Phys 221 Fall 2014

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Science III

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Recipe for Phys 221

1. Study hard (you may ask other students)
2. Come to class
3. Do the homework (minimal requirements)
4. Do not stay behind
5. If you have questions, get them answered
6. If you have a problem, tell me about it

Phys 221 Fall 2014

Chapter 1

Physics and Measurements

Chapter 1: Tooling Up

In this chapter we shall introduce the following concepts which will be used throughout this quarter (and beyond)

1. **Units and systems of units**
2. **Conversion of units**
3. **Dimensional analysis**
4. **Order-of-magnitude estimates**

I (not you!) skip: The building blocks of matter

Physics

- **Classical** (before 1900)
- **Modern** (after 1900)

In Phys221 we study **mechanics** that deals with the motion of physical bodies using Newton's equations. These equations yield accurate results provided that:

1. The bodies in question are **macroscopic** (roughly speaking large, e.g. a car, a mouse, a fly)
2. The bodies do not move very fast. How fast? The yardstick is the speed of light in vacuum.
   $c = 3\times10^8$ m/s

We must measure !

Example: I step on my bathroom scale and it reads 150

150 what? 150 lb? 150 kg?

For each measurement we need **units**.

Do we have to define arbitrarily units for each and every physical parameter?

The answer is **no.** We need only define arbitrarily units for the following **four** parameters:

Length, Mass , Time, Electric Current

In Phys221 we will need only units for the first three. We will define the units for electric current in Phys222

In this course we shall use the **SI** (systeme internationale) system of units as follows:

Parameter	Unit	Symbol
Length (L)	**meter**	**m**
Mass (M)	**kilogram**	**kg**
Time (T)	**second**	**s**
Electric Current	**Ampere**	**A**

