PHYS 1310 / 1110

Chapter 1

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The Nature of Physics

- Physics is an **experimental** science in which physicists seek patterns that relate the phenomena of nature.
- Discoveries in physics begin with a **hypothesis**.
- The patterns are called **physical theories**.
- A very well established or widely used theory is called a **physical law** or **principle**.
- Usually expressed in mathematical terms.

LEC 1: Overview

- Scientific Notation
- Significant Figures
- Units
- Dimensional Analysis
- Uncertainty

Scientific Notation

A most convenient way of expressing very large or small numbers in decimal form, generally expressed as…

$$m \cdot 10^n$$

where m is a real number between 1 and 10, and n is an integer referred to as an "order of magnitude."

- Example: 2,718,000,000 … m = 2.718, n = 9

$$\mathbf{2.718 \cdot 10^9}$$

- Example: 0.0000003141 … m = 3.141, n = -7

$$\mathbf{3.141 \cdot 10^{-7}}$$

When to use Scientific Notation

- When talking about the speed of light…

  $c = 299{,}792{,}458$ m/s $= 3.00 \cdot 10^{8}$ m/s

- When talking about the Gravitational constant…

  $G = 0.00000000006674 = 6.674 \cdot 10^{-11}$ N m^2/kg^2

- or when talking about any other ridiculous quantity having a significant number of zeros… ☺

SI Prefixes

	QUANTITY	NUMBER	S. N.	PREFIX	SYMBOL
•	Ten	10	$= 10^{1}$	deka	da
•	Hundred	100	$= 10^{2}$	**h**ecto	h
•	Thousand	1000	$= 10^{3}$	**K**ilo	k
•	Million	1,000,000	$= 10^{6}$	**M**ega	M
•	Billion	1,000,000,000	$= 10^{9}$	**G**iga	G
•	Trillion	1,000,000,000,000	$= 10^{12}$	**T**era	T
•	Quadrillion	1,000,000,000,000,000	$= 10^{15}$	**P**eta	P
•	Quintillion	1,000,000,000,000,000,000	$= 10^{18}$	**E**xa	E
•	Sextillion	1,000,000,000,000,000,000,000	$= 10^{21}$	**Z**etta	Z
•	Septillion	1,000,000,000,000,000,000,000,000	$=10^{24}$	**Y**otta	Y

SI Prefixes cont…

QUANTITY	NUMBER	S. N.	PREFIX	SYMBOL
• Tenth	0.1	$= 10^{-1}$	deka	d
• Hundredth	0.01	$= 10^{-2}$	centi	c
• Thousandth	0.001	$= 10^{-3}$	milli	m
• Millionth	0.000001	$= 10^{-6}$	micro	μ
• Billionth	0.000000001	$= 10^{-9}$	nano	n
• Trillionth	0.000000000001	$= 10^{-12}$	pico	p
• Quadrillionth	0.000000000000001	$= 10^{-15}$	femto	f
• Quintillionth	0.000000000000000001	$= 10^{-18}$	atto	a
• Sextillionth	0.000000000000000000001	$= 10^{-21}$	zepto	z
• Septillionth	0.000000000000000000000001	$=10^{-24}$	yocto	y

Numerical Applications

- What is the memory capacity of the Human Brain?

According to Dr. Paul Reber, professor of psychology at Northwestern University…

2.5 petabytes = $2.5 \cdot 10^{15}$ bytes

(“or” 2.5 million billion bits of information!!)

Ref: Scientific American, May 1, 2010

UNITS

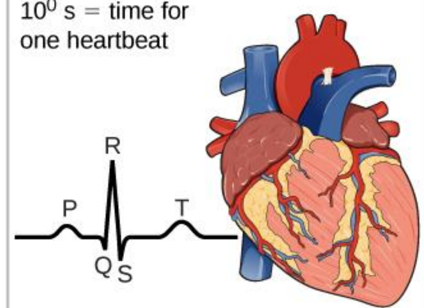
- The 7 fundamental units: (as defined by the International System of Units)

– **m (meter)**	**measure of length**	**“x”**
– **kg (kilogram)**	**measure of mass**	**“m”**
– **s (second)**	**measure of time**	**“t”**
– A (ampere)	measure of current	“I”
– K (kelvin)	measure of temperature	“T”
– mol (mol)	measure of amount	“mol”
– cd (candela)	measure of intensity	“Iv”

UNIT Combinations

- **Velocity ($v = x/t$) → (m/s)**
- **Acceleration ($a = x/t^2$) → (m/s^2)**
- **Momentum ($p = mv$) → ($kg \cdot m/s$)**
- **Force ($F = ma$) → ($kg \cdot m/s^2$) → N, “Newtons”**
- **Energy ($E = mv^2$) → ($kg \cdot m^2/s^2$) → J, “Joules”**
- **Power ($P = E/t$) → ($kg \cdot m^2/s^3$) → W, “Watts”**

