

# Physics 2311 (Sec 2) – Physics I

Dr. J. Pinkney

## Outline for Day 1

Attendance and a list of units

Discuss syllabus

Units & Measurements

Homework (Due Mon, 1/24)

Ch. 1 Read sections 2,3,4,6

Ch. 1 Probs: 25,26,30,31,46,50,  
51,53,66,77,79

(Note: odd soln's starting p. 914.)

# P231 Week 1: measurements

## Goals of Week 1:

- Learn about base and derived units
- Learn dimensions and dimensional analysis
- Understand the need for errors and significant figures
- Learn how to propagate errors in  $+$ ,  $-$ ,  $\times$ , and  $\div$
- Understand how  $\sigma$ , and  $\sigma_{\mu}$  are related to measurements and errors

# P231 Week 1: measurements

## Units

```
graph TD; Units --> BaseUnits[Base Units]; Units --> DerivedUnits[Derived Units];
```

### Base Units

### Derived Units

*Mechanical:*

<b>Quantity</b>	<b>MKS unit</b>	<b>cgs unit</b>	
mass	kg (kilogram)	g	miles/hour
length	m (meter)	cm	km/s
time	s (second)	s	mol/liter
			kg m/s <sup>2</sup>
			microsecond
			etc.
			etc.

*Other:*



# Making convenient units with prefixes

**TABLE 1.2** Multiples and Prefixes for Metric Units\*

<i>Multiple<sup>†</sup></i>	<i>Prefix (and Abbreviation)</i>	<i>Pronunciation</i>	<i>Multiple<sup>†</sup></i>	<i>Prefix (and Abbreviation)</i>	<i>Pronunciation</i>
10 <sup>24</sup>	yotta- (Y)	yot'ta ( <i>a</i> as in <i>about</i> )	10 <sup>-1</sup>	deci- (d)	des'i (as in <i>decimal</i> )
10 <sup>21</sup>	zetta- (Z)	zet'ta ( <i>a</i> as in <i>about</i> )	10 <sup>-2</sup>	centi- (c)	sen'ti (as in <i>sentimental</i> )
10 <sup>18</sup>	exa- (E)	ex'a ( <i>a</i> as in <i>about</i> )	10 <sup>-3</sup>	milli- (m)	mil'li (as in <i>military</i> )
10 <sup>15</sup>	peta- (P)	pet'a (as in <i>petal</i> )	10 <sup>-6</sup>	micro- ( $\mu$ )	mi'kro (as in <i>microphone</i> )
10 <sup>12</sup>	tera- (T)	ter'a (as in <i>terrace</i> )	10 <sup>-9</sup>	nano- (n)	nan'oh ( <i>an</i> as in <i>annual</i> )
10 <sup>9</sup>	giga- (G)	ji'ga ( <i>ji</i> as in <i>jiggle</i> , <i>a</i> as in <i>about</i> )	10 <sup>-12</sup>	pico- (p)	pe'ko ( <i>peek-oh</i> )
10 <sup>6</sup>	mega- (M)	meg'a (as in <i>megaphone</i> )	10 <sup>-15</sup>	femto- (f)	fem'toe ( <i>fem</i> as in <i>feminine</i> )
10 <sup>3</sup>	kilo- (k)	kil'o (as in <i>kilowatt</i> )	10 <sup>-18</sup>	atto- (a)	at'toe (as in <i>anatomy</i> )
10 <sup>2</sup>	hecto- (h)	hek'to ( <i>heck-toe</i> )	10 <sup>-21</sup>	zepto- (z)	zep'toe (as in <i>zeppelin</i> )
10	deka- (da)	dek'a ( <i>deck</i> plus <i>a</i> as in <i>about</i> )	10 <sup>-24</sup>	yocto- (y)	yock'toe (as in <i>sock</i> )

\*For example, 1 gram (g) multiplied by 1000 (10<sup>3</sup>) is 1 kilogram (kg); 1 gram multiplied by 1/1000 (10<sup>-3</sup>) is 1 milligram (mg).

<sup>†</sup>The most commonly used prefixes are printed in color. Note that the abbreviations for the multiples 10<sup>6</sup> and greater are capitalized, whereas the abbreviations for the smaller multiples are lowercased.

