Chapter 16

Units

History of Units

- A common denomination of units is essential for the development of trade and economics around the world
- Standards related to units and measurement are governed by treaty (agreements between nations)
- Little changes in such treaties can result in large commercial advantages to parties to the treaty

Standards and Basic Units

- Most common system of units worldwide is “Le Système International d’Unités” (SI).
- SI units defined by the Metre Convention, signed in Paris on May 20, 1875 and amended in 1921.
- Convention set up The International Bureau of Weights and Measures (Bureau International des Poids et Mesures -- BIPM) which resides near Paris.
- The current seven SI base units were determined at the 14th General Conference on Weights and Measures in 1971.
- Improvements in the definitions of the base units continue to be made as science dictates
- Majority of nations in the world today operate on the metric system because of its simplicity (multiples of 10)

United States Standards

- The National Bureau of Standards was created by Congress in 1901 to maintain traceability to the BIPM SI units through standards and methods.
- National Bureau of Standards adopted the English (now called US Customary) system of measurement at that time
- NBS was renamed the National Institute of Standards and Technology -- NIST -- in 1988.
- United States moved towards using the SI system of units circa 1971.
- Metric Conversion Act – 1975
- Executive Order 12770 - 1991

The SI System of Units

- Built on a foundation of seven base units
- Base units are those for which a standard exists and can be reproduced in a suitably equipped laboratory.
- All other SI units are derived from these seven units
- Types of standards include <u>fixed</u> or <u>reproducible</u>.
- A fixed standard (mass) exists in one place. <u>Secondary</u> standards are made in comparison to this standard.

SI Base Units

Physical Variable/Unit	Standard
1. mass/ kilogram (kg)	platinum-iridium cylinder kept at International Bureau of Weights and Measures, Sevres, France
2. time/ second (sec)	the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium-133 atom.
3. length/ meter (m)	the length of the path traveled by light in a vacuum during a time of 1/299,792,458 of a second (note this requires the second to be defined). NOTE: the book is wrong here.
4. temperature/ kelvin (K)	Many points on the temperature scale are defined by triple points of pure substances. Other points are defined by melting or freezing points at a fixed pressure. Since pressure is a mass x cubic length / square time, the above three units must be defined to determine temperature.

SI Base Units

Physical Variable/Unit	Standard
5. electric current/ ampere (A)	the constant current which, if maintained in two straight parallel conductors of infinite length and of negligible circular sections, and placed one meter apart in a vacuum would prduce a force equal to $2x10^{-7}$ newton per meter of length. The derived unit of force is used in this definition.
6. Substance amt/ mole (mol)	the amount of substance of a system which contains as many elementary entities as there are in 0.012 kg of carbon-12.
7. light intensity/ candela (cd)	the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and of which the radiant intensity in that direction is 1/683 watt per steradian. (NOTE: the book is wrong here.)

Calibration

- Calibration is the means by which a transducer is made to comply with known standard engineering units.
- Two types of calibration:
  1. comparison with a standard (usually an experiment) or
  2. comparison with the output from a transducer which has been calibrated to known accuracy.
- Traceability refers to the process of providing an audit trail between a laboratory measurement and the SI Units maintained at BIPM.
- Calibration refers to the procedure by which traceability is performed.

Type 1 Calibration Examples

- A force gage can be calibrated by imposing known, calibrated weights (a secondary standard) with graded values and recording the gages output. Knowing the acceleration due to gravity at the point where the measurement is taken, allows the values of the weight to be converted into known forces.
- Light sensors are calibrated by heating a black body up to a measured temperature. The intensity of light radiated is proportional to temperature and is wavelength independent.
- Sound sensors are calibrated by generating a sound wave from a calibrated source in an anechoic chamber.

Derived Units

- Derived units are those which are deduced from the base units and from either physical laws or scientific definitions.
- For example, velocity is defined as the first derivative of position, which is measured by length and has units of length divided by time.
- Force is defined by Newton’s second law, $F=ma$. Hence, force has units of mass times length divided by time squared.
- There are hundreds of derived units. These usually are grouped according to the discipline that uses them.
- For example: mechanical units (force, energy, power) come from the mechanical physical laws.
- Electrical units (volt, coulomb, farad) come from Maxwell’s laws.

The units formerly known as "supplementary"

- Supplementary units were abolished in 1979. Units formerly known as supplementary are now known as "derived."
- radian (rad) is the measure of angle. It is the angle subtended by an arc of the same length as the radius. (Compare radian to degree.)
- steradian (sr) is the measure of solid angle.
- Both steradian and radian are dimensionless dimensions.

Derived Units

- Quantities whose units are expressed in terms of base units

Quantity	SI Unit	SI Symbol
Area	Square meter	m^2
Speed, velocity	Meter per second	m/s
Density	Kilogram per cubic meter	kg/m^3

Derived Units

- Quantities whose units have special names

Quantity	SI Name	SI Symbol	Other SI Units
Frequency	hertz	Hz	cycle/s
Force	newton	N	$kg*m/s^2$
Electrical Resistance	ohm	Ω	V/A

Derived Units

- Units used with the SI System

Name	Symbol	Value in SI Units
Minute	min	1 min = 60 s
Hour	h	1 h = 3600 s
Degree	°	1° = π/180 rad

Prefixes

- Used instead of writing extremely large or very small numbers
- All items in a given context should use the same prefix, for example in a table
- Notation in powers of 10 is often used in place of a prefix
- Multiples and sub-multiples are expressed using a decimal system
- The first letter of a symbol is capitalized if the name of the symbol is derived from a person’s name, otherwise it is lowercase
- When the symbol’s full name is used, the first letter is lower case

Prefixes

Multiplication Factor	Prefix	Symbol	Term (USA)
$1000000 = 10^{6}$	mega	M	One million
$1000 = 10^{3}$	kilo	k	One thousand
$.001 = 10^{-3}$	milli	m	One thousandth
$.000001 = 10^{-6}$	micro	µ	One millionth

Numerals

- A space is always left between the numeral and the unit name or symbol, except when we write a degree symbol
  - 3 m = 3 meters; 8 ms = 8 milliseconds
- SI units a space is used to separate groups of three in a long number
  - 3,000,000 = 3 000 000
  - .000005 = .000 005
- This is optional when there are four digits in a number (3456 = 3 456; .3867 = .386 7)

Numerals

- A zero is used for numbers between -1 and 1 to prevent a faint decimal point from being missed
- Rounding
- Significant Digits

Conversions

To convert from:	To:	Multiply by:
Degrees	Radians	0.017 453
Inches	Centimeters	2.54
Newtons	Pounds	0.224 81

Dimensional Analysis/Checking

- In engineering, many equations are used and much algebra is applied to convert to the final result
- In any equation, the units on each side of the equality must be the same
- Dimensional analysis refers to the technique of reducing the units to base units
- Formal statement is called the Buckingham-π Theorem

Reduce units to Basics

- Convert base units to their generic type (mass (M), length (L), time (T), temperature (Θ), current (I), candela (C), substance (S)
- Convert derived units to the appropriate combination of base units (e.g., Force would have generic units of ML/T/T)
- Group and cancel all generic units until the simplest expression of units remains. Compare on both sides of the equation.
- More generally, specific engineering constants are defined (e.g., the Reynold’s number) to remove dimension from equations.