# PHYS 110 TECHNICAL PHYSICS STUDENT WORKBOOK

(3<sup>rd</sup> Edition July 2020)

Kevin Kimball, B.S.

**USN** – retired

**Professor - SMCC Physical Science Department** 



# ABOUT THIS WORKBOOK

This book is based on the formatted notebook model used by United States Navy class "A" technical schools. This format is a well proven and time-tested method of instruction; no fluff, no filler, and yet comprehensive and thorough.

As an example, this method allows a Navy student to complete a *fully transferrable undergraduate level three-credit course in Oceanography in two weeks!* 

Key points in this format:

- 1. It minimizes the potential for ambiguity and enables the student to more effectively identify key points in a given lecture
- 2. It enables the student to more effectively "compare notes" with classmates
- 3. Both student and instructor are literally "on the same page."
- 4. Student **ownership** of specific course information is clearly delineated
- 5. It WORKS!

# Topic/Lab 1: SCIENTIFIC NOTATION

Scientific Notation: Provides a means of managing and calculating

	and numbers
Based on an understanding of	
and the	*
Algebra:	Scientific Notation:
3 x <sup>2</sup>	3 x 10 <sup>2</sup>
The same rules pertaining to	,, and
in Scientific Notation a	also apply in algebra.
Coefficient:	*
Base:	
	Oog, the Cave Man
Exponent:	

Positive Exponents

Negative Exponents

## **Bottom line:**

A negative exponent means you're dealing with a \_\_\_\_\_\_ or a \_\_\_\_\_\_

"Zero" power: ( $x^0$ )

Any non-zero number to the "zero power" equals \_\_\_\_\_\_

Rationale:

First power:  $(x^1)$ 

Any number to the 1<sup>st</sup> power equals \_\_\_\_\_\_

Standard Notation:

Lab exercises:

3.8 <sup>°</sup> =	
$3.8 \times 10^{\circ} =$	
3.8 <sup>1</sup> =	
$3.8 \times 10^1 =$	
5 <sup>3</sup> = (standard notation)	
672 x 10 <sup>3</sup> = (standard notation)	
6 <sup>-2</sup> = (include both possible answers)	
In the expression "3.12 x 10 <sup>4</sup> " the "3.12 is called the	
9.36 <sup>-1</sup> =	
$x^5 \times x^7 =$	
$y^6 \div y^4 =$	
53 <sup>0</sup> =	
87 <sup>1</sup> =	
$2.38 \times 10^{0} =$	
Definition of an exponent:	
In the expression "8.75 x 10 <sup>7</sup> " the "10" is called the	
A negative exponent indicates you're dealing with a or a	
5 <sup>15</sup> x 5 <sup>-17</sup> = (include all possible answers)	

Converting numbers in standard notation to scientific notation         If the decimal point moves to the, the exponent goes         If the decimal point moves to the, the exponent goes         Converting numbers in Scientific Notation to Standard Notation         If the exponent moves, the decimal point moves         If the exponent moves, the decimal point moves		L	R
If the decimal point moves to the, the exponent goes         If the decimal point moves to the, the exponent goes         Converting numbers in Scientific Notation to Standard Notation         If the exponent moves, the decimal point moves	Converting numbers in standard	I notation to scientific	<u>c notation</u>
If the decimal point moves to the, the exponent goes         Converting numbers in Scientific Notation to Standard Notation         If the exponent moves, the decimal point moves	If the decimal point moves to the	e, tl	he exponent goes
Converting numbers in Scientific Notation to Standard Notation         If the exponent moves, the decimal point moves         If the exponent moves, the decimal point moves         "Cheater Rule" for Standard Notation:         Any number in standard notation can be expressed as times         General Rule for correct scientific notation:	If the decimal point moves to the	e, ti	he exponent goes
If the exponent moves, the decimal point moves	Converting numbers in Scientific	c Notation to Standard	d Notation
If the exponent moves, the decimal point moves         "Cheater Rule" for Standard Notation:         Any number in standard notation can be expressed as times         General Rule for correct scientific notation:	If the exponent moves	, the decim	al point moves
"Cheater Rule" for Standard Notation:   Any number in standard notation can be expressed as times   General Rule for correct scientific notation:	If the exponent moves	, the decim	al point moves
Any number in standard notation can be expressed as times General Rule for correct scientific notation:	"Cheater Rule" for Standard Not	tation:	
General Rule for <u>correct</u> scientific notation:	Any number in standard notation	n can be expressed as	times
	General Rule for <u>correct</u> scientif	ic notation:	
"Only one in theto the of the decimal"	"Only one in the	to the	of the decimal"

