Session 03 Lecture Notes

Announcements

1. Reading:
   (a) Read and sign the Electrical and Computer Engineering Laboratories Safety and Access agreement
   (b) Making Better Graphs
   (c) Using SI Units
2. To Hand In:
   (a) Homework 2 is due on Friday, 2020-01-24
3. Supplemental materials:
   (a) General Chemistry Online: Are there simpler rules for counting significant digits?

Quantities and Units

A *quantity* or **dimension** is a measurable characteristic of something.

- *Area* is a characteristic of a *surface*
- *Mass* is a characteristic of a *body*
- *Resistance* is a characteristic of a *resistor*
- *Resistivity* is a characteristic of a *material*

A *unit* is a specific standard amount of a dimension.

- A *meter squared* is an amount of *area*
- A *kilogram* is an amount of *mass*
- An *ohm* is an amount of *resistance*
- An *ohm meter* is an amount of *resistivity*

The SI System

The *SI* system is the internationally accepted definition of metric measurement. The acronym comes from the French name *Le Système International d'Unités*.

There are seven *base units* in the SI system.

Base units are defined in terms of measurable, reproducible physical phenomena (except the kilogram).

Base quantity	Unit Name	Unit Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

All other quantities are defined in terms of these base units.

Note that the *names* of the units are treated as normal nouns in English, even when they are taken from the names of persons (e.g. ampere, kelvin). The names are not capitalized unless they are used in a situation where any other word would be capitalized, such as the first word in a sentence.

The *symbols* for the units are always capitalized if they are derived from the name of a person (e.g. A, K). The capital L may be used for the liter to avoid confusion between the lower-case L and the numeral 1. All of the unit symbols must be written in an upright font and not italicized. This is particularly important when the same letter is used as the symbol for a unit (V for volts) and as the symbol for a quantity (V for some voltage). For example, it would be correct to say $V = 1\,\mathrm{V}$.

When using the kelvin to measure temperature we don't use the word "degree", so you say "a temperature increase of ten kelvins" instead of "a temperature increase of ten *degrees* kelvins".

Derived Units

Other units that are defined in terms of the base units are called *derived units*.

Quantity	Name	Symbol	Definition	
acceleration				$(\mathrm{m} \cdot \mathrm{s}^{-2})$
force	newton	N		$(\mathrm{m} \cdot \mathrm{kg} \cdot \mathrm{s}^{-2})$
energy, work	joule	J	$\mathrm{N} \cdot \mathrm{m}$	$(\mathrm{m}^2 \cdot \mathrm{kg} \cdot \mathrm{s}^{-2})$
power	watt	W	J/s	$(\mathrm{m}^2 \cdot \mathrm{kg} \cdot \mathrm{s}^{-3})$
electric potential difference	volt	V	W/A	$(\mathrm{m}^2 \cdot \mathrm{kg} \cdot \mathrm{s}^{-3} \cdot \mathrm{A}^{-1})$
electric resistance	ohm	Ω	V/A	$(\mathrm{m}^2 \cdot \mathrm{kg} \cdot \mathrm{s}^{-3} \cdot \mathrm{A}^{-2})$

Non-SI Units

1 survey foot $\equiv \frac{1200}{3937}\,\mathrm{m}$

1 international foot $\equiv 0.3048\,\mathrm{m}$

1 inch $\equiv 0.0254\,\mathrm{m}$

1 slug $= 14.593\,90\,\mathrm{kg}$

1 U.S. gallon $= 0.003\,785\,412\,\mathrm{m}^3$

1 pound (avoirdupois) $= 453.592\,37\,\mathrm{g}$

Engineering Notation

Engineering notation uses only prefixes that represent exponents that are multiples of 3

Multiplier	Prefix	Symbol
$1\,000\,000\,000 = 10^9$	giga	G
$1\,000\,000 = 10^6$	mega	M
$1000 = 10^3$	kilo	k
$0.001 = 10^{-3}$	milli	m
$0.000\,001 = 10^{-6}$	micro	μ
$0.000\,000\,001 = 10^{-9}$	nano	n

The *number* should be at least 0.1 and less than 1000, and the prefix should be selected accordingly.

There are some situations where you should intentionally violate this rule for the sake of clarity. Engineering drawings often use the same unit for all dimensions (e.g. millimeters) even if some numbers are very small or very large. When values are given in a table you may use the same unit for all values in a given column, rather than attaching a unique unit to each value. This practice also makes it easier to grasp the relative magnitude of the values in a column.