## Unit systems

<b>System</b>	<b>L</b>	<b>M</b>	<b>T</b>
mks (or SI)	m	kg	s
cgs	cm	g	s
US Customary	ft (foot)	slug	s

Note: “US Customary” system is sometimes called “fps” for “foot, pound, second”, but this reinforces a misconception about the pound! The pound is not a unit of mass!!!



# Physics 2311 (Sec 2) – Physics I

Dr. Pinkney

## Outline for Day 2

Unit Standards (cont.)

Dimensional analysis

Measurements

Significant figures

Errors

## Homework (Due next Wed)

Ch. 1 Read sections 2-4,6

Ch. 1 Probs: 25,26,30,31,46,50,  
51,53,66,77,79

Read unfinished parts of this PPT.

# Unit Standards

**Standard: how we define a unit.**

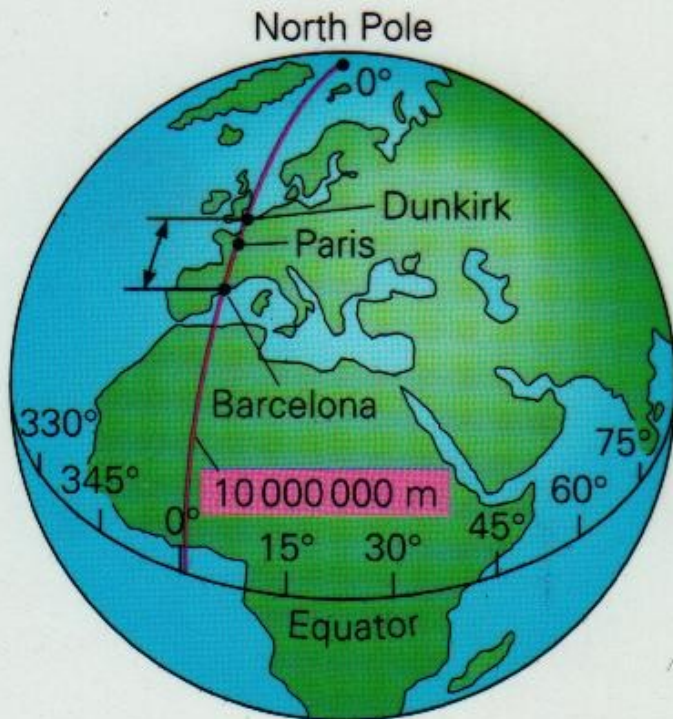
- **Used to be real-life objects**
- **Now units are based on physical constants ( $c$ ,  $h$ )**

**Why do we need standards?**

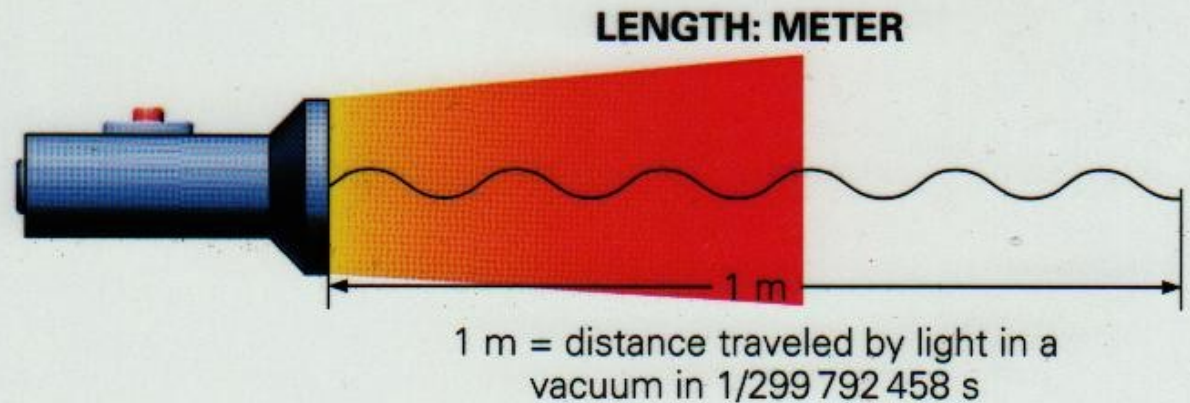
**Communication!**

- \* **between scientists discussing experimental results**
- \* **between international businessmen selling goods**  
**“by the gallon” or “by the pound”**
- \* **between Earth and alien life (some day?)**

# Unit Standards Length



(a)

