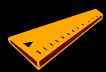



Measurement
Metrics
Dimensional Analysis

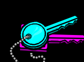

LPT

Units

Assume you run out of gas
You ask by-standers, "How far to nearest gas station?"

One bystander points left and says, "four"
Another points right and says, "six"
Duh!!!!!!!
4 or 6 feet, yards, meters, rods, blocks, miles, light years ?

Measurements are meaningless without units
- Units provide a scale (magnitude)
- Units identify the type (m, g, s, etc.) of measurement
- Units provide key to solving problems



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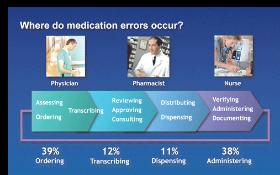
Measurement Systems

	English	Metric
Origin	Conquest	Convention
	Based on royalty	Based on decimal 10
Conversions	Not-uniform	Uniform
	Not-consistent	Consistent
Communication	Confuses	Facilitates
	Regional	Universal in science


LPT

Correct Measurements Are Not Trivial



Improper Measurements / Calculations Can Cost Lives

1990: ~ 98,000 deaths / year from hospital errors

2016: > 440,000 deaths / year from hospital errors

Third Leading Cause of deaths in the US

~ 1.7 million non-fatal injuries

Lab Notebook Documentation Absolutely Essential

Not following procedures can be lethal

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Famous Failures

15 million doses lost:
Employees mixed wrong ingredients
$ 150 million loss

Hubble Space Telescope:
Mirror surface shape
Curve Off by 1.3 mm
(Billions $ to repair)

Mars Orbiter:
One group in km/sec
Another group in mi/hr
Orbiter Crashed:
$125 million

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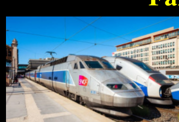
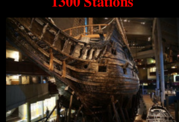
Famous Failures



French Rail System
2000 trains too wide for
1300 Stations



Warship VASA
Builders used different length measures
Sank 20 minutes into maiden voyage

Laufenberg Bridge across Rhine
Swiss-German
Measured sea level from different point
54 cm (~ 21 in) height difference when they met

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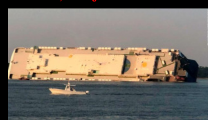
Correct Measurements Are Not Trivial

Spain's S-80 Sub (2003)
Misplaced decimal in specifications
770 tons too heavy
Added length to compensate for too heavy
Result: too long to fit naval base
1 billion Euro total cost / per sub
More than twice original cost

Disney Japan Space Mountain
Error in length conversion
Wrong axle size
Cars derailed
1 dead, 10 injured



Freighter Capsizes
Improper Buoyancy Calculations
$200 million lost

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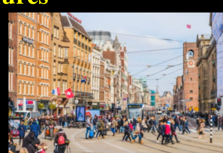
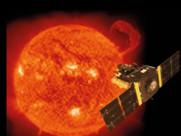
Famous Failures

Sochi Biathlon Track
40 m too short



Amsterdam Subsidies to the poor
Sent out € 188 million instead of 18.8



SOHO satellite lost communications
Improper Metric to English conversions

Gimli Glider
Ran out of fuel @ 40,000 feet
Wrong units for fuel calculation

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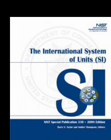
Basic SI (Systeme International) Units

How much?
- mass = kilogram (kg)
- length = meter (m)
- time = second (s)
- chemical quantity = mole (mol)



2 Different Systems:
kms: kilogram-meter-second (preferred)
cgs: centimeter-gram-second (commonly used in labs)

Measurement incomplete without "units"
Absolutely essential when working problems!

