Physics 2311 – Physics I
Dr. J. Pinkney

Jan 22, noon

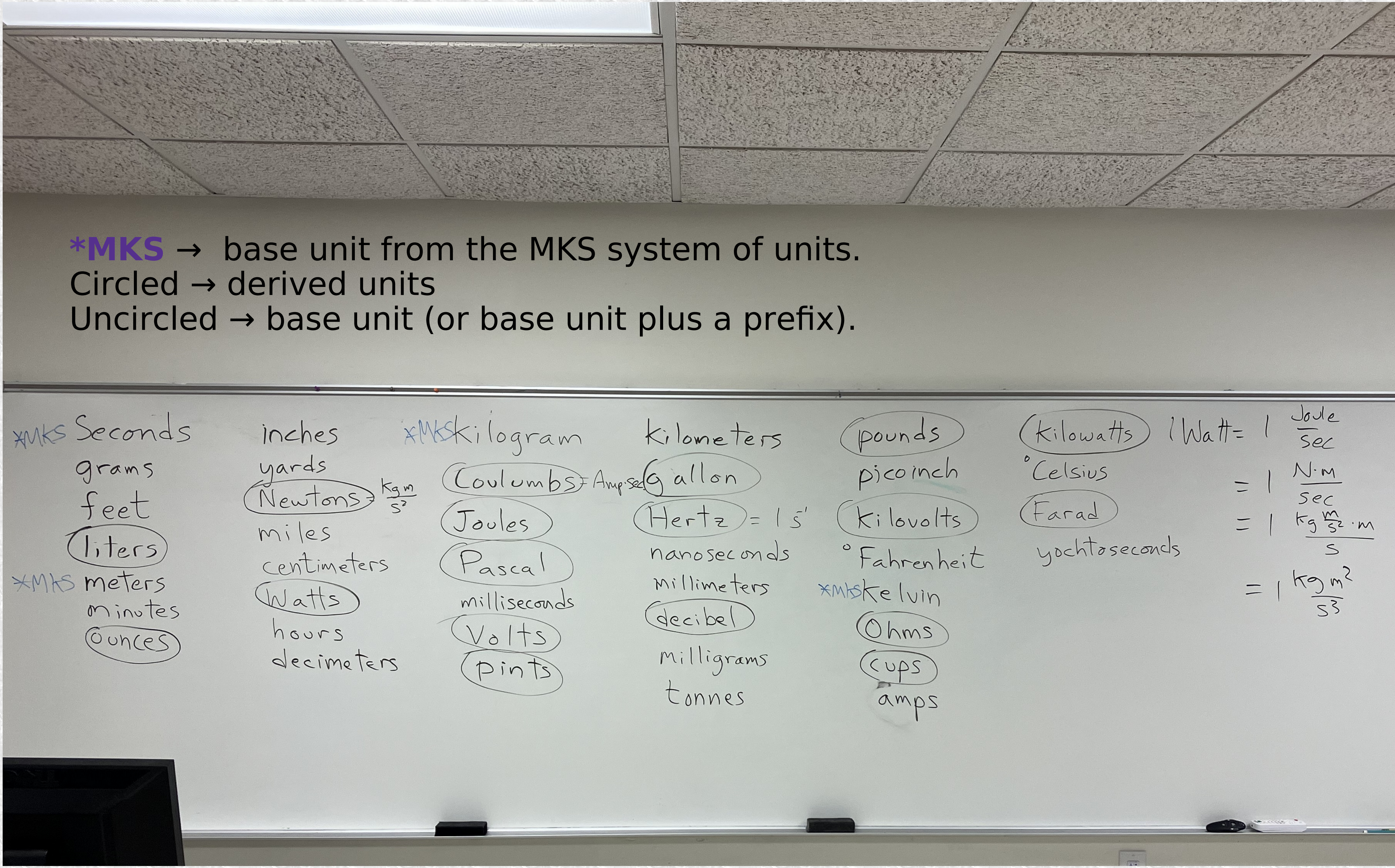
Outline for Day 1
Attendance and a list of units
Discuss syllabus
Units & Measurements

Homework (do by Mon)
Ch. 1 Read sections 3-5,7 (skim 1 & 2)
Ch. 1 MisConcQs: 2-8,10; Probs:1-8,14,15,17,18,
23,24,54-56

Notes: Attend lab this week – bring $15 for supplies.
Tutoring on Thursdays 7-9 SA116.