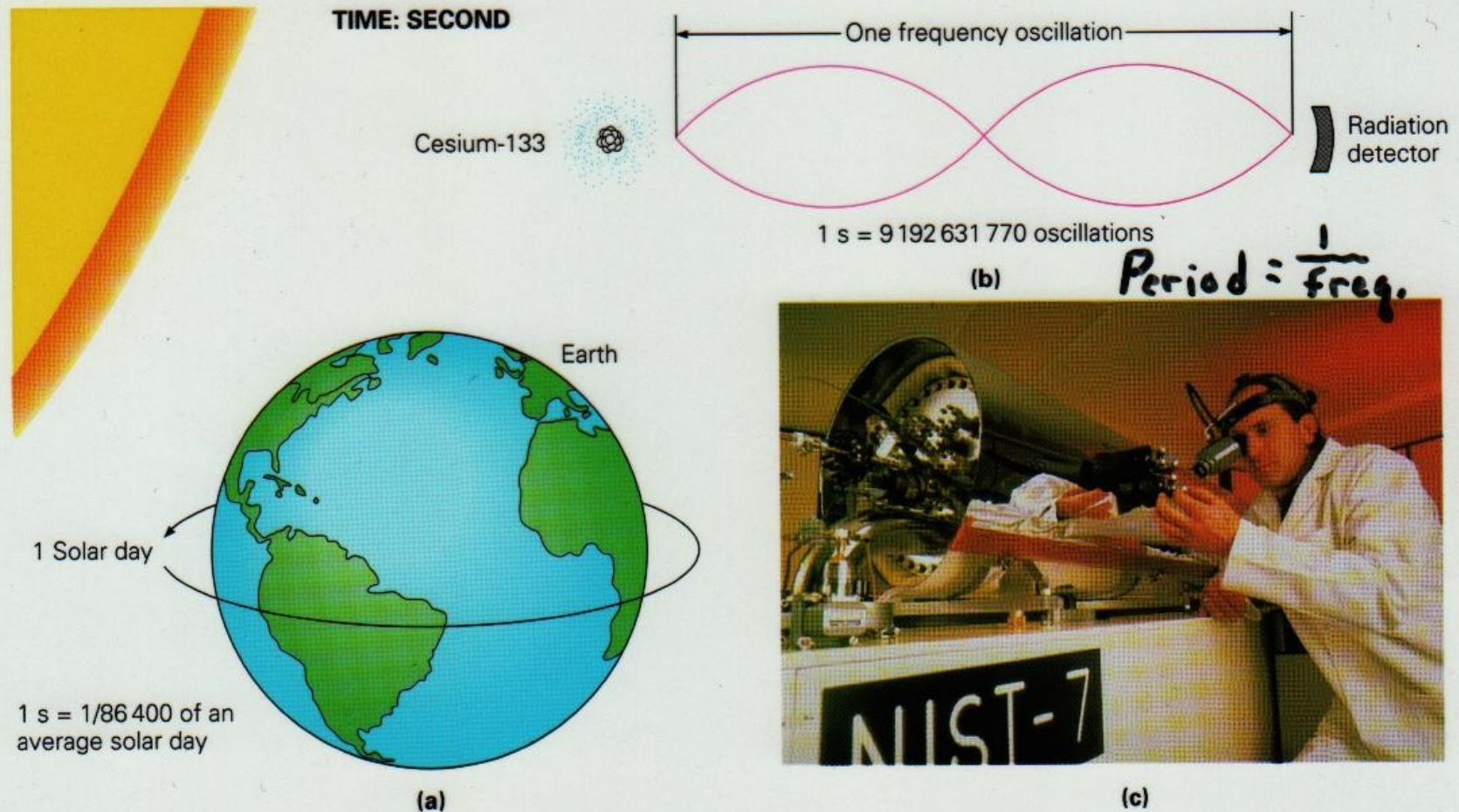


(b)

