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 +, -, ×, and ÷
- Understand how σ, and σ_{μ} are related to measurements and errors

Units

Base Units

Mechanical:

Quantity	**MKS unit**	**cgs unit**
mass	kg (kilogram)	g
length	m (meter)	cm
time	s (second)	s

Other:

Quantity	**MKS unit**
temperature	K (Kelvin)
current	A (amps)
amount of matter	mol (mole)
luminous intensity	cd (candela)

Derived Units

miles/hour
km/s
mol/liter
kg m/s^2
microsecond
etc.
etc.

Making convenient units with prefixes

TABLE 1.2 Multiples and Prefixes for Metric Units*

Multiple†	*Prefix (and Abbreviation)*	*Pronunciation*	*Multiple*†	*Prefix (and Abbreviation)*	*Pronunciation*
10^{24}	yotta- (Y)	yot′ta (*a* as in *a*bout)	10^{-1}	deci- (d)	des′i (as in *deci*mal)
10^{21}	zetta- (Z)	zet′ta (*a* as in *a*bout)	10^{-2}	centi- (c)	sen′ti (as in *senti*mental)
10^{18}	exa- (E)	ex′a (*a* as in *a*bout)	10^{-3}	milli- (m)	mil′li (as in *mili*tary)
10^{15}	peta- (P)	pet′a (as in *peta*l)	10^{-6}	micro- (μ)	mi′kro (as in *micro*phone)
10^{12}	tera- (T)	ter′a (as in *terra*ce)	10^{-9}	nano- (n)	nan′oh (*an* as in *ann*ual)
10^{9}	giga- (G)	ji′ga (*ji* as in *ji*ggle, *a* as in *a*bout)	10^{-12}	pico- (p)	pe′ko (*peek-oh*)
10^{6}	mega- (M)	meg′a (as in *mega*phone)	10^{-15}	femto- (f)	fem′toe (*fem* as in *fem*inine)
10^{3}	kilo- (k)	kil′o (as in *kilo*watt)	10^{-18}	atto- (a)	at′toe (as in an*atom*y)
10^{2}	hecto- (h)	hek′to (*heck-toe*)	10^{-21}	zepto- (z)	zep′toe (as in *zep*pelin)
10	deka- (da)	dek′a (*deck* plus *a* as in *a*bout)	10^{-24}	yocto- (y)	yock′toe (as in *sock*)

*For example, 1 gram (g) multiplied by 1000 (10^3) is 1 kilogram (kg); 1 gram multiplied by 1/1000 (10^{-3}) is 1 milligram (mg).

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

Unit systems

System	L	M	T
mks (or SI)	m	kg	s
cgs	cm	g	s
US Customery	ft (foot)	slug	s

Note: “US Customery” 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!!!

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<u>Outline for Day 2</u>
Unit Standards (cont.)
Dimensional analysis
Measurements
  Significant figures
  Errors