Student’s list of units

***MKS** → base unit from the MKS system of units.
Circled → derived units
Uncircled → base unit (or base unit plus a prefix).



Making convenient units with prefixes

Name a unit!

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 *an*nual)
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.

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 (skip)

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

knots (1.15 mph)
mph (miles/hour)
km/s
Liter (volume, dm^3)
Newton (kg m/s^2)
microsecond(base quantity)
m^3/s (flow rate)
etc.

Using prefixes to make more "convenient" units

"Convenient" units allow the number to be between about 0.1 and 10.

Example) The mass of the Sun is 2×10^{30} kg, or 2,000,000,000,000,000,000,000,000,000,000 kg. A more convenient unit is the solar mass, $M_\odot$. The mass of the Sun is 2.0 $M_\odot$.

Ex) What unit would be equivalent to 1×10^{-6} seconds?

Ans: 1 microsecond (1 μs)

What unit is equivalent to 1×10^{3} Newtons?

What unit is equivalent to 10^{6} phon?

What unit is equivalent to 10^{-3} pedes?

What unit is equivalent to 10^{12} dactyls?

What unit is equivalent to 10^{-12} boos?

How could you express 2×10^{3} mockingbirds using a prefix?

Etc.

Making convenient units with prefixes

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Outline for Day 2

Unit systems
Unit Standards
Dimensional analysis

Homework (Due by end of Mon)
Ch. 1 Read sections 3-5,7 (skim 1,2)
Ch. 1 MisConcQs: 2-8,10; Probs:1-8,14,15,17,18,
23,24,54-56
Preview the rest of the powerpoint slides.

Notes: Tutoring on Thursdays 7-9 Heterick Library.
Try Practice Quiz on "Units ..."

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 mis-conception about the pound: the pound is not a unit of mass!!!

Unit systems – Weights and Masses

2.2 lbs/kg is an **improper conversion** because lbs is a unit of weight and kg is a unit of mass!!! (It's only true on Earth's surface.)

Weight = force of gravity on an object (depends on which planet you're on).

W = m * g   where g = acceleration due to gravity

Mass = a measure of how much matter is in an object

Weight units include pounds (lbs) and Newtons (N).

Ex) What is the weight of 1 kg?

In Newtons: W = m g = (1 kg)*(9.8 m/s^2)

In Pounds: W = m g

Need m in slugs and g in ft/s^2… 1 kg = 0.0689 slug

g = 32 ft/s^2

W = .0689 slug * 32 ft/s^2 = 2.21 lbs

Ex) How many kg in a slug?