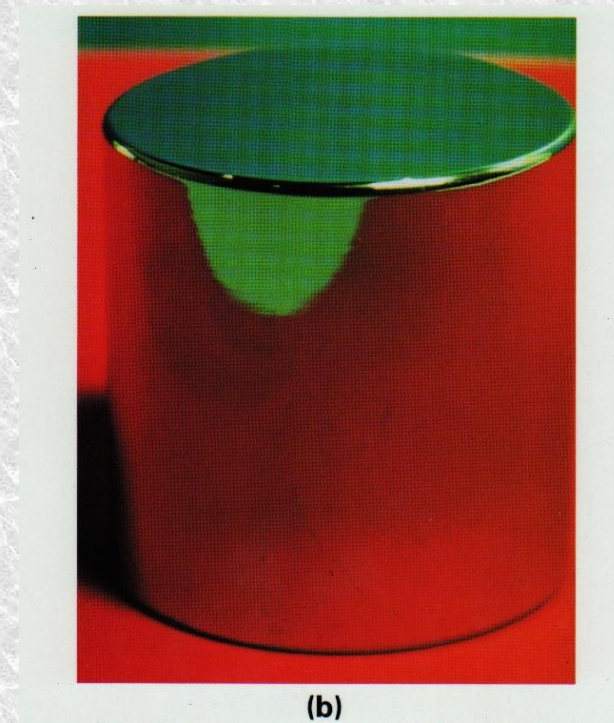
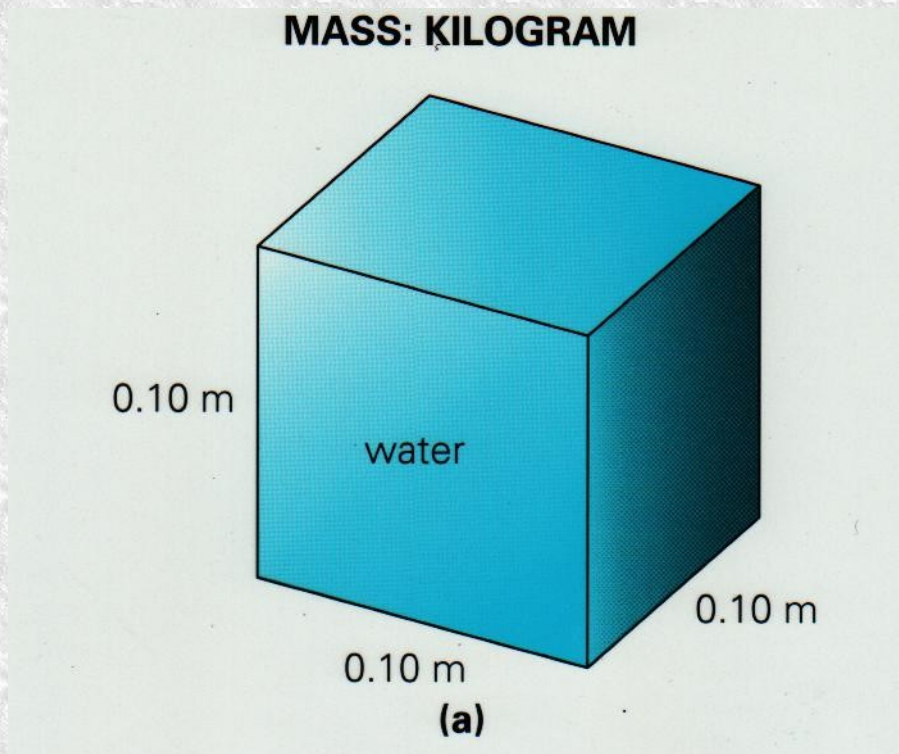
**The meter is now based on the speed of light in a vacuum.**



# Unit Standards Time



# Unit Standards Mass



**Pt Ir cylinder in Sevres, France**

**Since Nov. 2019, the kg is based on the meter, the second, and defining Planck's constant as exactly  $h=6.62607015 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}$ !**



## Dimensions



*“The dimension of a physical quantity expresses its dependence on the base quantities as a product of symbols (or powers of symbols) representing those base quantities.”*

*dimension: the physical nature of a quantity expressed in terms of L, M, and T.<sup>†</sup>*

For mechanical base units ...

Quantity	Dimension
mass	M
length	L
time	T

For some derived units ...

[miles/hour] =	L/T
[km/s] =	L/T
[knot] =	L/T
[L (liter)] =	L <sup>3</sup>
[kg m/s <sup>2</sup> ] =	ML/T <sup>2</sup>
[density]=	M/L <sup>3</sup>

Use of brackets: “[x]=” means “the dimensions of x are ...”

<sup>†</sup>The dimensions of the Amp, Kelvin, Mole and Cd are I, Θ, N, J.