All other units follow from the arbitrarily defined four units listed above

Note: SI used to be called the “MKSA” system of units

Note: In CGS the first three units are enough

Basic Quantities and Their Dimension

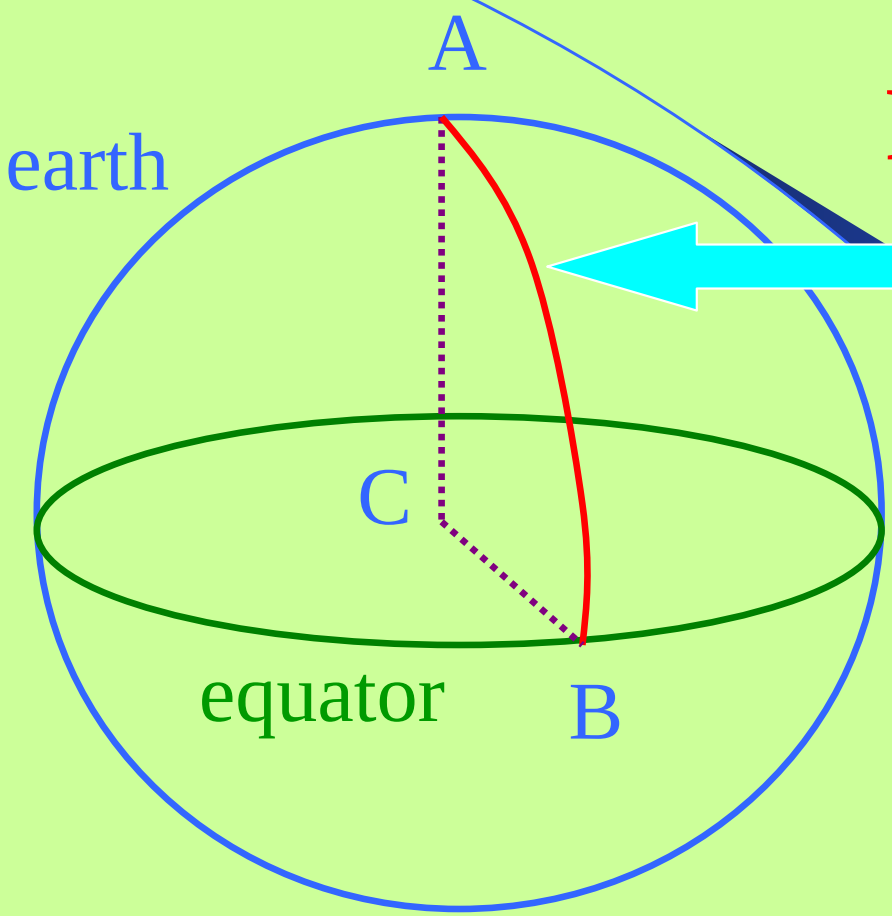