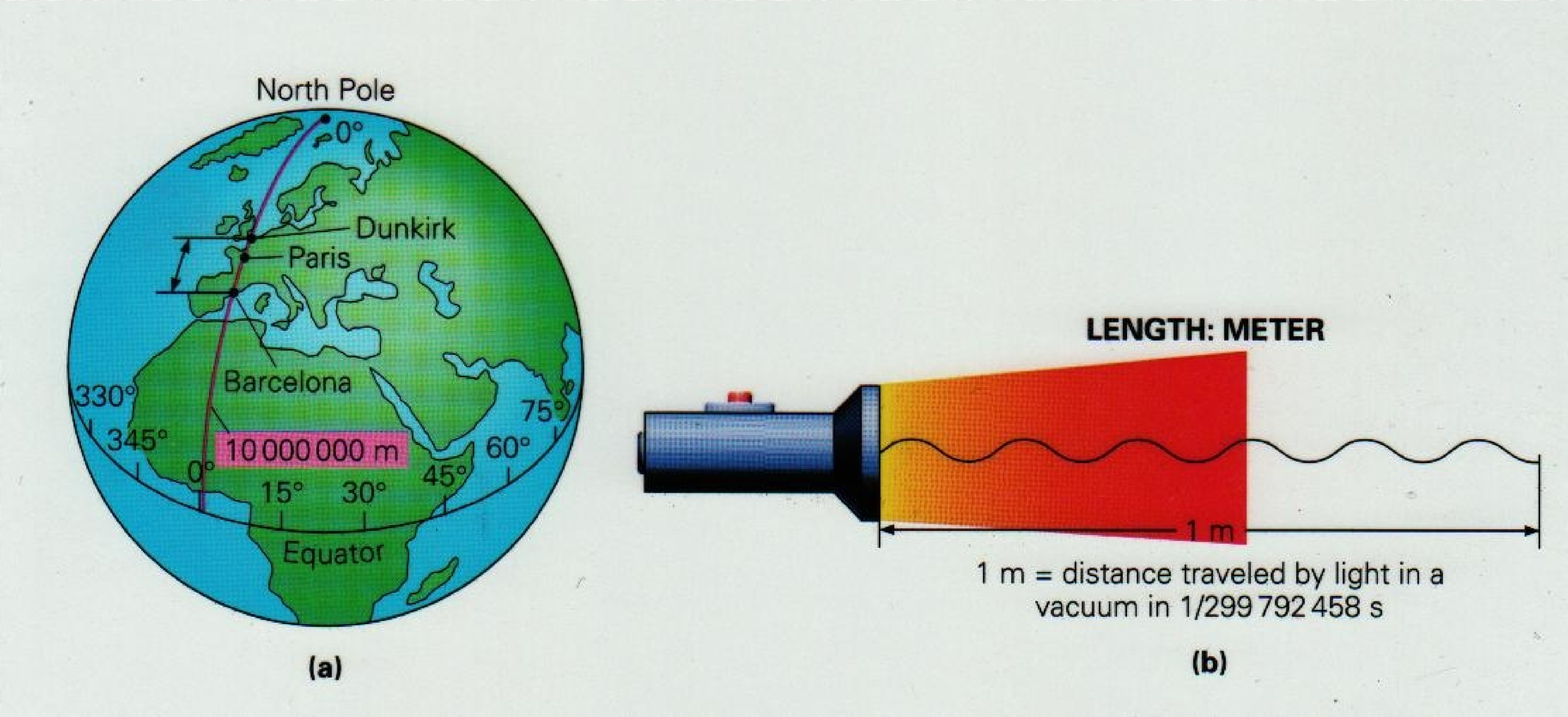
1 kg/.0689 slug = 14.5 kg/slug

Unit Standards

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

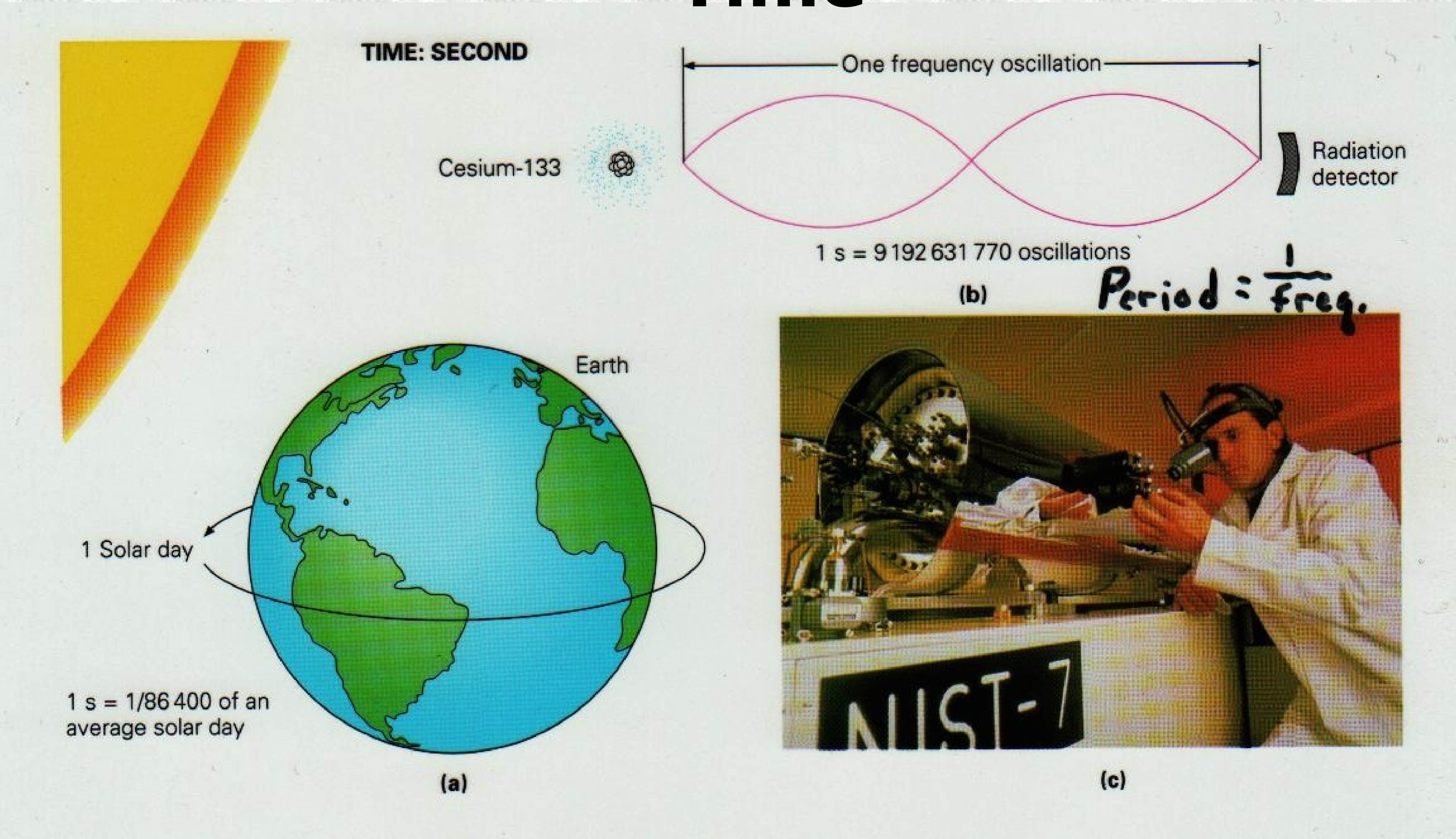
Why do we need standards?
Communication!
  * between scientists discussing experimental results
  * between international businessmen selling goods "by the gallon" or "by the pound"
  * between Earth and alien life (some day?)