# Dimensional Analysis

- *a way to figure out if an equation is (dimensionally) correct*
- *allows you to decide which equation to use.*

Ex. 1) Is this equation dimensionally correct?

$$ma = \frac{1}{2}mv^2$$

where  $m$ =mass,  $v$ =speed ( $L/T$ ),  $a$ =acceleration ( $L/T^2$ )

Soln:  $[ma]=ML/T^2$  and  $[\frac{1}{2}mv^2]=ML^2/T^2$   
since  $ML/T^2 \neq ML^2/T^2$  the equation cannot be correct.

Ex. 2) Is this equation dimensionally correct?

$$y = at^2$$

where  $y$ =position ( $L$ ),  $t$ =time,  $a$ =acceleration= $L/T^2$

Soln:  $[y]=L$ ,  $[at^2]=L/T^2 * T^2=L$ .  
since  $L = L$ , the equation is dimensionally correct.  
However, the equation is still wrong! How?

<sup>†</sup> $1/2$  is a dimensionless constant

## Dimensional Analysis (cont)

Ex. 3) How long does it take to drive 20 miles (to Lima) at a constant 60 mph?

Soln: Let  $v$ =speed ( $L/T$ ),  $d$ =distance ( $L$ ) and  $t$ =time ( $T$ ).

Possible (linear) equations:  $t=v*d$ ,  $t=v/d$ ,  $t=d/v$

Check dimensions:  $L^2/T$        $1/T$        $T$

so:  $t=d/v = 20/60 = \underline{1/3 \text{ hr or 20 minutes.}}$

# In-class quiz #1 – for attendance

## *Instructions:*

- 1) take out clean sheet of paper.*
- 2) Write “In-class #1” on top left, and your name on top right.*
- 3) Write answers to the following questions in 2 minutes.*
- 4) Turn in at end of class.*

*You may use your notes to find answers.*

- 1) Power is an energy per time, usually measured in Watts.  
Is the Watt a base or a derived unit?
- 2) What are the dimensions of  $m^X a^Y$  if  $m$ = mass,  
 $a$ =acceleration,  $X=3$ , and  $Y=-2$ ?
- 3) What are the dimensions of density?
- 4) How was the foot defined back in 1100 AD?
- 5) From which units is the pound derived?



# Physics 2311 (Sec 3) – Physics I

Dr. Pinkney

## Outline for W2 Day 3

### Measurements

Significant figures (LSDs)

Errors, (mean, SD, SDOM)

1D motion

## Homework (Due Wed 9/1)

Ch. 1 Read sections 1,3,4,6

Ch. 1 Probs: 1a,8,9,11,16,20,21

Ch. 2 Read sections 1,2

Ch. 2 Probs: 2-6

Read unfinished parts of this PPT.

# Measurements

measurement: the act or result of measuring

Example: use a plastic ruler to measure a shoe's length  
to be  $L=12.0\pm0.1$  inches.

Example: use a Vernier scale to measure the same shoe length  
to be  $L=12.13\pm0.04$  inches.

Notice:

- A measurement consists of a *number*, an *error* (or uncertainty, or tolerance), and a *unit*. 3 things!
- The number of significant digits shown is related to the error in the measurement. (more sig figs for smaller fractional errors.)
- The number of significant digits shown is indicative of the *precision* of the measurement.
- The Vernier caliper is more *precise* than the ruler.
- We did not yet determine which measurement is more *accurate*.

# Measurements

Accuracy and precision

- i. accuracy: how close the measurement is to some accepted “true” value
- ii. precision: how close repeated measurements (using the same device and procedure) are to each other



# Measurements -accuracy and precision

Example: two bathroom scales.

Step on and off them repeatedly in a consistent way.

digital scale

analog (yellow) scale

155.1 lbs

150. lbs

155.0

148

155.1

149

155.2

149

155.3

151

Q: Which scale has the greater “spread” in values?

Q: Which scale is more precise?

Q: Which scale is most accurate?

You go to the doctors office and they tell you 149.2 lbs.

Q: Which scale is most accurate?

Q: Which scale is more precise?



# Measurements

## Significant figures or (significant digits)

-- a way of suggesting precision.

significant figure: any digit of a number that is known with some certainty. The least significant digit (LSD) is the rightmost significant digit and it is least certain.

Count the “sig figs”:

Examples:

- 1) 4,567,000    4
- 2) 4.567 0    5
- 3) 4,567,000    6
- 4) 4,567,000.    7
- 5) 0.03450    4
- 6) 30.003    5

Notes:

- 1. The digit left of a decimal point is significant for numbers greater than 1. (Ex. 4 & 5)
- 2. Errors should have 1 significant figure.
- 3. For homework after week 1, answers with 3 - 4 significant digits are ok.
- 4. The weights from the yellow scale should not be quoted to more than the 1's place.