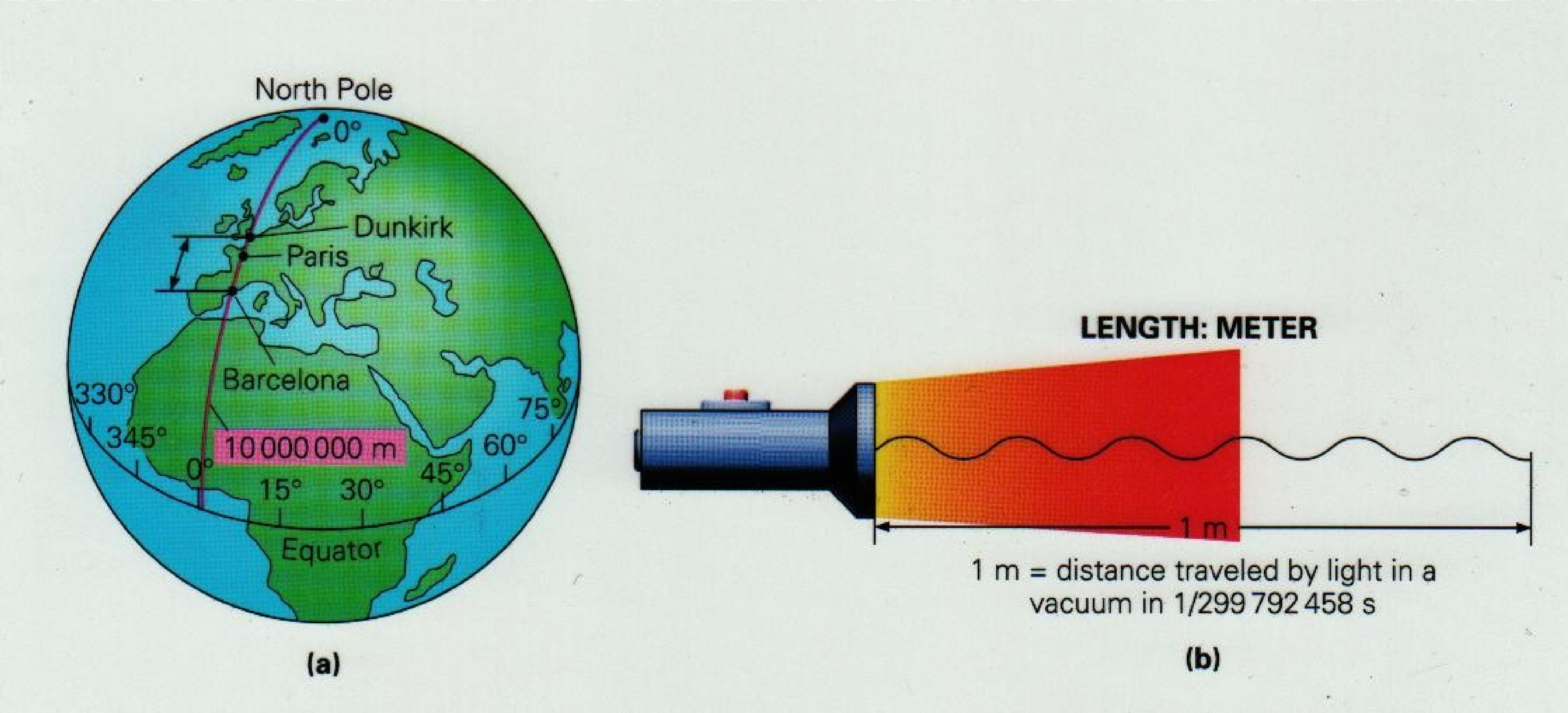
<u>Homework (Due Monday)</u>
Ch. 1 Read sections 2-4,6
Ch. 1 Probs: 25,26,30,31,46,50,
51,53,66,77,79
Read unfinished parts of this PPT.

Unit Standards

<u>Standard</u>: how we define a unit.
- **Used to be real-life objects**
- **Now units are based on physical constants (*c*, *h*)**