Unit Standards
Length



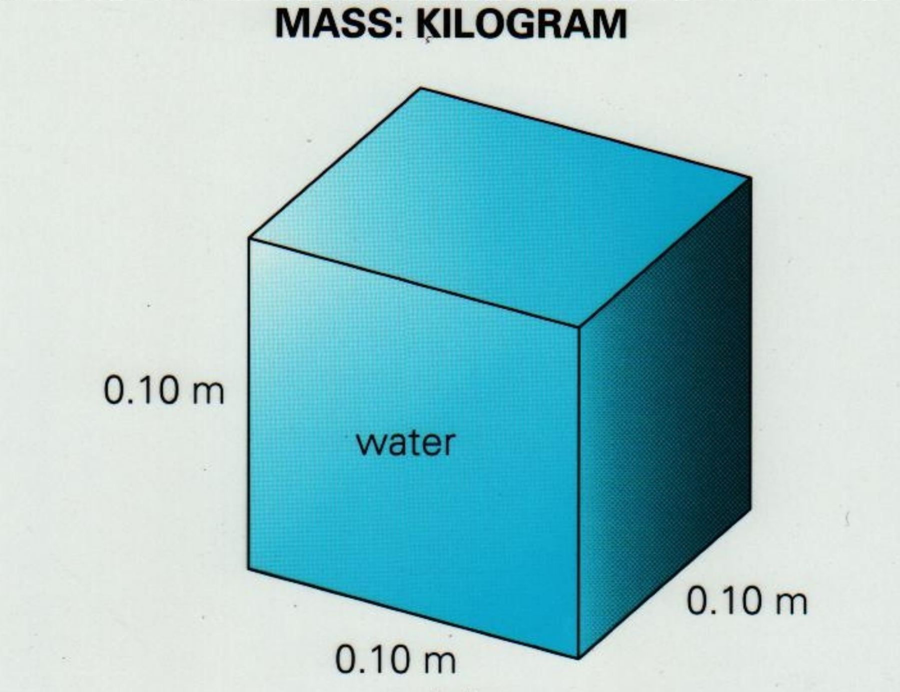
The meter is now based on the speed of light in a vacuum.

