Units and unit conversions important for ENES 100

Handout prepared by Prof. Sheryl Ehrman, Fall 2008

The objective of this handout is to review the topic of units and unit conversions. Measured or counted quantities have a numerical value (9) as well as a unit (9 of what?). As engineers, we may have to work with several different units to describe the same measured quantity. In the sciences, it is common to use SI (Systeme Internationale d'Unites) units, but in engineering practice, one might use the American engineering (Am. Eng) system. We may do design calculations in SI but we have to go to a hardware store and purchase supplies and parts in Am. Eng units. Thus, in addition to units, we need to know how to convert between them. Let's start with reviewing these two systems of units.

Systems of units:
A table of base units is given below in Table 1:

Table 1: SI base units.

Quantity	Unit
Length	meter, m
Mass	kilogram, kg
Time	second, s
Temperature	kelvin, K
Electric current	ampere, A
Light intensity	candela, cd
Amount of substance	mole, mol

Base units in the American engineering system are the foot (ft) for length, the pound-mass (lb_m) for weight, and seconds for time. Multiple units are defined as multiples or fractions of base units. For example a meter is a base unit, but a millimeter is a multiple unit. Commonly used prefixes for multiple units are given for SI in Table 2. Derived units (units for pressure, force, velocity etc..) can be obtained by multiplying and/or dividing base or multiple units. Some commonly used derived SI units are given, with their equivalent in base units in Table 3. Units are written following the numerical value, with a space in between the value and the unit. Five meters would be written 5 m, not 5m.

Table 2: Prefixes used for multiples or fractions of units.

Multiple	Fractional
kilo (T) 10^3	centi (c) 10^{-2}
mega (M) 10^6	milli (m) 10^{-3}
giga (G) 10^9	micro (μ) 10^{-6}
tera (T) 10^{12}	nano (n) 10^{-9}

Table 3: Commonly used derived units in SI.

Quantity	Unit	Symbol	Equivalent in terms of base units
Volume	liter	L	0.001 m^3
Force	newton	N	1 kg m/s^2
Pressure	pascal	Pa	1 N/m^2
Energy, work	joule	J	1 N m = 1 kg m^2/s^2
Power	watt	W	1 J/s = 1 kg m^2/s^3

Rules for using units in mathematical operations:
For addition and subtraction, quantities can only be added or subtracted if the units are the same. Examples: 3 m + 9 m = 12 m, but 3 m + 900 cm = ?
In order to perform the second operation, one would have to either convert 3 m to cm or convert 900 cm to m. Think of an analogy to algebra. You can add 3x + 9x = 12x, but you can't add 3x + 900y.

For multiplication and division, though, just like algebra, you can combine units.

$$\frac{100 \text{ kilometers}}{0.5 \text{ h}} = \frac{200 \text{ km}}{\text{h}}$$

Unit Conversions:
The equivalence between two expressions of the same quantity but different units, say 10 mm, 1 cm and 0.01 m, can be defined in terms of a ratio:

$$\frac{1 \text{ cm}}{0.01 \text{ M}}$$

or

$$\frac{10 \text{ mm}}{1 \text{ cm}}$$

These ratios are known as conversion factors and they can be used to convert units from one to another. They do not change the quantity since multiplying by a conversion factor is the same thing as multiplying a number by unity. To convert a quantity expressed in one unit to another unit, multiply the quantity by the conversion factor (new unit/old unit) so that the old units cancel out and you are left with the new units. Unit conversions do not change the number of significant figures (regardless of the number of significant figures in the quantities in the conversion factor!). If you have three significant figures before converting units, you have three significant figures afterwards.

For example, if we want to convert 185 grams to the kilograms, we can write:

$$185 \text{ g x} \left(\frac{1 \text{ kg}}{1000 \text{ g}}\right) = 0.185 \text{ kg}$$

or you can use the horizontal and vertical line method:

$$\frac{185 \text{ g}}{} \left| \frac{1 \text{ kg}}{1000 \text{ g}} \right. = 0.185 \text{ kg}$$

If you write out all the units, you can use this as a check to make sure you have not made a mistake. For example:

$$\frac{185 \text{ g}}{} \left| \frac{1000 \text{ g}}{1 \text{ kg}} \right. = 185000 \ \frac{\text{g}^2}{\text{kg}} = ?$$

One tricky conversion factor arises with units that are raised to a power. For example to convert 41 square inches to cm^2, we can write:

$$41 \text{ in}^2 \text{ x} \left(\frac{2.54 \text{ cm}}{1 \text{ in}}\right)^2 = 260 \text{ cm}^2$$

Many students forget to square the conversion factor, especially when they are in a hurry, say during a midterm examination. They multiply 41 in^2 by 2.54 not 2.54^2 and get an incorrect answer. Do not let this happen to you!