Length, Mass, and Time…

Length in Meters (m)	Masses in Kilograms (kg)	Time in Seconds (s)
10^{-15} m = diameter of proton	10^{-30} kg = mass of electron	10^{-22} s = mean lifetime of very unstable nucleus
10^{-14} m = diameter of large nucleus	10^{-27} kg = mass of proton	10^{-17} s = time for single floating-point operation in a supercomputer
10^{-10} m = diameter of hydrogen atom	10^{-15} kg = mass of bacterium	10^{-15} s = time for one oscillation of visible light
10^{-7} m = diameter of typical virus	10^{-5} kg = mass of mosquito	10^{-13} s = time for one vibration of an atom in a solid
10^{-2} m = pinky fingernail width	10^{-2} kg = mass of hummingbird	10^{-3} s = duration of a nerve impulse
10^{0} m = height of 4 year old child 	10^{0} kg = mass of liter of water 	10^{0} s = time for one heartbeat 
10^{2} m = length of football field	10^{2} kg = mass of person	10^{5} s = one day
10^{7} m = diameter of Earth	10^{19} kg = mass of atmosphere	10^{7} s = one year
10^{13} m = diameter of solar system	10^{22} kg = mass of Moon	10^{9} s = human lifetime
10^{16} m = distance light travels in a year (one light-year)	10^{25} kg = mass of Earth	10^{11} s = recorded human history
10^{21} m = Milky Way diameter	10^{30} kg = mass of Sun	10^{17} s = age of Earth
10^{26} m = distance to edge of observable universe	10^{53} kg = upper limit on mass of known universe	10^{18} s = age of the universe

Unit Consistency and Conversions

- An equation must be **dimensionally consistent**. Terms to be added or equated must **always** have the same units. (Be sure you're adding "apples to apples.")
- Always carry units through calculations.
- Convert to standard units as necessary, by forming a ratio of the same physical quantity in two different units, and using it as a multiplier.
- For example, to find the number of seconds in 3 min, we write:

$$3\ \text{min} = (3\ \cancel{\text{min}})\left(\frac{60\ \text{s}}{1\ \cancel{\text{min}}}\right) = 180\ \text{s}$$

Dimensional Analysis

- Given: $F = \frac{GMm}{R^2}$

-what are the units for "G" (the Universal Gravitational constant)?

$$G = \frac{FR^2}{mM}$$

$$= \frac{(N)(m)^2}{(kg)(kg)} = \frac{(kg\cdot\frac{m}{s^2})(m)^2}{kg^2} = \frac{m^3}{kg\cdot s^2}$$

$$= m^3 kg^{-1} s^{-2}$$

Applications of Dimensional Analysis

- To check the correctness of an equation or any other physical relation based on the principle of homogeneity. There should be dimensions on two sides of the equation. The dimensional relation will be correct if the L.H.S and R.H.S of an equation have identical dimensions. If the dimensions on two sides are incorrect, then the relations will also be incorrect.

- Dimensional analysis is used to convert the value of a physical quantity from one system of units to another system of units.

- It is used to represent the nature of physical quantity.

- The expressions of dimensions can be manipulated as algebraic quantities.

- Dimensional analysis is used to derive formulas.

Selected Physical Constants

- **acceleration due to gravity:** **$g = 9.81\ m/s^2$**
- **Universal gravitation constant:** **$G = 6.674 \cdot 10^{-11}\ N\ m^2/kg^2$**
- Solar mass: $m_S = 1.989 \cdot 10^{30}$ kg
- speed of light: $c = 3 \cdot 10^8$ m/s
- Elementary charge $e = 1.602 \cdot 10^{-19}$ A s (C)
- Permittivity of free space: $\varepsilon_o = 8.854 \cdot 10^{-12}$ C/N m^2
- Permeability of free space: $\mu_o = 1.257 \cdot 10^{-6}$ T m/A
- Avagadro constant: $N_A = 6.022 \cdot 10^{23}$ /mol
- Boltzman constant: $k = 1.381 \cdot 10^{-23}$ J/K
- Gas constant: $R = N_A k = 8.314$ J/mol K
- Neutron mass: $m_n = 1.675 \cdot 10^{-27}$ kg
- Proton mass: $m_p = 1.672 \cdot 10^{-27}$ kg
- Electron mass: $m_e = 9.109 \cdot 10^{-31}$ kg
- Plank's constant $h = 6.626 \cdot 10^{-23}$ J s

Uncertainty and Significant Figures

- The uncertainty of a measured quantity is indicated by its number of **significant figures**.

- For multiplication and division, the answer can have no more significant figures than the **smallest** number of significant figures in the factors.

- For addition and subtraction, the number of significant figures is determined by the term having the fewest digits to the right of the decimal point.

- As this train mishap illustrates, even a small percent error can have spectacular results!

Significant Figures

- A significant figure is a digit in a number that adds to its precision.
- The additional advantage of scientific notation is that the number of significant figures is unambiguous.
- However, when taking the average of any particular data set, the number of significant figures is restricted to the least precise number of that data set. For example…

Significant Figures cont…

- How many significant figures would you use to represent the average given the following set the data?