Unit Standards
Time

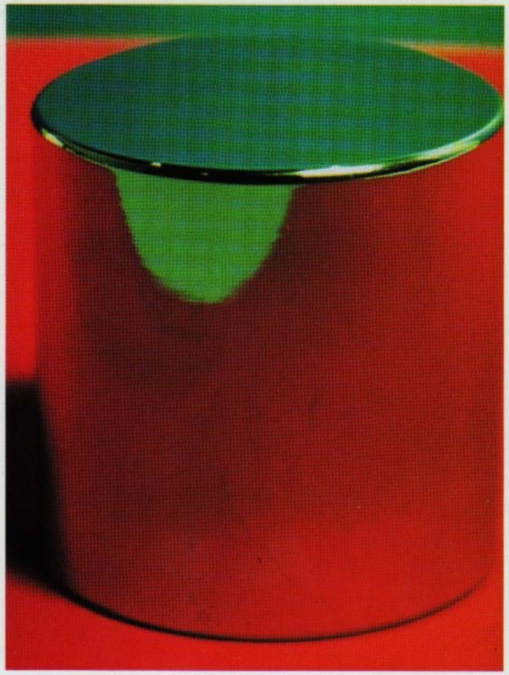


1 second = the time for 9,192,631,770 oscillations of Ce133 atom.

Unit Standards
Mass



(a)


(b)

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}!

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

My 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

Instructions:
1) ~~take out clean sheet of paper~~. Write in your notebook.
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 for attendance.
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? (A unit is kg m^{-3}.)
4) What was the original standard for the second?
5) From which units is the pound derived?

In-class quiz #1 – answers

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) What was the original standard for the second?

1/86400 th of the mean solar day (rot of E rel to Sun)

5) From which units is the pound derived?

1 pound = 1 slug ft / s^2

Measurements

<u>measurement:</u> 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 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 signifigant digit and it is the 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. Zeros on the right side of a number are not significant unless indicated by a bar or a decimal point. (Ex. 3 and 4)
2. It is easiest to show that a zero is significant using scientific notation: 4.56700×10^6 has 6 s.f..
3. A zero left of a decimal point is not significant for numbers less than 1. (Ex. 5).

Which number is the LSD for each of the above?
Which place is occupied by the LSD in the above?

Mistake,
not error.

Measurements

Errors types of errors

<u>*random errors, instrumental errors, tolerance*</u>
- related to the <u>precision</u> of the measurement

<u>*systematic errors, discrepancies*</u>
- related to the <u>accuracy</u> of the measurement
- an effect that shifts all measurements in the same direction.

Ex) You use the previous yellow scale to weigh yourself.
It reads 5 lbs before you stand on it! Your wt will be 5 lbs too high. (Need to adjust the zeropoint dial!)

Ex) Measuring temperatures with an alcohol thermometer, you need to submerge thermometer a specified depth.

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

Error (uncertainty, tolerance)

-- a number to quantify precision (random errors) or accuracy (systematic errors).

How do you determine the *random* 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.) 32.4 could mean 32.4±0.05, or 32.4±0.1 (Ch. 1), or 32.4±0.5.

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!

Measurements

Ways to express **errors** that reflect precision:

absolute errors

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

fractional errors

155 +- 8 lbs has a fractional error of 0.052

percentage errors

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

Ways to express **errors** that quantify accuracy:

Discrepancy: difference between measured and true value.

– Ex) true weight = 150 lbs, discrepancy = 155-150 = 5 lbs.

absolute discrepancy (5 lbs)

fractional discrepancy (5/150) = 0.033

percentage discrepancy (5/150)*100% = 3.3%

"Propagation"

Measurements

Error Propagation
How do you figure out the error for a number that was calculated from measurements?

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

b) Multiplication and division:

1) simple way: "adding the fractional errors"

Ex) Area of a rectangular plate. L=21.3±0.2, W=9.8±0.1 cm.

2) correct way: add fractional errors in quadrature.

(Most Physics I texts 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, like in prev slide.