+ Standards of

Mass M

Length L

Time T

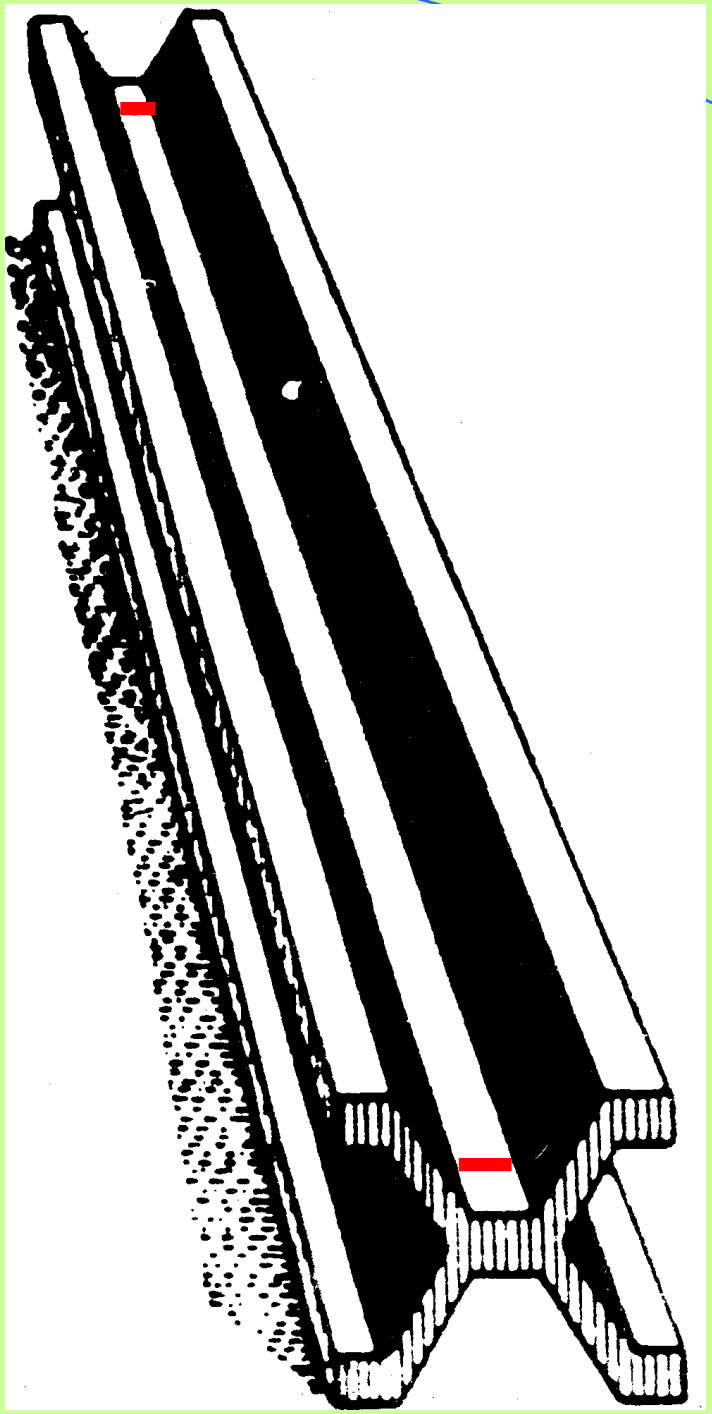
The meter



Paris

$$1 \text{ meter} \equiv AB/10^7$$

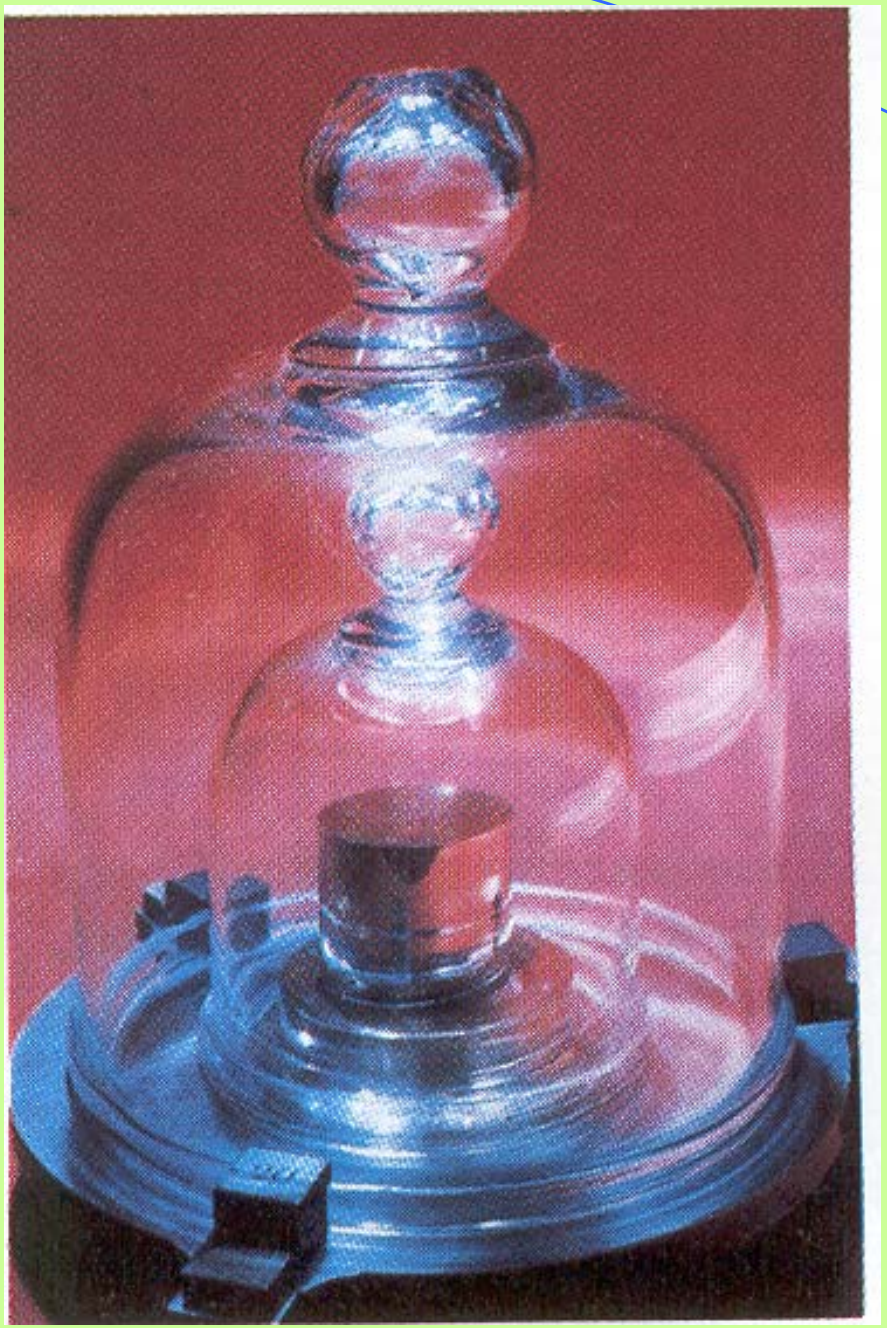
A particular
longitudinal line AB?