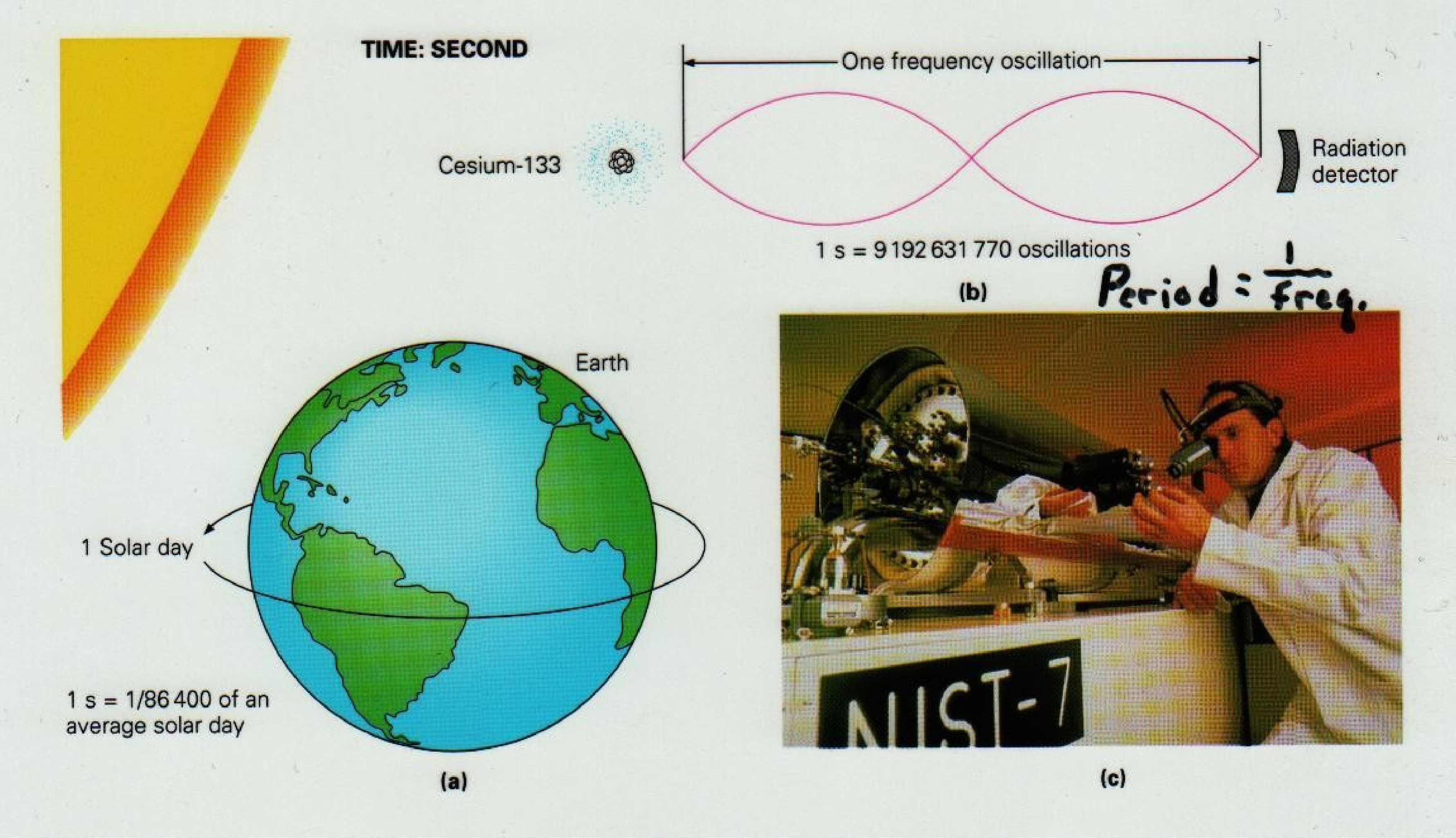
Why do we need standards?
Communication!
- **between scientists discussing experimental results**
- **between international businessmen selling goods "by the gallon" or "by the pound"**
- **between Earth and alien life (some day?)**