Measurements

Errors and statistics

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

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

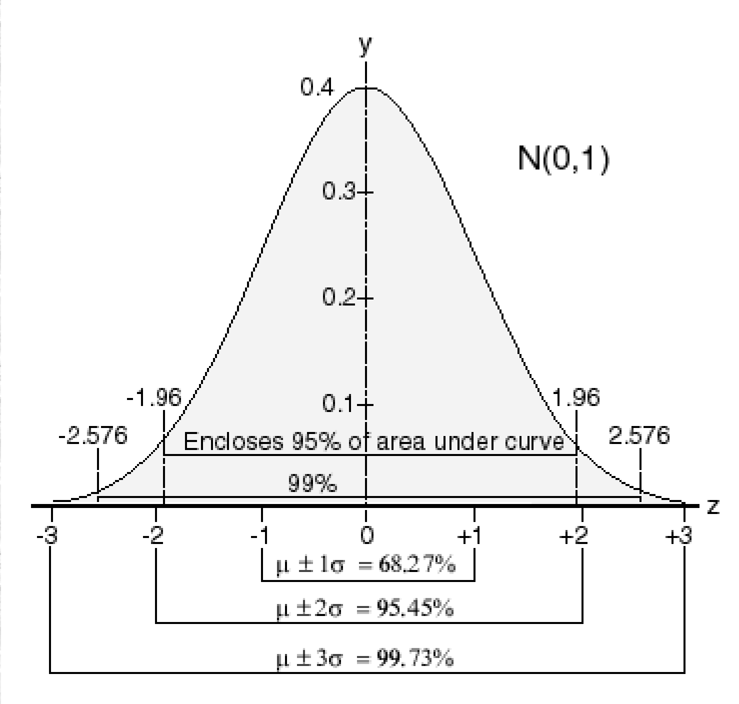
→ Gives error in a single measurement

Standard Deviation of the mean:

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

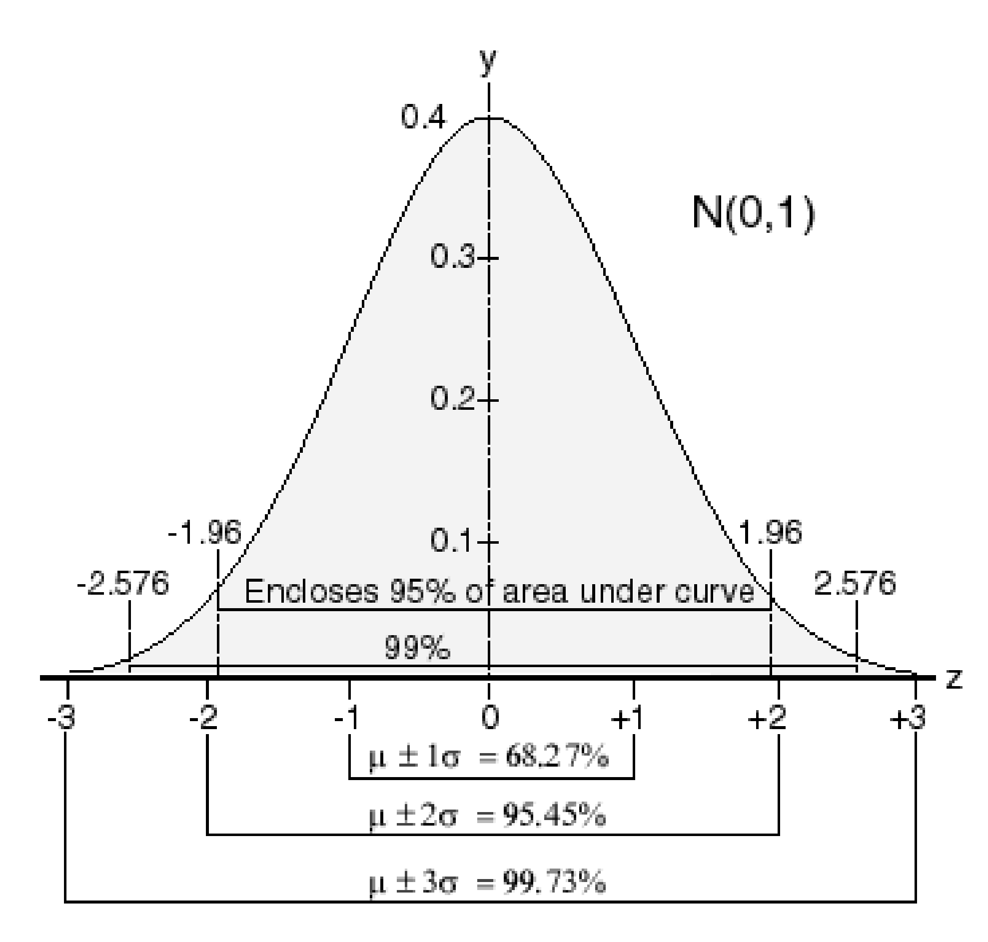
→ Gives error in the mean of all N measurements. Your final error.

Normal or Gaussian distribution



Measurements

Errors and statistics



IMPORTANT CONCEPT:
A distribution of measurements can be interpreted as a Gaussian <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%.