The standard meter

It is a bar of Platinum-Iridium kept at a constant temperature
The meter is defined as the distance between the two scratch marks

Redefined in 1983:
the distance traveled by light in vacuum during the Time of 1/299,792,458 sec



The kilogram (kg)

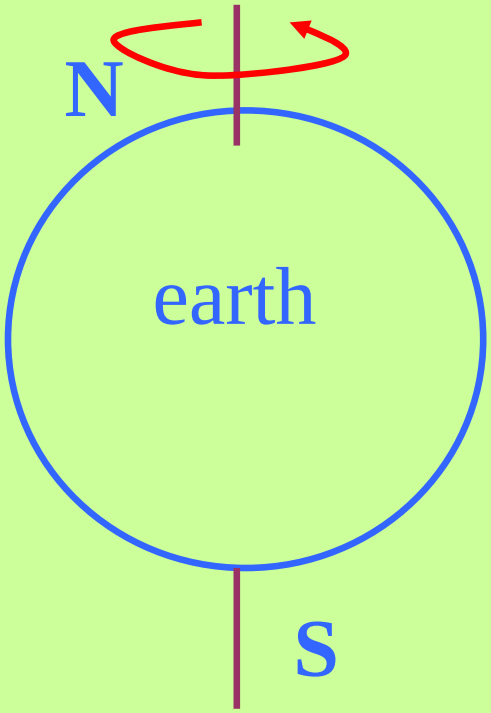
It is defined as the mass equal to the mass of a cylinder made of platinum-iridium made by the International Bureau of Weights and Measures. All other standards are made as copies of this cylinder

Established in 1887

Still going strong …

(1-9)

The second (s)



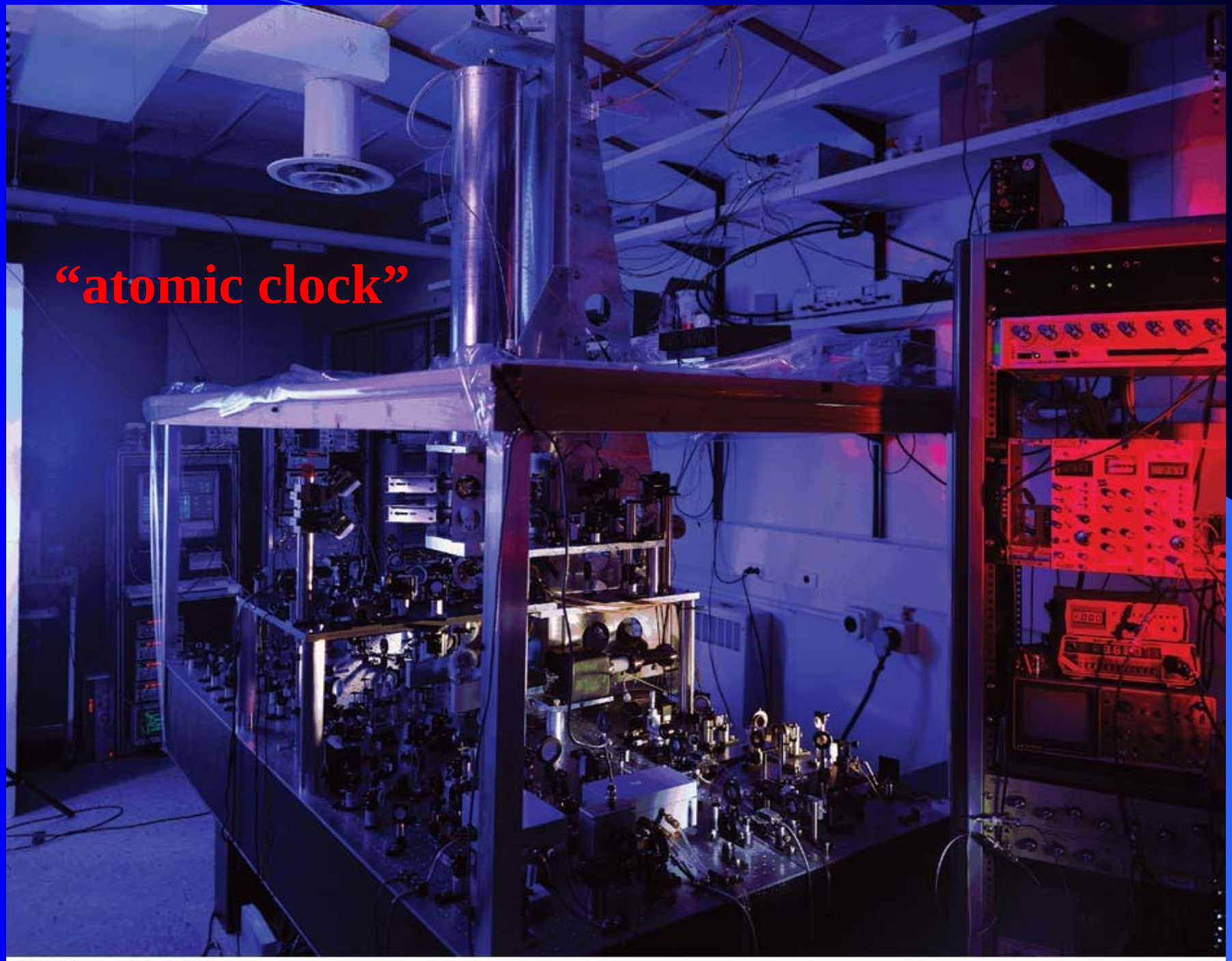
The second is defined as the duration of the mean solar day divided by 86400