Which number is the LSD for each of the above?

Which place is occupied by the LSD in the above?

# Measurements

**Error** (uncertainty, tolerance)

-- the best way to quantify precision.

How do you determine the error on a measurement?

a) From the number of significant figures?

Not good. There is NO universally accepted rule for deriving errors from significant digits.

Ex.) one convention is 32.4 means  $32.4 \pm 0.05$

b) By looking at the smallest “tickmarks” on your instrument.

“Instrumental error” is  $\frac{1}{2}$  of the smallest tickmark spacing.

c) By considering how difficult it is to use the instrument.

Ex. using a stopwatch.

d) By repeating the measurement many times and finding the spread of measurements. (standard deviation,  $\sigma$ ) BEST!



Mistake,  
not error.

# Measurements

**Errors** types of errors

random errors, instrumental errors, tolerance

- related to the precision of the measurement

systematic errors

- related to the accuracy of the measurement
- an effect that shifts all measurements in the same direction.

Ex) You use the previous yellow scale to weigh yourself.  
It's zeropoint can be adjusted!

Ex) You are measuring the volume of an air-filled ball.  
Answer will change depending on the pressure  
and temperature inside and outside of the balloon.

Ex) You are measuring a length with a ruler.

- \* parallax
- \* worn down ends
- \* non-perpendicularity
- \* cheap rulers have bad tickmarks
- \* lengths change w/T



# Measurements

**Errors** ways of mathematically expressing errors

absolute errors

-- 155  $\pm$  8 lbs has an absolute error of 8 lbs

fractional errors

-- 155  $\pm$  8 lbs has a fractional error of 0.052

percentage errors

-- 155  $\pm$  8 lbs has a percentage error of 5.2%



# Measurements

## Error Propagation

How do you figure out the error for a number that was calculated from several measurements? (**Append. B.8**)

I. If only significant figures are shown:

a) Addition and subtraction: the final answer should have its LSD in the same place as the least precise input measurement

Ex)  $5800 \text{ m} + 121 \text{ m} = 5900 \text{ m}$

Ex)  $612800 \text{ s} + 2011.5 \text{ s} = 614,800 \text{ s}$

Ex)  $220. - 115 = 105$

b) Multiplication and division: the final answer should have the same number of sig figs as the input number with the fewest sig. figs.

Ex)  $2000 \times 15.143 = 30,000$

Ex)  $382,500 \times 11. = 4,200,000$  (not 4,207,500)

Ex)  $520 / 3 = 200$  (not 173.3)





# Measurements

## Error Propagation - cont.

### II. If errors are explicitly shown

#### a) Addition and subtraction:

##### 1) simple way: add error

$$\text{Ex) } 580. \pm 2 \text{ m} + 121 \pm 3 \text{ m} = 701. \pm 5$$

(This is an overestimate.)

##### 2) correct way: add errors "in quadrature"

$$\text{Ex) } 580. \pm 2 \text{ m} + 121 \pm 3 \text{ m} = 701. \pm e$$

$$\text{where } e = \sqrt{(2)^2 + (3)^2} = \sqrt{13} = 3.61 \quad (\text{round up, } e = 4 \text{ m})$$

#### b) Multiplication and division:

##### 1) simple way: "adding the fractional errors"

Ex) **Appendix B.8, Examples B.8-10.**

##### 2) correct way: add fractional errors in quadrature.

(We will use method 1 instead.)

**Note: the LSD of the answer must match the LSD of the error!**

**Note: the number of sig figs in the final answer does not have to be the same as the least precise input number, ala prev slide.**

# Measurements

## Errors and statistics

Mean  $\mu = \frac{\sum x_i}{N}$

Standard Deviation  $\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{(N - 1)}}$