#### Very Important Exception:

It is often more convenient to ignore this rule during \_\_\_\_\_\_

(In other words, don't get hung up on this and create more problems than necessary)

Example 1:	Example 2:	Example3:
Convert 873.463 into correct	Convert 0.00785 into correct	Convert 56.98 x 10 <sup>5</sup> into correct
scientific notation	scientific notation	scientific notation

#### Convert to correct scientific notation:

186, 000	0.0045
5280	34.78 x 10 <sup>3</sup>
783.487 x 10 <sup>-8</sup>	2.85
0.000859 x 10 <sup>-9</sup>	0.0835 x 10 <sup>6</sup>
0.0000386 x 10 <sup>12</sup>	73.96
1/4	.937

#### Convert to standard notation:

$1.63 \times 10^{3}$	$3.637 \times 10^{-1}$
2.94 x 10 <sup>-6</sup>	36.345 x 10 <sup>2</sup>

### **Operations in Scientific Notation**

#### **Multiplication Critical Rules:**

Multiply \_\_\_\_\_

Retain \_\_\_\_\_

Add \_\_\_\_\_

NOTE: Adding a negative number is the same as \_\_\_\_\_\_ a \_\_\_\_\_

Example 1:

(4.75 x 10<sup>3</sup>) x (2.43 x 10<sup>7</sup>)

Example 2:

 $(3.72 \times 10^7) \times 1.67 \times 10^{-2})$ 

#### **Division Critical Rules:**

Divide \_\_\_\_\_

Retain \_\_\_\_\_

Subtract \_\_\_\_\_

NOTE: Subtracting a negative number is the same as \_\_\_\_\_ a \_\_\_\_\_

Example 1: (9.35 x  $10^8$ ) ÷ (3.54 x  $10^4$ )

Example 2:

 $(8.62 \times 10^{6}) \div (3.97 \times 10^{-3})$ 

#### Page 10

## Addition/Subtraction Critical Rules:

Exponents \_\_\_\_\_

Add/Subtract \_\_\_\_\_

Retain \_\_\_\_\_

Retain \_\_\_\_\_

Example 1:

 $(6.72 \times 10^3) + (2.97 \times 10^3)$ 

Example 2 :

(9.56 x 10<sup>5</sup>) - (8.47 x 10<sup>4</sup>)

#### Page 11

#### **Squaring and Cubing numbers in Scientific Notation - Critical Rules**

Square / Cube \_\_\_\_\_

Retain \_\_\_\_\_

Multiply \_\_\_\_\_\_ by \_\_\_\_\_ or \_\_\_\_\_

**RECALL:** 

Multiplying unlike signs results in a \_\_\_\_\_

Multiplying like signs results in a \_\_\_\_\_

Example 1:	Example 2:
2. 3.2	Example 2.
(2.56 x 10 <sup>°</sup> ) <sup>-</sup>	(2.56 x 10°)
Example 3:	Example 4:
Example 3: $(3.12 \times 10^{-6})^2$	Example 4: $(3.12 \times 10^{-6})^{3}$
Example 3: $(3.12 \times 10^{-6})^2$	Example 4: $(3.12 \times 10^{-6})^3$
Example 3: $(3.12 \times 10^{-6})^2$	Example 4: $(3.12 \times 10^{-6})^3$
Example 3: (3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: $(3.12 \times 10^{-6})^3$
Example 3: (3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: $(3.12 \times 10^{-6})^3$
Example 3: (3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: $(3.12 \times 10^{-6})^3$
Example 3: (3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: $(3.12 \times 10^{-6})^3$
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: $(3.12 \times 10^{-6})^3$
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: (3.12 × 10 <sup>-6</sup> ) <sup>3</sup>
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: (3.12 × 10 <sup>-6</sup> ) <sup>3</sup>
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: (3.12 x 10 <sup>-6</sup> ) <sup>3</sup>
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: (3.12 x 10 <sup>-6</sup> ) <sup>3</sup>
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: (3.12 x 10 <sup>-6</sup> ) <sup>3</sup>
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: $(3.12 \times 10^{-6})^3$
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: (3.12 x 10 <sup>-6</sup> ) <sup>3</sup>
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: (3.12 x 10 <sup>-6</sup> ) <sup>3</sup>
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: (3.12 × 10 <sup>-6</sup> ) <sup>3</sup>
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: (3.12 × 10 <sup>-6</sup> ) <sup>3</sup>
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: (3.12 × 10 <sup>-6</sup> ) <sup>3</sup>
(3.12 x 10 <sup>-6</sup> ) <sup>2</sup>	Example 4: (3.12 × 10 <sup>-6</sup> ) <sup>3</sup>

