THE UNITY OF UNITS

A Look at the Basics of the SI Unit System of Measures
For AOCP Theory Students

1. Introduction

Horsepower, acre, footpound, BTU, there is such a bewildering number of units in the world to measure speed, distance, pressure, indeed all kind of things electrical and mechanical. What adds to the confusion is that the relationship between many of those units is often far from obvious. Fortunately Australia has officially adopted the SI system of measures. This is a logical, coherent and user-friendly system once you get to see how the basics hang together.

2. The SI System of measures

The SI system of measures starts by defining a minimal number of basic measures or units. Other units are derived from these base units in the simplest possible way. The end result is a completely coherent system of measures which covers all mechanical and electrical entities. The measure of power, for instance, is always the same (viz. the watt), whether we are dealing with mechanical or electrical power.

The SI system, which originated in Europe (see para. 8), has gradually been adopted – or its adoption is planned – in most countries of the world. The one major exception at the time of writing is the United States of America.

In the following we shall look at the four basic units on which the system is built. We will also look at those few derived units you should know in order to cope with the first few readings of the AOCP course. Additional derived units will be gradually introduced throughout the course. These should be relatively easy for you to fit in once you've the hang of the basics of the SI system.

3. The Basic Mechanical Units

There are only 3 basic mechanical units. All other mechanical units are derived from these three.

3.1 The Unit of Mass

The unit of mass is the **kilogram** (kg). It is defined as the quantity of matter that has the same mass as the standard kilogram which is kept in Sėvres by the International Committee of Measures and Weights [1)] .
(If this sounds arbitrary to you, that's exactly what it is).

3.2 The Unit of Time

The unit of time is the **second** (s). The standard second has become steadily more precise as more accurate hardware became available. The standard second is presently determined by a caesium clock [2)] .

3.3 The Unit of Length

The unit of length is the **metre** (m). The standard metre has become steadily more precise as more accurate measurements became available. It is currently defined in terms of light travelling in vacuum [3)].

4. Some Derived Mechanical Units

There are a great number of derived mechanical units, we only need to deal with a few of them here.

4.1 The Unit of Speed

Speed (or velocity) is the distance (length) which an object travels per unit of time. As the unit of length is the metre and the unit of time is the second, the unit of speed logically becomes **metres per second** (m/s)

4.2 The Unit of Acceleration

We just saw that speed is measured in metres per second (m/s). If an object goes faster and faster its speed (in m/s) will become greater and greater every second. The unit of acceleration thus logically is “metres per second per second” or **metres per second squared** (m/s^2).

4.3 The Unit of Force

Newton’s law states that:

A body remains at rest or in uniform motion (i.e. at constant speed) *unless it is subjected to a force.*

This force, according to Newton’s law, is directly proportional to the mass of the body and its acceleration.

In other words: force equals mass times acceleration or F = m x a

In honour of Newton and his laws the unit of force has been named the **newton** (N) and it is defined as the force which gives a mass of 1kg an acceleration of 1metre per square second.

In other words the newton equates to **1kgm/s^2**.

4.4 The Unit of Energy

Moving a force along a certain amount of distance takes energy: work is being done. In honour of another physicist the unit of energy has been named the **joule** (J) It is defined as the amount of energy necessary to move a force of 1 newton by 1 metre.

In other words the joule equates to a **Nm**.

4.5 The Unit of Power

The more power you’ve got the more work you can do in a given amount of time. In honour of yet another great man the unit of power has been named the **watt** (W). It is defined as the amount of power that enables the expenditure of 1 J of energy every second.

In other words the watt equates to a **Nm/s**.

5 Basic Electrical Units

There is only the one. All other electrical units are derived from this basic electrical unit combined with one or more mechanical units.

Note: The School readings define the *coulomb* - the unit of electical charge - as the basic electrical unit. This is certainly one way to go about it and you may wish to remember the definition given in the readings. However, the official SI definitions don't go this way. These days the basic electrical unit defined under the SI system is the unit of current: the *ampere*. Don't worry too much about this detail: the system in its totality works out the same way whichever way you take the definitions.

5.1 The Unit of Current

The unit of current has been named the **ampere** (A) (after a French physicist). The ampere is defined as the current which, if maintained in two straight parallel conductors of infinite length, of negligible cros-section, and placed in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.

6. Some Derived Electrical Units

6.1 The Unit of Electrical Charge

The unit of electrical charge has been named the **coulomb** (C) after yet another French physicist. In your readings you have seen the coulomb defined as the basic electrical unit. However, under the SI system the coulomb is a derived electrical unit. The coulomb is simply defined as the amount of electrical charge that is moved past a certain point each second by a current of one ampere.

In other words, the coulomb equates to 1**As**

6.2 The Unit of Electromotive Force

The unit of electromotive force – or voltage - has been named the **volt** (V) (after an Italian this time). For its definition we have to go back to our earlier definition of power. As it needs energy – and hence power – to move a mechanical force along a distance, so it requires energy to move electromotive force by current. We saw earlier on that the unit of power – the watt – was defined mechanically. But the SI system has been cleverly designed because lo and behold, the same watt

also applies to electrical units. The volt is defined such that one unit of electromotive force (a volt), combined with one unit of electric current (an amp), also produces one watt of power.
In other words, the volt equates to a **W/A**.

6.1 The Unit of Resistance

The unit of resistance is the **ohm** (Ω) (after a German physicist this time). Resistance is that property of an electric circuit which opposes the flow of current: the higher the resistance, the lower the current at a given voltage.
The ohm is defined as the resistance which requires one volt of electromotive force to result in one ampere of current.
Ohm's law is often written as R = E / I
In other words, the ohm equates to a **V/A**.

Further electrical units will be covered in the course readings.

7. Does the SI System Represent Reality?

No, not really. The SI system is based on a Newtonian clockwork universe in which planes are flat, the shortest distance between two points is a straight line, constants are indeed constant, and simple formulas like Newton's and Ohm's law apply. Planck, Einstein, Heisenberg and others have been showing us since that the universe behaves differently at the extremes of speed, size or temperature.
Nonetheless the SI system represents a great toolkit for use in man's everyday measurements on and around earth, which is was it was meant to be.
By the way, you can find excellent further information on the SI system on the internet at:
http://physics.nist.gov/cuu/Units/current.html

8. A Bit of History

The early beginnings of the SI system (or Systeme Internationale de Poids et mesures, to give it its full French name) go back to Napoleon's time. Napoleon not only wanted to conquer Europe, he also wanted to hold and administer it. To achieve the latter he considered it essential to have a common decimal currency and a comprehensive common system of measures.
The development of a common system has been a lengthy and stormy business with academics and politicians from opposing camps fighting like rabbits in favour of their particular system. As late as the 1940s it could happen that students at the same university were faced with any of three quite different systems of measures, depending on whether they were doing physics, mechanical- or electrical engineering. Some electrical units from the "small dynamic system" (e.g. the gauss as a unit of magnetic saturation) persisted for a long time. It is only in the latter half of the 20th century that the SI system appeared to have won the day.

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1) Note the difference between the kilogram as a unit of *mass* as opposed to a unit of *weight*. Weight is the force with which the earth pulls on a body. Go into space and there's no weight. Mass is a property which matter always has, no matter where it is. You can look upon mass as that property of a body of matter which gives it inertia against a change in velocity or direction of movement.

2) If you really want to know: the second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the Cesium 133 atom. You don't really want to know this, do you?

3) To be precise, the metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second. Another bit of information you may want to forget quickly.