The mean solar day is the average time it takes the earth to complete one revolution around its axis

Where does the 86400 come from?

Redefined in 1960:
now "atomic clock" in use

1 day = 24 hours
1 hour = 60 minutes
1 minute = 60 seconds
Thus: 1 day $24 \times 60 \times 60 = 86400$ s



Other units

- Such as millimeter (mm) and nanosecond (ns), where **prefix** denote multiplier of the basic units based on various powers of ten

$$1\,\text{mm} = 10^{-3}\,\text{m}$$

$$1\,\text{km} = 10^{3}\,\text{m}$$

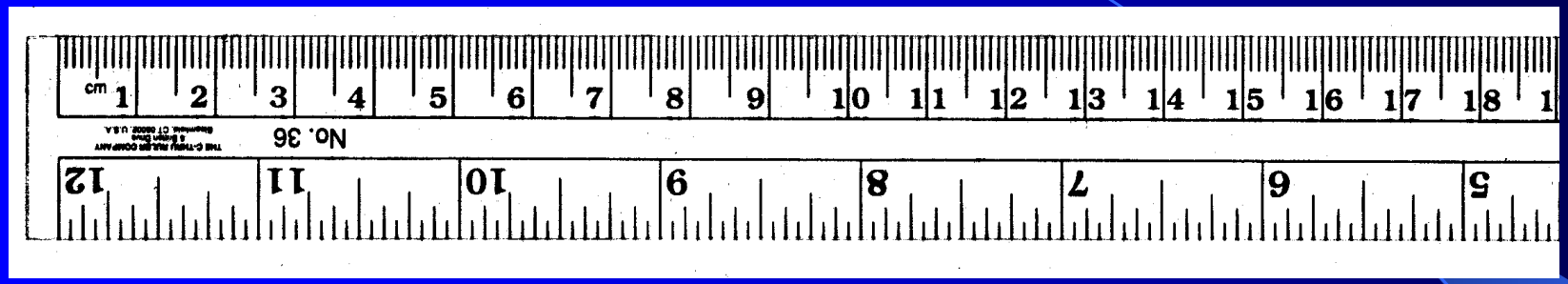
$$1\,\text{ns} = 10^{-9}\,\text{s}$$

Table 1.4

Prefixes for Powers of Ten

Power	Prefix	Abbreviation
10^{-24}	yocto	y
10^{-21}	zepto	z
10^{-18}	atto	a
10^{-15}	femto	f
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
10^{-2}	centi	c
10^{-1}	deci	d
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E
10^{21}	zetta	Z
10^{24}	yotta	Y

Conversion of units



millimeters

inches

1 m = 39.37 in = 3.281 ft

1 in = 0.0254 m = 2.54 cm

1 mi = 1609 m = 1.609 km

etc.