4.1278
12.1
6.00001
47,000,000
0.00000009

Uncertainty

- …is the range of possible values within which the true value of the measurement lies.
- This is what we call our “error bar.”
- There are many ways to represent uncertainty, for which the most common ways include:
  - **(1) Experimental Error**
  - **(2) Standard Deviation**
  - **(3) Standard Error**

Experimental (percent %) Error

- When the theoretical value is known, the experimental error expresses how close to that value we are.
- Experimental Error can be defined as…

$$ER = \frac{|Theoretical - Experiement|}{Theoretical} \; X \; 100\%$$

Ex: Experimental Error

- Suppose our measurements for Earth's gravitation constant (9.81 m/s) are as follows:

g_x = 9.92, 9.88, 9.91, 9.95, 9.83

$$g_{ave} = \frac{\sum_i^n g_x}{n} = \frac{9.92 + 9.88 + 9.91 + 9.95 + 9.83}{5} = \frac{49.49}{5} = 9.90 \text{ m/s}$$

$$ER = \frac{|Theoretical - Experiement|}{Theoretical} X\, 100\%$$

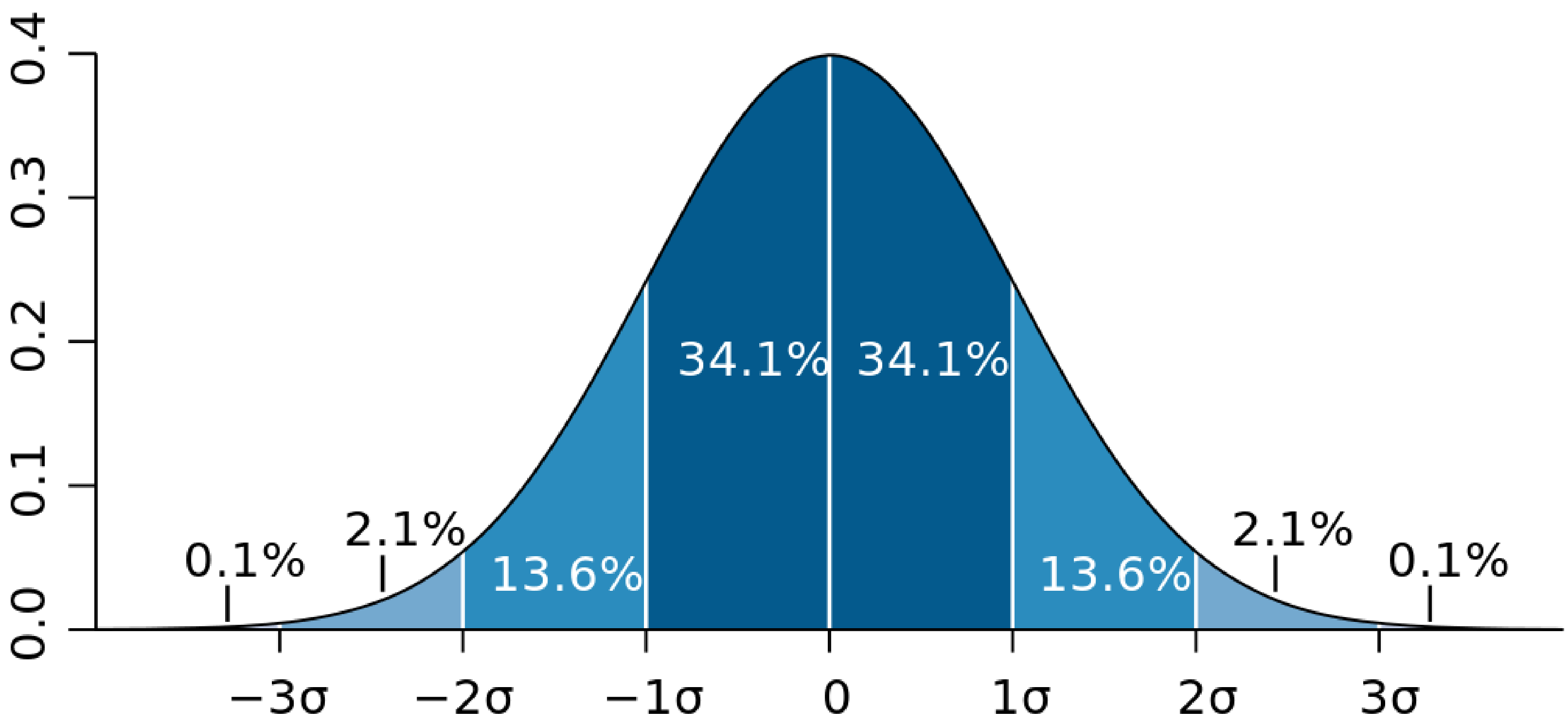
$$ER = \frac{|9.81 - 9.90|}{9.81} X\, 100\% = 0.009\, X\, 100\% = \pm 0.9\%$$

- Therefore:

$$g_{exp} = 9.90\, m/s \pm 0.9\%$$

Standard Deviation

- The measure of the amount of variation for a given set of values.



Standard Deviation cont…

- Sigma (standard deviation) is defined

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}}$$

- Where xi is each value of the population, μ is the population mean, and N is the size of the population.

- Use excel "STDEV" to calculate.