Weight, mass and force:
The difference between weight and mass is important and this distinction can be confusing when we are working in both SI and Am. Eng. units. Mass is a base unit, and it is a measure of the amount of matter in an object. Weight is a measure of the force exerted on the object by gravity. So an object's weight might vary depending on the gravitational force (say on the moon versus on the earth), but the mass would remain the same. Force is defined as the product of mass times acceleration according to Newton's second law of motion. Force in terms of base units is defined is kg m/s^2 in SI and lb_m ft/s^2 in Am. Eng. So that we don't have to carry all of these units around in calculations, derived units have been defined in each system, Newtons in SI and pound-force in Am. Eng.

1 Newton ≡ 1 N ≡ 1 kg m/s^2
1 pound-force ≡1 lb_f ≡ 32.174 lb_m ft/s^2

In the Am. Eng. system, the pound-force is defined as the product of a unit mass and the acceleration of gravity at sea level and 45 degree latitude, 32.174 ft/s^2.

The conversion factor required to convert from derived to base force units is called g_c and is defined as

for SI $$g_c = \frac{1 \text{ kg m/s}^2}{1 \text{ N}}$$

for Am. Eng. $$g_c = \frac{32.174 \text{ lb}_m\text{ft /s}^2}{1 \text{ lb}_f}$$

Pressure, gauge versus absolute:
One important unit for this course is pressure. Pressure is defined as force per unit area. In the American engineering system, pressure can be described using units of pounds-force per square inch (psi) and in SI, the units are N/m^2 or Pascals (Pa). It is important to distinguish between gauge and absolute pressure. Absolute pressure is the pressure relative to vacuum (zero pressure). However, in common practice it may be more convenient to use gauge pressure. Typically, when you measure the tire pressure of your bike or car tire, you are measuring gauge pressure, also known as pounds-force per square inch gauge (sometimes the symbol psig is used). This is the pressure relative to atmospheric pressure and atmospheric pressure is the force exerted on objects per unit area by the air around us. In other words, if your tire gauge reads zero, there is no air pressure in your tire relative to atmospheric pressure (no air will hiss out) and you need to think about fixing your tire. Gauge pressure P_{gauge} and absolute pressure $P_{absolute}$ are related through atmospheric pressure $P_{atmosphere}$ by:

$$P_{gauge} = P_{absolute} - P_{atmosphere} \quad [1]$$

Atmospheric pressure is not a true constant. It will depend upon elevation and weather conditions. However, standard atmospheric pressure (1 atm) has been defined as being the typical pressure at sea level. 1 atm = 14.696 psi = 1.01325×10^5 N/m^2 (Pa). Also note that it may not always be clear whether gauge or absolute pressure is being used. If you are not sure, ask!

Measurement of pressure with manometers is discussed in your textbook in chapter 3. It is common in engineering practice to report pressure in units equivalent to the height of liquids (inches of water, millimeters of mercury for example). These units arose because of the use of manometers. If someone states that the gauge pressure in the hovercraft plenum is equal to 0.2 inches of water, this is what he or she really means: “The pressure inside the hovercraft plenum is enough to support a column of water 0.2 inches high using a manometer open to the atmosphere”. In some unit conversion tables you may see units conversions reported at a specific temperature. For example, 1 atm = 33.9 ft H_2O at 4 °C. This is because the density of liquids varies slightly with temperature, so the temperature of the fluid is given with the unit conversion. In practice, since this variation is slight and since we will be working at temperatures at or around room temperature you do not need to adjust for density variations when you convert between units based on liquid height.

On converting units, you can directly convert between gauge pressures of different units and you can convert between absolute pressures of different units.

Example:
Convert 1.5 inches of water at 4 °C (gauge) to Pa (gauge)

$$1.5\text{ in x}\left(\frac{1\text{ft}}{12\text{ in}}\right)x\left(\frac{1.01325\text{ x}10^5\text{ Pa}}{33.9\text{ ft H}_2\text{O}}\right)=370\text{ Pa (gauge)}$$

Convert 775 mm Hg at 0 °C (absolute) to Pa (absolute)

$$775\text{ mm Hg x}\left(\frac{1.01325\text{ x}10^5\text{ Pa}}{760\text{ mm Hg at 0 }^\circ\text{C}}\right)=103000\text{ Pa (absolute)}$$

However, if you want to convert from gauge pressure to absolute pressure you will need to add atmospheric pressure to gauge pressure (see equation 1).

Example: convert 15.0 inches of water at 4 °C (gauge) to Pa (absolute)
Step 1 convert to a common unit (I choose Pa)
Step 2 convert from gauge to absolute

Details:
Step 1

$$15.0\text{ in x}\left(\frac{1\text{ft}}{12\text{ in}}\right)x\left(\frac{1.01325\text{ x}10^5\text{ Pa}}{33.9\text{ ft H}_2\text{O}}\right)=3700\text{ Pa (gauge)}$$

Step 2
Rearranging equation 1,

$P_{gauge} + P_{atmosphere} = P_{absolute}$

so:

3700 Pa (gauge) + 1.01325 x105 Pa = 1.05×10^5 Pa

Further reading:
http://physics.nist.gov/cuu/Units/units.html