Dimensional Analysis

The dimensional analysis of a physical parameter such as velocity v, acceleration a , etc expresses the parameter as an algebraic combination of length [L], mass [M], and time [T]. This is because **all** measurements in mechanics can be ultimately be reduced to the measurement of length, mass , and time.

L, M, and T are known as **primary dimensions**

How do we derive the dimensions of a parameter? We use an equation that involves the particular parameter we are interested in. For example: $v = x/t$. In every equation

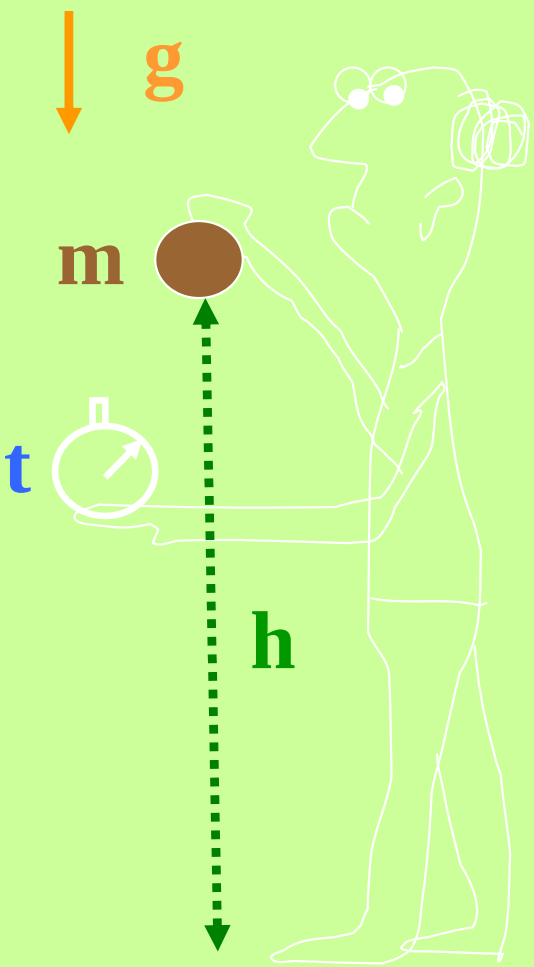
[Left Hand Side] = [Right Hand Side]

Thus: $[v] = L/T = L\,T^{-1}$

Note: The dimensions of a parameter such as velocity **does not** depend on the units. $[v] = L\,T^{-1}$ whether v is expressed in m/s, cm/s, or miles/hour

Dimensional analysis can be used to detect errors in equations

Example:



$h = gt^2/2$ $\quad$ [LHS] = [RHS]