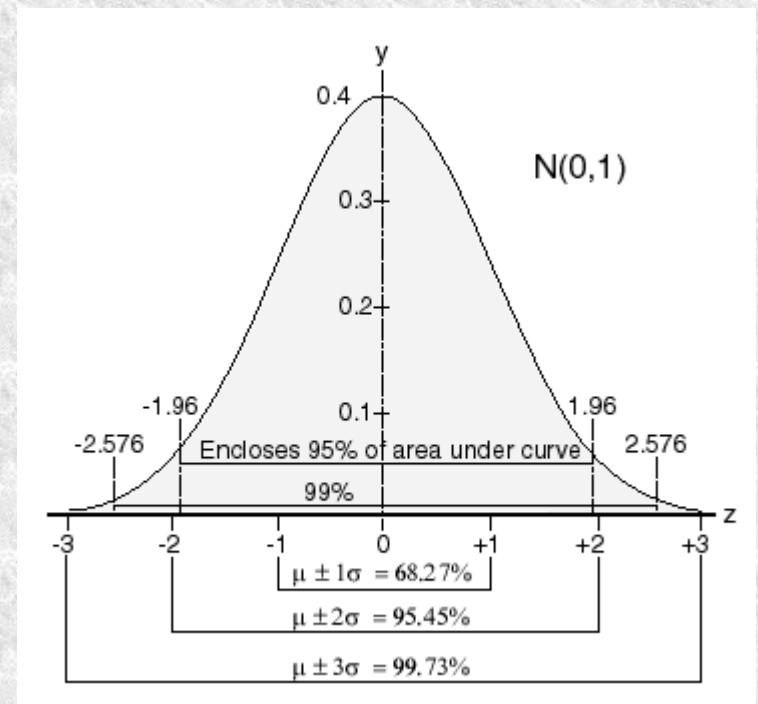
→ Gives error in a single measurement

Standard Deviation of the mean:

$$\sigma_{\mu} = \frac{\sigma}{\sqrt{N}}$$

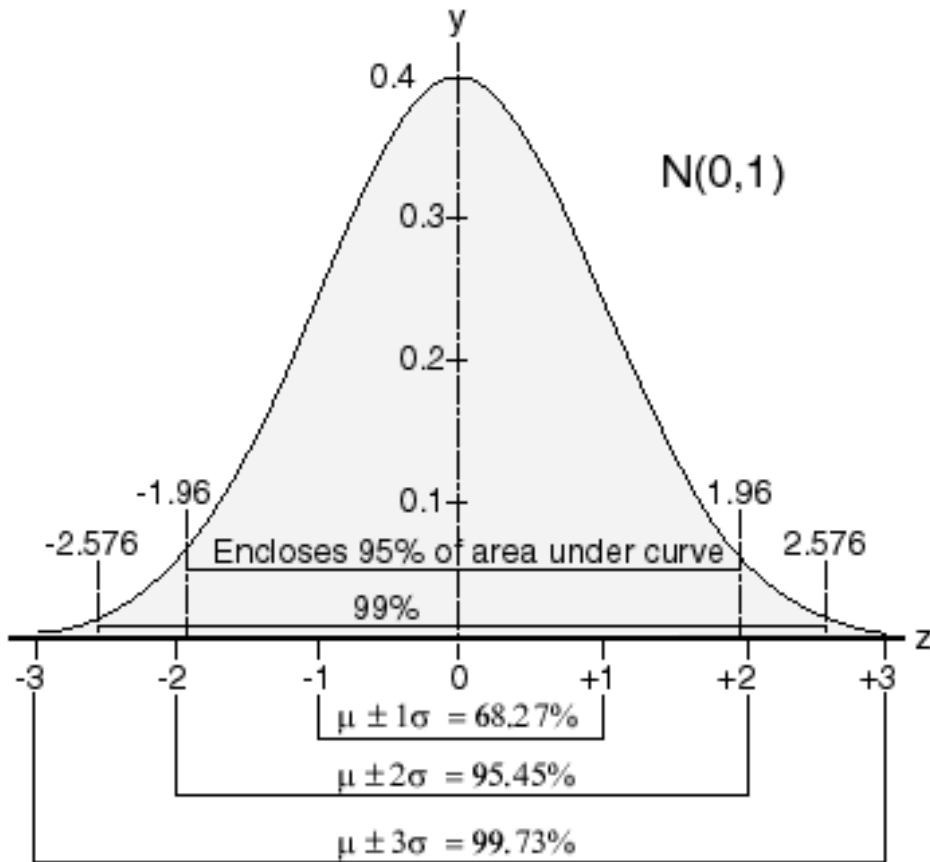
→ Gives error in the mean of all N measurements. Your final error.

Normal or Gaussian distribution



# Measurements

## Errors and statistics



### IMPORTANT CONCEPT:

The Gaussian distribution can be interpreted as a probability distribution.