166 pages

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Derived Units

Any combination of more than one unit

Examples:

- Area = length x width (units of length^2)
- Volume = length x width x height (units of length^3)
- Volume (mL, L, cm^3, cc) is ALWAYS a derived unit
- Density = mass / volume (combination of units)
- Speed = distance / time (combination of units)
- Force = mass x acceleration (combination of units)

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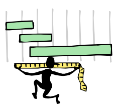
Metric Prefixes

kilo-
Larger; multiply by 1000



centi-
Smaller; divide by 100

milli-
Smaller; divide by 1000

Metric Conversions

1000 m = 1 km

100 cm = 1 m

1000 mm = 1 m

"per expressions"

1000 m = 1 x (1000) m
kilo = 1000

100 x (1/100) m = 1 m
centi = 1/100

1000 x (1/1000) m = 1 m
milli = 1/1000

Same numerical value on each side of =

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Metric Prefixes

Metric System Prefixes

Prefix	Symbol	Multiplier (Scientific Notation)	Multiplier
Exa	E	10^{18}	1,000,000,000,000,000,000
Peta	P	10^{15}	1,000,000,000,000,000
Tera	T	10^{12}	1,000,000,000,000
Giga	G	10^{9}	1,000,000,000
Mega	M	10^{6}	1,000,000
Kilo	k	10^{3}	1,000
Hecto	h	10^{2}	100
Deka	da	10^{1}	10
Deci	d	10^{-1}	0.1
Centi	c	10^{-2}	0.01
Milli	m	10^{-3}	0.001
Micro	µ	10^{-6}	0.000,001
Nano	n	10^{-9}	0.000,000,001
Pico	p	10^{-12}	0.000,000,000,001
Femto	f	10^{-15}	0.000,000,000,000,001
Atto	A	10^{-18}	0.000,000,000,000,000,001

Meter = m = 1

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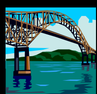
Dimensional Analysis

Fancy term for "Canceling Units"



Universal Method
For
Solving Measurement Problems
'cause it
bridges gap between
known information and wanted information

Known → Wanted

Canceling Units defines a "Path"

Let the units drive the solution

LPT

Doing the Math

Measurements are two parts:

4.78 cm

Numeral — Unit

Addition / Subtraction
- Quantities MUST HAVE the same units
- Can't do:
  - Apples + oranges
  - km + m
  - miles + gal

Let the units drive the solution

Multiplication / Division
- Numbers & units separately multiplied or divided

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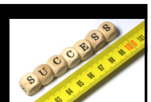
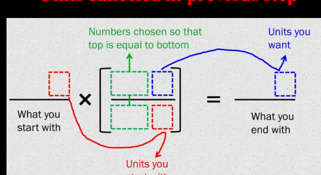
Per Expressions



Always has the form:

$$\frac{\text{Units wanted in next step}}{\text{Units canceled in previous step}}$$



Let the units drive the solution

LPT


Doing the Math

345 m x $\frac{1 \text{ km}}{1000 \text{ m}}$ = 0.345 km

To "cancel" units:

Numerator unit (top) of first term
Same as
Denominator unit (bottom) of next term

Let the units drive the solution

LPT

Use "per expressions" to place the "numbers"

Numbers & units on either side of the "per expression" = stay together

For per expression: 1000 g = 1 kg

Starting with g:

g x $\frac{1 \text{ kg}}{1000 \text{ g}}$

Starting with kg

kg x $\frac{1000 \text{ g}}{1 \text{ kg}}$

Per expressions also termed:
Conversion Factors
Equivalences

Let the units drive the solution

LPT



Measurement without Units
Leads to Disaster!



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Key to Solving Problems

Process:

- Write Given or Known (Left side of =)
- Write Wanted (Right side of =)
- Select "per expression" to cancel given unit
- If units same on left and right of = , do the math
- If units not the same, add another per expression
- Continue "linear string" until units same on both sides of the =
- Once units correct, solve as a single linear string calculation

Let the units drive the solution

LPT

Doing the Math

Convert 345 m to km:

Write "known" and "wanted"

$345\text{ m} \times \qquad = ?\text{ km}$

Next, start conversion factor so starting unit "cancels"

$345\text{ m} \times \frac{\qquad}{\text{m}} = ?\text{ km}$

Now, add wanted unit

$345\text{ m} \times \frac{\text{km}}{\text{m}} = ?\text{ km}$

Add the "per expression" numbers

$345\text{ m} \times \frac{1\text{ km}}{1000\text{ m}} = ?\text{ km}$

If units "cancel" and give "wanted", then do the math

$345\text{ m} \times \frac{1\text{ km}}{1000\text{ m}} = 0.345\text{ km}$

Let the units drive the solution

LPT

LPT

Calculator Does The Arithmetic; You Do The Units

Using Units
Prevents
Inappropriate calculations

Using Units
Provides
Path to solution

LPT

Doing the Arithmetic

Calculate the number of milligrams in 158 grams

1. What is wanted ➔ ? milligrams (mg)
2. What do I know ➔ 158 g
3. Going from 2 ➔ 1

$$158\ g \times \frac{1000\ mg}{1\ g} = 158{,}000\ mg$$

If I use only numbers & put them in wrong place, I get :