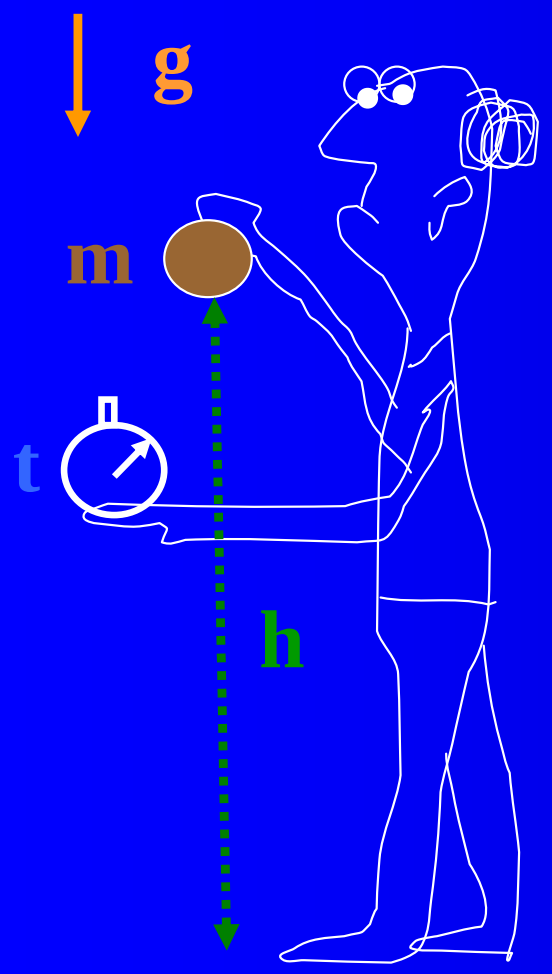
[LHS] = [h] = L

$[RHS] = [gt^2/2] = [g][t^2] = LT^{-2}\,T^2 = L$

Indeed [LHS] = [RHS] = L as might be expected from the equation $h = gt^2/2$ which we know to be true.

Note 1: If an equation is found to be dimensionally incorrect then it is incorrect

Note 2: If an equation is dimensionally correct it does not necessarily means that the equation is correct.



Example: Lets try the (incorrect) equation

$h = gt^2/3$ [LHS] = L

[RHS] = [g][t^2] = L

Even though [LHS] = [RHS] equation

$h = gt^2/3$ is wrong!

Dimensional Analysis, cont

- Cannot give numerical factors:
  this is its limitation
- Dimensions of some common quantities:

Table 1.6

Units of Area, Volume, Velocity, Speed, and Acceleration

System	Area (L^2)	Volume (L^3)	Speed (L/T)	Acceleration (L/T^2)
SI	m^2	m^3	m/s	m/s^2
U.S. customary	ft^2	ft^3	ft/s	ft/s^2

Estimates and Order-of-Magnitude Calculations

- Approximation based on a number of assumptions
  - May need to modify assumptions if more precise results are needed
- An *order of magnitude* of a certain quantity is the **power of 10** of the number that describes that quantity
- The symbol ~ for "is on the order of"

Estimates

N_A = # of particles in 1 mole = 6.022×10^{23}

Or 10^{24} ?

$N_A \sim 10^{23}$ Avogadro's number

Order-of-magnitude calculations

Breaths in a Lifetime?

Lifetime =70 y ~ 70 x 400 days x 25 h/day x 60 min/h ~

~ (70 x 60) x (400x 25) min ~ $(4 \times 10^3) \times 10^4 \sim 4 \times 10^7$ min

Breaths ~ 4×10^7 min x 10 breath/min ~ 4×10^8

Uncertainty in Measurements

- There are uncertainty in every measurement
- This uncertainty carries over through the calculations
  - need a technique to account for this uncertainty!
- We will use rules for *significant figures* to approximate the uncertainty in results of calculations

Significant figures

The measured values are known only to within the limits of experimental uncertainty

1 500 g ? possibility of misinterpretation

Use scientific notations to indicate # of significant figures!

1.5×10^3 g two significant figures

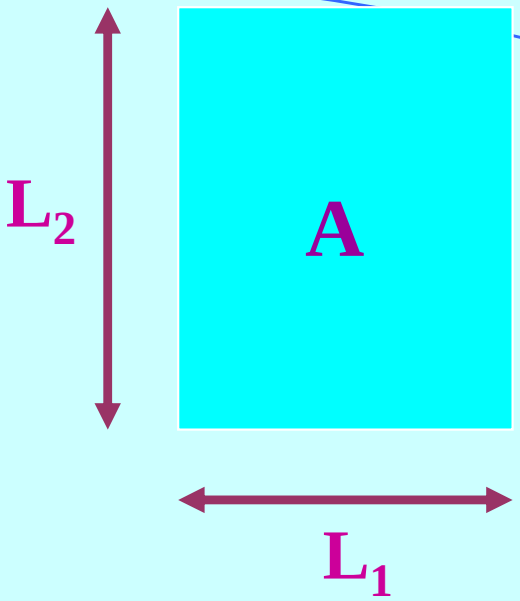
1.500×10^3 g four significant figures

Uncertainty in Measurement

There is no such thing as a perfectly accurate measurement. Each and every measurement has an uncertainty due to: **1.** the observer, **2.** the instrument, and **3.** the procedure used. How do we express the uncertainty in a measurement?