Unit Standards
Length

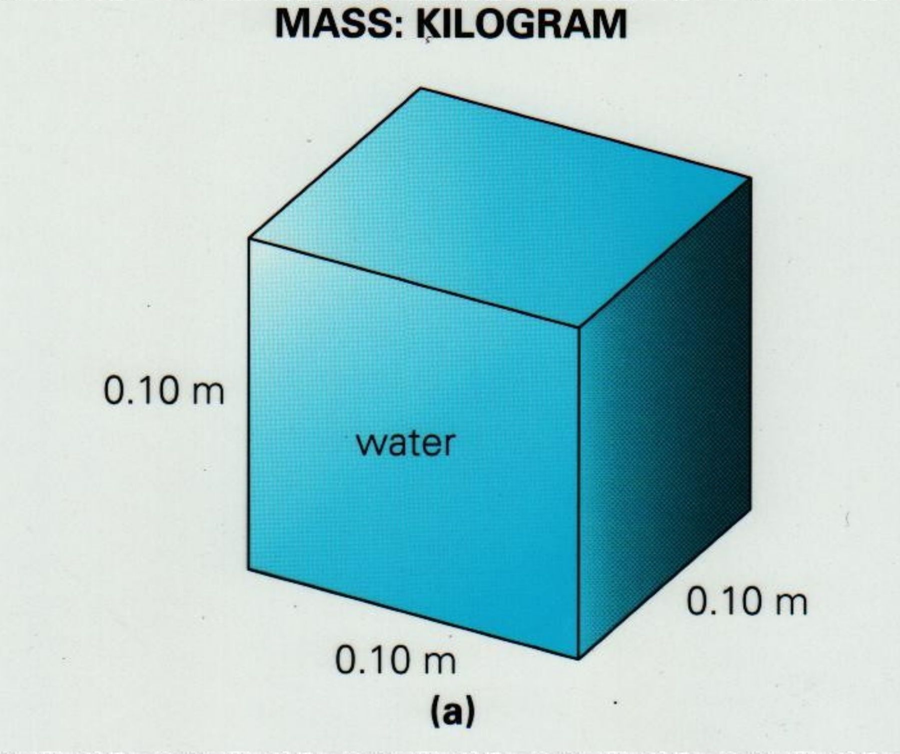


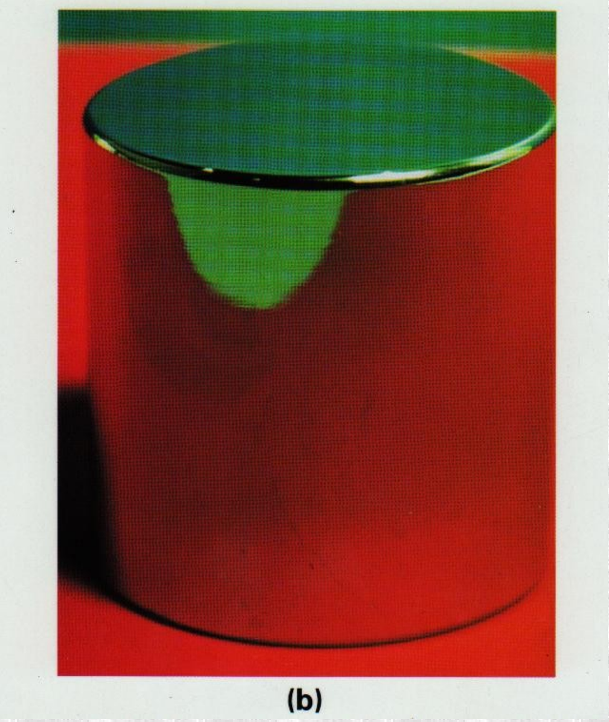
The meter is now based on the speed of light in a vacuum.

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=6.62607015x10^{-34} kg m^2 s^{-1}!

P231 Week 1: measurements

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.†

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^3
[kg m/s^2] =	ML/T^2
[density]=	M/L^3

Use of brackets: "[x]=" means "the dimensions of x are …"
†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?

$$ma = \tfrac{1}{2}^{\dagger} mv^2$$

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

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

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 <u>is dimensionally correct</u>.
However, the equation is still wrong! How?

† 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 = 1/3 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~~ 1700 AD?
5) From which units is the pound derived?

In-class quiz #1 – answers

Instructions:
1) take out your NOTEBOOK.
2) Write "In-class #1"
3) Write BOTH the question and MY answer to the question.

1) Power is an energy per time, usually measured in Watts. Is the Watt a base or a derived unit?

Derived

2) What are the dimensions of $m^X a^Y$ if m= mass, a=acceleration, X=3, and Y=-2?

$M^3 L^{-2} T^4$

3) What are the dimensions of density?

$M L^{-3}$

4) How was the yard defined back in 1700 AD France?

King Louis said the king's foot defines 1 foot.

5) From which units is the pound derived?

1 pound = 1 slug ft / s^2

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. <u>accuracy:</u> how close the measurement is to some accepted "true" value

ii. <u>precision:</u> 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 doctor’s 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 number of “sig figs” in these numbers:

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. 4,6)
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+-0.05

b) By looking at the smallest "tickmarks" on your instrument.
"Instrumental error" is ½ 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, σ) 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
* cheep rulers have bad tickmarks * lengths change w/T

Measurements

Errors ways of mathematically expressing errors

<u>*absolute errors*</u>

-- 155 +- 8 lbs has an absolute error of 8 lbs

<u>*fractional errors*</u>

-- 155 +- 8 lbs has a fractional error of 0.052

<u>*percentage errors*</u>

-- 155 +- 8 lbs has a percentage error of 5.2%

New from OpenStax:
Discrepancy: difference between measured and true value.

– If true weight = 150 lbs, discrepancy = 155-150 = 5 lbs.
– Quantifies accuracy. (Other above quantify precision.)

“Propagation”

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 m + 121 m = 5900 m

Ex) 612800 s + 2011.5 s = 614,800 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 x 15.143 = 30,000

Ex) 382,500 x 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

Ex) 580.±2 m + 121 ±3 m = 701.±5

(This is an overestimate.)

2) correct way: add errors "in quadrature"

Ex) 580.±2 m + 121±3m = 701.±e

where $e=\sqrt{(2)^2+(3)^2}=\sqrt{13}=3.61$ (round up, e=4 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 $$\sigma=\sqrt{\frac{\sum (x_i-\mu)^2}{(N-1)}}$$