$$158\ g \times \frac{1\ g}{1000\ mg} = 0.158\ g^2 / mg$$

Let the units drive the solution

LPT

Doing the Arithmetic

Calculate the number of cm in 85.9 mm

1. What is wanted ➔ ? centimeters (cm)
2. What do I know ➔ 85.9 mm
3. Going from 2 ➔ 1 (as "linear string")

$$85.9\ mm \times \frac{1\ m}{1000\ mm} \times \frac{100\ cm}{1\ m} = 8.59\ cm$$

If I use only numbers & put them in wrong place, I get :

$$85.9\ mm \times \frac{1\ m}{1000\ mm} \times \frac{1\ m}{100\ cm} = 0.000859\ m^2/cm$$

Let the units drive the solution

LPT

Doing the Arithmetic

The wrong units spell disaster

If the units are wrong, the answer is wrong!

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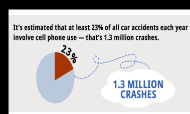
Practical Problem

A typical texting message takes a minimum of 10 seconds.
At 60 mph (88.0 ft/sec), how much distance is traveled in 10.0 sec?

$$\frac{88.0 \text{ ft}}{\text{sec}} \times 10.0 \text{ sec} = 880 \text{ feet}$$



This corresponds to the length of

$$880 \text{ ft} \times \frac{1 \text{ yd}}{3 \text{ ft}} \times \frac{1 \text{ football field}}{100 \text{ yd}} = 2.93 \text{ football fields}$$

Let the units drive the solution

LPT

Practical Problem

A fast food lunch consists of
- A burger: 610 kcal
- Large fries: 500 kcal
- Vanilla Milk Shake: 530 kcal ➔ Total = 1640 kcals

If walking a mile takes 100 kcal,
how many miles must you walk to "burn off" this meal?

$$1640 \text{ kcals} \times \frac{1 \text{ mile}}{100 \text{ kcals}} = 16.4 \text{ miles}$$

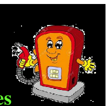
At 2.5 mi / hr, how long will this take?

$$16.4 \text{ miles} \times \frac{\text{hours}}{2.5 \text{ mi}} = 6.6 \text{ hours}$$

Let the units drive the solution

LPT

Practical Problem



You have a ten dollars. If gas is $2.45 a gallon and your car gets 34.2 miles per gallon, how many miles will you be able to drive on ten dollars?

$$\$\,10.00 \times \frac{1 \text{ gal}}{\$\,2.45} \times \frac{34.2 \text{ mi}}{\text{gal}} = 140 \text{ miles}$$

If you get 15.4 miles per gallon:

$$\$\,10.00 \times \frac{1 \text{ gal}}{\$\,2.45} \times \frac{15.4 \text{ mi}}{\text{gal}} = 62.8 \text{ miles}$$

Let the units drive the solution

LPT

Practical Problem

Captain Kirk and Mr. Spock were stranded in the US circa 1935. Mr. Spock asked for 5.00 pounds of platinum ($280 /oz). How long would it take our intrepid Captain Kirk working at 15 cents an hour to obtain the funds necessary to obtain this amount of platinum for Mr. Spock?

$$5.00 \text{ lbs} \times \frac{12 \text{ oz}}{\text{lbs}} \times \frac{\$280.00}{\text{oz}} \times \frac{100 \text{ cents}}{1\ \$} \times \frac{1 \text{ hr}}{15 \text{ cent}} = 112{,}000 \text{ hrs}$$

Convert to years

$$112{,}00 \text{ hrs} \times \frac{1 \text{ day}}{24 \text{ hrs}} \times \frac{1 \text{ year}}{365 \text{ days}} = 12.8 \text{ years}$$

Let the units drive the solution

LPT

The Sooner "Canceling Units" is Yours, The easier this class will be!

Use Units

Don't Use Units

SUCCESS
FINDS A WAY..
FAILURE
FINDS AN EXCUSE

LPT