Ex) You measure a mean of 10000 weights to be 70.0 lbs with a standard deviation of  $\sigma = 10.0$  lbs. If the weights are normally distributed, what is the probability that a single, new measurement will have a value greater than 90 lbs?

$$90 - 70 = 20 \text{ lbs}$$

$$20 \text{ lbs} = 2 \times 10 = 2 \times \sigma$$

Area under curve between  $z = 2 \times \sigma$  and  $z = +\infty$  is  $(100\% - 95.45\%) / 2 = 2.275\% = \text{Ans.}$

Ex) What is probability that a single new measurement will be 50 or lower?

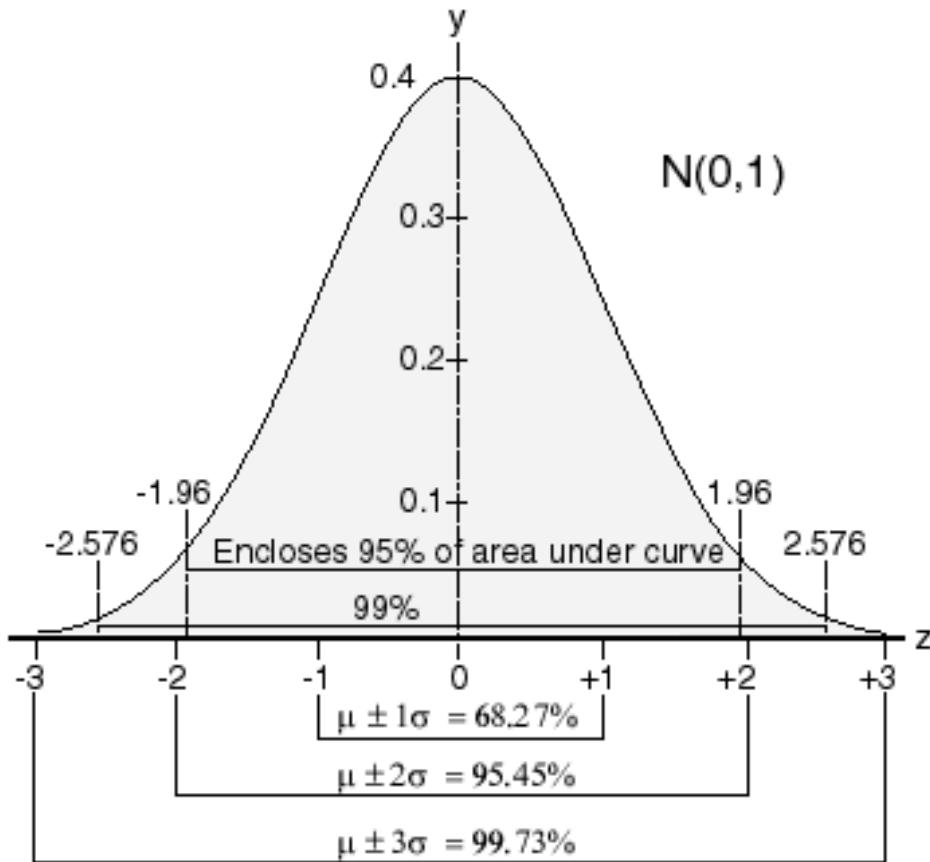
$$\text{Ans} = 2.275\%$$

Ex) What is the probability that a single new measurement will be within  $70 \pm 10$  lbs?  $\text{Ans} = 68.27\%$ .



# Measurements

## Errors and statistics



### IMPORTANT CONCEPT:

The Gaussian distribution can be interpreted as a probability distribution.

Ex) You measure a mean of 10000 weights to be 70.0 lbs with a standard deviation of  $\sigma = 10.0$  lbs. If the weights are normally distributed, what is the probability that a single, new measurement will have a value greater than 90 lbs?

$$90 - 70 = 20 \text{ lbs}$$

$$20 \text{ lbs} = 2 \times 10 = 2 \times \sigma$$

Area under curve between  $z = 2 \times \sigma$  and  $z = +\infty$  is  $(100\% - 95.45\%) / 2 = 2.275\% = \text{Ans.}$

Ex) What is probability that a single new measurement will be 50 or lower?

$$\text{Ans} = 2.275\%$$

Ex) What is the probability that a single new measurement will be within  $70 \pm 10$  lbs?  $\text{Ans} = 68.27\%$ .