Assume that we are asked to measure the length L of an object with the ruler shown on the previous page The smallest division on this ruler is 1 mm. The uncertainty δL in L using that particular ruler is 1 mm. (If one is careful one can reduce it to 0.5 mm). If L is found to be 21.6 cm we write this as: **L = (21.6 ± 0.1) cm** This simply means that the real value is somewhere between 21.5 cm and 21.7 cm. We can give L using **three significant figures**

$$\text{Percentage Uncertainty} = \frac{\delta L}{L} \times 100 = \frac{0.1}{21.6} \times 100 = 0.5\%$$



We are given the same ruler and are asked to measure the width L_1 and height L_2 of the rectangle shown

$L_1 = (21.6 \pm 0.1)$ cm

$L_2 = (27.9 \pm 0.1)$ cm

Area $A = L_1 L_2 = 21.6 \times 27.9 \text{cm}^2 = 602.6 \text{ cm}^2$

The uncertainties δL_1 and δL_2 in the measurement of L_1 and L_2 will results in an error δA in the calculated value of the rectangle area A. This is known as **error propagation**.

Step 1: $\dfrac{\delta L_1}{L_1} = \dfrac{0.1}{21.6} = 0.005 \qquad \dfrac{\delta L_2}{L_2} = \dfrac{0.1}{27.9} = 0.004$

Step 2: $\dfrac{\delta A}{A} = \dfrac{\delta L_1}{L_1} + \dfrac{\delta L_2}{L_2} = 0.005 + 0.004 = 0.009$

$\delta A = 0.009 A = 0.009 \times 602.6 = 5 \text{ cm}^2 \qquad A = (603 \pm 5) \text{ cm}^2$

Significant Figures

- A significant figure is one that is *reliably* known
- All non-zero digits are significant
- Zeros are significant
  - when between other non-zero digits
  - after the decimal point and after another significant figure
  - can be clarified by using scientific notation

Quick Quiz

- How many significant figures are in each of the following numbers?

	Answer:
a) 1.234	4
b) 1.2340	5
c) 1.234×10^{-3}	4
d) 1.2340×10^{-3}	5
e) 1234	4 ?
f) 12340	4 or 5 ?
g) 0.012340	5 (or 6?)

Operations with Significant Figures: General Principle

- When combining measurements with different degrees of accuracy and precision:

  the accuracy of the final answer can be no greater than **the least accurate measurement**

150.0 g H_2O
+ 0.507 g salt

The cost of the copper in an old penny

Mass = 2.531 grams

The price of copper is 67 cents per pound

2.531 g x (1 lb/453.6 g) x (67 cents/lb)

Addition and Subtraction

150.0 g H_2O
+ 0.507 g salt

150.5 g solution

- **When measurements are added or subtracted, the answer can contain no more *decimal places* than the least accurate measurement**

http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch1/sigfigs.html#determ

Multiplication and Division

The cost of the copper in an old penny?
Mass of one penny = 2.531 grams, pure Cu
The price of copper is 67 cents per pound

2.531 g x (1 lb/453.6 g) x (67 cents/lb)
= **0.373847 cents**

Your calculator gives probably this value. Do you believe in this?

How many significant figures?

Only 2! Round off!

Physically correct answer: 0.37 cents

Operations with Significant Figures

- *multiplying* or *dividing*: the **number of significant figures** in the final answer is the same as the number of significant figures in the quantity having the lowest number of significant figures

- *adding* or *subtracting*: the number of **decimal places** should equal the smallest number of decimal places of any term in the sum