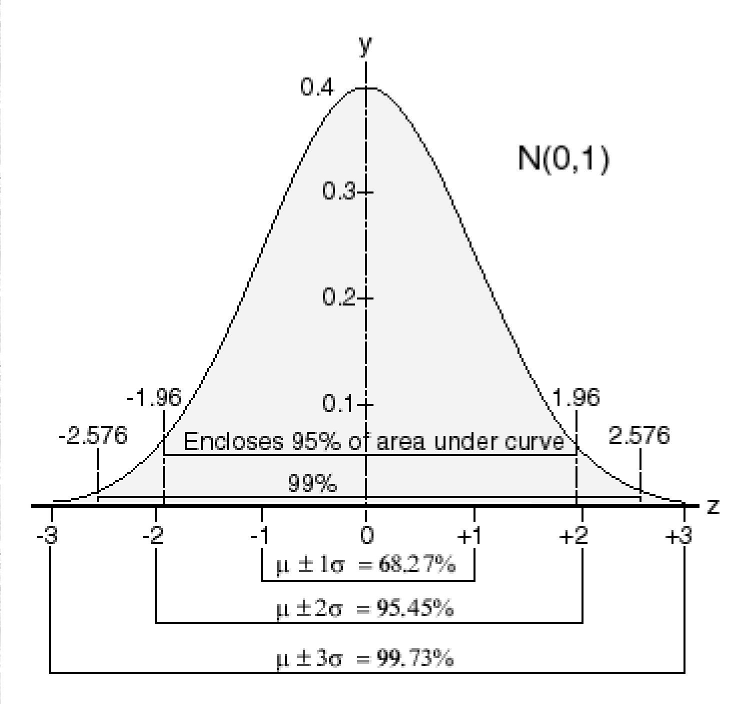
→ Gives error in a <u>single</u> measurement

Standard Deviation of the mean:

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

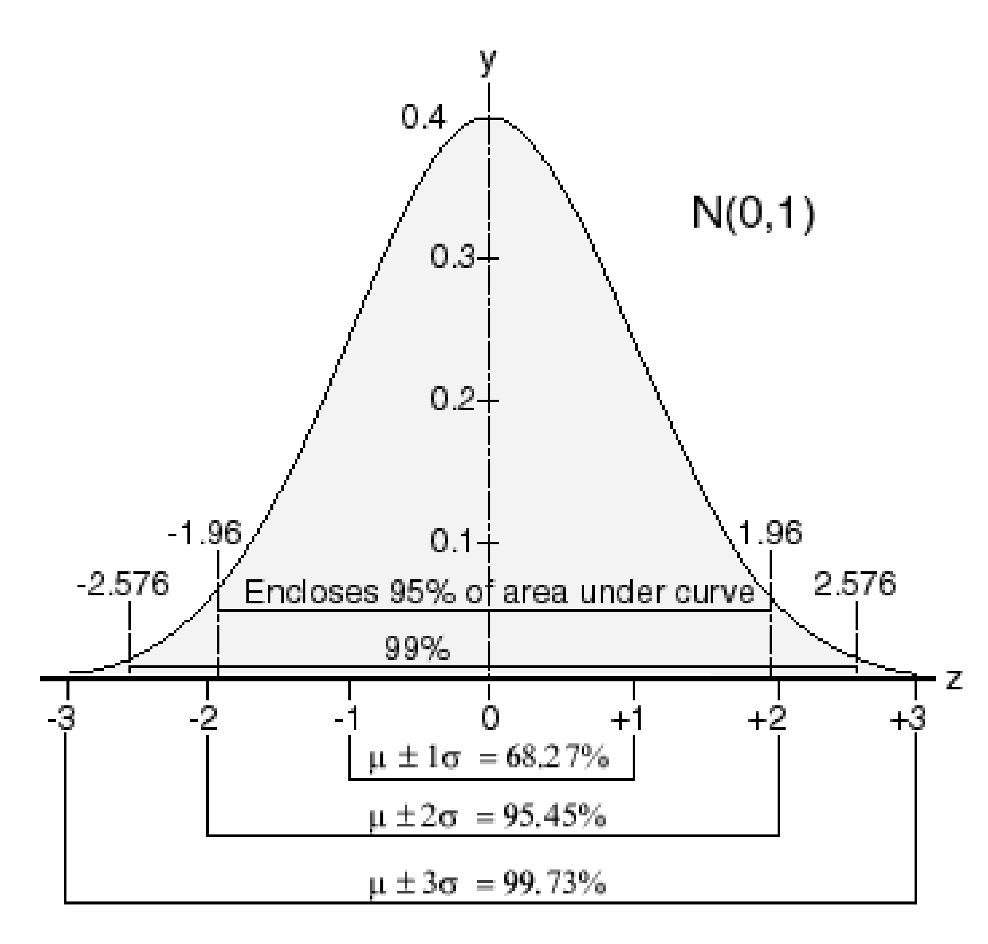
→ Gives error in the mean of all N measurements. Your final error.

Normal or Gaussian distribution



Measurements

Errors and statistics



IMPORTANT CONCEPT:
The Gaussian distribution can be interpreted as a <u>probability</u> distribution.

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

90-70 = 20 lbs

20 lbs = 2*10 = 2*σ

Area under curve between z=2*σ and z=+∞ is (100%-95.45%)/2 =2.275%=Ans.

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

Ans=2.275%

Ex) What is the probability that a single new measurement will be between 60 and 80 lbs?
Ans=68.27%.