#### Page 12

Square Roots/Cube Roots in Scien	tific Notation - Critical Rules
Exponent must be divisible by	or
Square/Cube root	
Retain	
Divide	by or
RECALL:	
Dividing unlike signs results in a	
Dividing like signs results in a	
Example 1: $\sqrt{0.46 \times 106}$	Example 2: $\sqrt[3]{0.46}$
v 9.46 x 10 <sup>5</sup>	√9.46 x 10°
Example 3:	Example 4:
$\sqrt{8.1 \mathrm{ x} \mathrm{ 10^5}}$	$\sqrt[3]{8.1 \text{ x } 10^5}$

$(3.93 \times 10^7) \times (5.37 \times 10^6)$	Answer:
$(2.02 \times 10^3) \times (2.48 \times 10^{-5})$	Appwor
(3.92 X 10 ) X (3.48 X 10 )	Answer.
$(8.14 \times 10^7) \div (4.05 \times 10^9)$	Answer:
$(8.16 \times 10^{-5}) \div (4.89 \times 10^{6})$	Answer:

$(3.93 \times 10^7) \times (5.37 \times 10^6)$	
$3.93 \times 10^{7}$ $5.37 \times 10^{6}$ $21.104 \times 10^{13}$ $= 2.1104 \times 10^{14}$	2.1104 x 10 <sup>14</sup>
(3.92 x 10 <sup>3</sup> ) x (3.48 x 10 <sup>-5</sup> )	
$3.92 \times 10^{3}$ $3.48 \times 10^{-5}$ $13.642 \times 10^{-2}$	1.364 x 10 <sup>-1</sup>
= 1.364 x 10 <sup>-1</sup>	
$(8.14 \times 10^7) \div (4.05 \times 10^9)$	
$\frac{8.14 \times 10^{7}}{4.05 \times 10^{9}}$	2.0098 x 10 <sup>-2</sup>
$= 2.0098 \times 10^{-2}$	
$(8.16 \times 10^{-5}) \div (4.89 \times 10^{6})$	
$\frac{8.16 \times 10^{-5}}{4.89 \times 10^{6}}$ = 1.669 × 10 <sup>-11</sup>	1.669 x 10 <sup>-11</sup>

$\sqrt{2.36 \times 10^7}$	
$(2.64 \times 107) (1.27 \times 107)$	
$(2.04 \times 10^{7})(1.37 \times 10^{7})$	
$(3.93 \times 10^7)^2$	
$(5.37 \times 10^6)^3$	
$\sqrt{8.26 \times 10^8}$	
$\sqrt[3]{5.06} \times 10^{16}$	

$\sqrt{2.36 \times 10^7}$	
Change to : $\sqrt{23.6~ imes~10^6}$ (exponent divisible by 2)	4.858 x 10³
$= 4.858 \times 10^3$	
$(2.64 \times 10^7) - (1.37 \times 10^7)$	
2.64 x 10 <sup>7</sup>	1.27 x 10 <sup>7</sup>
$-1.37 \times 10^{7}$	
1.27 x 10 <sup>7</sup>	
$(3.93 \times 10^7)^2$	
$= 15.445 \times 10^{14}$	$1.5445 \times 10^{15}$
$= 1.5445 \times 10^{15}$	
$(5.37 \times 10^6)^3$	
$= 154.854 \times 10^{18}$	1.5485 x 10 <sup>20</sup>
= 1.54854 x 10 <sup>20</sup>	
$\sqrt{8.26 \times 10^8}$	
2.874 x 10⁴	2.874 x 10 <sup>4</sup>
$\sqrt[3]{5.06 \times 10^{16}}$	
change to: $\sqrt[3]{50.6} imes 10^{15}}$ (exponent divisible by 3)	3.699 x 10⁵
2 600 - 105	
$= 3.099 \times 10^{\circ}$	

