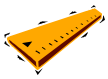

# Measurement
# Metrics
# Dimensional Analysis



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## 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 |





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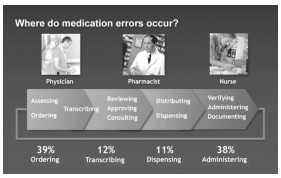
## Correct Measurements Are Not Trivial


**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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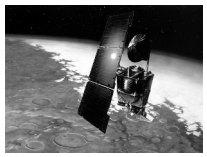
## Famous Failures

**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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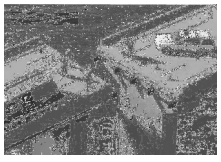
## Famous Failures

**French Rail System**
**2000 trains too wide for**
**1300 Stations**



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

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



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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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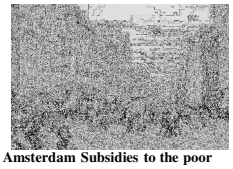
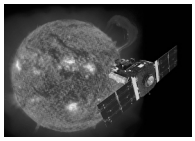
## Famous Failures

**Sochi Biathon 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 | Meter = m = 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 | |



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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**



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## 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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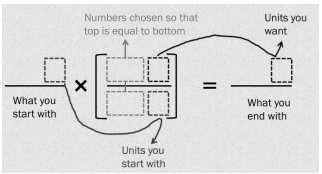
## Per Expressions


**Always has the form:**

**Units wanted in next step**
**Units canceled in previous step**




Let the units drive the solution



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## Doing the Math

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

To "cancel" units:

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

**Let the units drive the solution**



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## 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:

$$g \times \frac{1\ kg}{1000\ g}$$


Starting with kg

$$kg \times \frac{1000\ g}{1\ kg}$$

Per expressions also termed:
Conversion Factors
Equivalences

**Let the units drive the solution**



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**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**



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## Doing the Math

### Convert 345 m to km:

**Write "known" and "wanted"**

$$345\ m \times \qquad = ?\ km$$

**Next, start conversion factor so starting unit "cancels"**

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

**Now, add wanted unit**

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

**Add the "per expression" numbers**

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

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

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

**Let the units drive the solution**



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## Calculator Does The Arithmetic; You Do The Units


**Using Units**
**Prevents**
**Inappropriate calculations**

**Using Units**
**Provides**
**Path to solution**

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## 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**



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## 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**



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## Doing the Arithmetic

**The wrong units spell disaster**

**If the units are wrong, the answer is wrong!**



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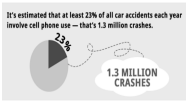
## Practical Problem

**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**



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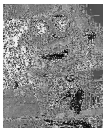
## Practical Problem

**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**



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## 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**



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## 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**



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## The Sooner "Canceling Units" is Yours,

## The easier this class will be!

**Use Units**


**Don't Use Units**




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