Binary Prefixes

> The SI prefixes **shall not** be used to denote multiplication by powers of two.
>
> – IEEE Std 1541 (emphasis added)

$$1\,\text{kbit} = 1000\,\text{bit} \neq 2^{10}\,\text{bit}$$

$$\begin{aligned}
2^{10}\,\text{bit} = 1\,\text{Kibit} &= \text{ one kibibit}\\
2^{20}\,\text{B} = 1\,\text{MiB} &= \text{ one mebibyte}\\
2^{30}\,\text{bit/s} = 1\,\text{Gibit/s} &= \text{ one gibibit per second}
\end{aligned}$$

Rounding

In general, I will expect that your answers to homework and exam problems will be rounded to 3 significant digits. For your answer to have 3 significant digits you will probably need to maintain at least 5 significant digits in your intermediate calculations.

NIST rounding algorithm (section B.7.1):

1. If the first (left-most) digit to be discarded is a *4* or less, simply discard the digits.
2. If the first digit to be discarded is a *6* or more, add 1 to the kept digits.
3. If the first digit to be discarded is a *5* and any other discarded digit is *nonzero*, add 1 to the kept digits.
4. If the first digit to be discarded is a *5* and all of the other discarded digits are *0*:

   (This rule also applies if you are discarding just one digit and that digit is a 5.)

   (a) If the digit to the left of the five is *odd*, add 1.

   (b) If the digit to the left of the five is *even*, simply discard the digits.

   This means that if the digits to be discarded consist of a 5 followed by some number of zeros then the digits that are kept will end up being even; and odd number is incremented but an even number is left as-is.

The reason for this complex rounding algorithm is to make sure that if you round a bunch of random values then the **average** rounding error will be zero.

Measurement Accuracy, Resolution, Precision

- **Accuracy** is an indication of how close a measured value is to the **true, actual value**.

  When we estimate the accuracy of a meter or a measurement we are really talking about its **uncertainty**.
- **Resolution** is the smallest **observable change** in a measured value.
- **Precision** is the **reproducibility** and **repeatability** of a measurement.
- **Tolerance** describes the **allowable deviation** of a measured value from its specified value.

Be critical thinkers! A high degree of resolution or precision **does not** imply a high level of accuracy! An old wristwatch that is off by five minutes is more accurate than your computer's clock if it is set to the wrong timezone.

Significant Digits

The notion of **significant digits** says that the way you **write** the value of a measurement implies its **uncertainty**.

The marked value of our 5% resistors has **two** significant digits.

When describing the **marked** or **nominal** value of a resistor you should not use more significant digits than are given in the resistor color bands or other marking. For the 5% resistors in our labs, you should write the nominal resistor value as $1.0\,\mathrm{k\Omega}$, but not as $1\,\mathrm{k\Omega}$ or as $1.00\,\mathrm{k\Omega}$.

When describing the **measured** value of a resistor you should use a number of significant digits that reflects the uncertainty of the ohmmeter.

The AD2 gives us 2 or 3 significant digits **if calibrated**.

For this course you can assume that measurements from the AD2 have 3 significant digits.

When doing arithmetic on measured values:

- For multiplication (or division) the number of significant digits in the result is equal to the **minimum** number of significant digits in the operands.

  Suppose you multiply $105.67\,\mathrm{V}$ times $0.3456\,\mathrm{A}$. The voltage has five significant digits and the current has four significant digits. Your calculator says the product is $36.519\,552$ but the product should have just four significant digits. So, the result should be rounded and written as $36.52\,\mathrm{W}$.

- For addition (or subtraction) determine the **place value** of the rightmost significant digit in each of the operands. The rightmost significant digit in the result will be in the place value equal to the **maximum** place value for any of the operands.

  Suppose you add $105.67\,\mathrm{V}$ and $0.3456\,\mathrm{V}$. The rightmost significant digit in the first operand is in the 0.01 place, for the second operand it is in the 0.0001 place. When added together the rightmost significant digit will be in the 0.01 place. So, your calculator gives the sum as 106.0156 but the result should be rounded and written as $106.02\,\mathrm{V}$.

Minding the significant digits is really a substitute for using statistical techniques to provide a proper estimate of error. A common problem with significant digits is how to represent significant **zeros** that are to the right of non-zero digits but to the left of the decimal point. How many significant digits are there when we right $100\,\Omega$?