sometimes units can be very complicated, making the supposedly "simple" solution itself a source of confusion. Weight, for example, is actually a force, the product of a mass and an acceleration, in this case, the acceleration imparted to a mass by the gravitational attraction of the Earth. The units for mass are straightforward, kg. An acceleration, on the other hand is a change of speed with time, or (meters per second) per second (no, I did not inadvertently repeat "per second"). Its units in simple ratio form are m/s/s. Or should it be (m/s)/s? Or should it be m/(s^2)? And when we multiply it by mass to get a weight (properly designated with units of newtons, N), the potential for confusion abounds. Is it kg*m/s/s? Is it kg*(m/s/s)? kg*((m/s)/s)?

Or we could simply write it as I did above, as kg m s^{-2}. By writing the units with the inverses explicit as negative integral powers, the unit can be specified unambiguously and without the need to decode placements and closures of brackets.

SI units are use many prefixes, like *m*m, or *k*J. These prefixes represent multipliers to the basic units. For example, the standard unit of length is the meter (m). Sometimes it is inconvenient to express a length in meters, though. The distance between, say, New York City and San Francisco, is 4,713,600 meters, but it is more common to express it at 4,714 km, where the k (kilo) represents a multiplier of 1000 or 10e3.

SI units also specify certain standard multipliers that differ from one another by powers of three, that is each multiplier is 1000 times the multiplier just below it. Thus, the prefix M (mega) represents the multiplier of one million, or one thousand times one thousand, k(kilo). These multipliers, again, allow us to write otherwise awkward numbers more easily. So, for example, we might express the distance between San Francisco and New York as 4,714 km, but we could more easily (and properly) write it as about 4.7 Mm (although common numbers like distances would never be expressed this way – it brings us too close to the Dilbertian world of pocket pen protectors and calculator holsters).

The prefixes and the multiples they represent are, from largest to smallest, as follows:

prefix	how it is said	Multiplier
T	tera-	10e12
G	giga-	10e9
M	mega-	10e6
k	kilo-	10e3
-	-	10e0 (1)
m-	milli-	10e-3
m	micro-	10e-6
n	nano-	10e-9
p	pico-	10e-12
f	femto-	10e-15
a	atto-	10e-18

For handy online conversion tools, see http://www.onlineconversion.com/