## Metric System

# Major advantage of the metric system:

It can be applied directly to			
Uses a system of and			
Units relate to specific	("whatcl	na got")	
Prefixes are specific	("ho	w many you go	t")
Prefixes are mathematically	w	ith	of
Examples of units:	Example	es of prefixes:	
UNIT: MEASUREMENT OF:	PREFIX:	EQUIVALENT	-
Meter	Centi		or
Liter	Milli		or
Gram	Kilo		or
Hence:			
8.5 centimeters = 8.5 x n	neters		
500 milliliters = 500 x liters			
6.75 kilograms = 6.75 x grams			
BOTTOM LINE:			
Any prefix can be replaced or subs	itituted with a	of _	

# COMMONLY USED METRIC PREFIXES: (Required knowledge!)

Pre	efix:	/ Standard notation:	/ Fraction:	/ Power of ten:
	giga			
	mega			
	kilo			
	centi			
	milli			
	micro			

self check:

centi = (standard notation)	
kilo = (power of ten)	
10 <sup>9</sup> = (prefix)	
10 <sup>-3</sup> = (standard notation)	
0.01 = (prefix)	
giga = (power of ten)	
1000 = (power of ten)	
10 <sup>6</sup> = standard notation)	
milli = (power of ten)	
micro = (standard notation)	
10 <sup>-2</sup> = (prefix)	
0.001 = (power of ten)	
$10^3 = (\text{prefix})$	
mega = (standard notation)	
milli = (standard notation)	
1,000,000 = (power of ten)	
0.000001 = (power of ten)	
kilo = standard notation	
10 <sup>6</sup> = (prefix)	
1,000,000,000 = (power of ten)	

## Informal Lab Exercise:

	Scientific Notation	Standard Notation
8.97 Kilograms =grams		
6.5 centimeters =meters		
7.5 gigavolts =volts		
4.7 microFarads = Farads		
6,7 megawatts = watts		
9.87 milliliters liters		

Quantity	Equivalent quantity with prefix
5483 grams	
0.0200 m store	
0.0268 meters	
9,700,000,000 volts	
0.0000056 Farads	
0.0045 liters	
4,300,000 watts	

## Conversion hack:

# Convert 3.567 x $10^5$ gigavolts to millivolts

5.98 x 10 <sup>4</sup> kilograms = _?_ grams	
8.34 x 10 <sup>-1</sup> meters = _?_ centimeters	
5.92 x 10 <sup>-4</sup> megawatts = _?_ watts	

#### (Answer in <u>standard</u> notation:)

500 millivolts = _?_ volts	
345 grams = _?_ kilograms	
6.73 x 10 <sup>5</sup> centimeters = _?_ meters	
3.81 x 10 <sup>-4</sup> volts = _?_ microvolts	

#### (Answer in <u>correct</u> scientific notation:)

$3.45 \times 10^5$ microvolts = _?_ kilovolts	
7.93 x 10 <sup>-5</sup> kilograms = _?_ milligrams	
5.78 x 10 <sup>3</sup> millimeters = _?_ centimeters	
4.32 x 10 <sup>3</sup> gigahertz = _?_ megahertz	

Displacement:	
Definitior	ı(s):
	1and
	2 and
Symbol: _	
Standard	units:
	1. British ("U.S Standard"):
	2. Metric:
NOTE: In this co Force:	ntext "displacement" does NOT refer to
Definitior	n(s):
	1 or a
	2. That which may
Symbol: _	(Weight is a measure of)
Standard	units:
	1. British ("English"):
	2. Metric:
NOTE:	
Since a	is a unit of force, then it is NOT a measure of

# Mass:

Definition(s	):
	1
	2*
	3
* "	" : resistance to a in
Standard ur	iits:
	1. British: ( <u>not</u> )
	2. Metric:/ ( <u>not</u> )
Volume:	
Definition:	
	1
Standard ur	iits:
	1. British: ( )
* NOTE: "	2. Metric: ()* " are also frequently used to measure volume in metric terms,
but are no longer	considered as "standard units."
<u>Time:</u>	
Definition:	
1. "That wh	nich we
Standard u	nit: (both British and metric)
	1 ( NOT or )

a measure of inertia	
that which we measure with a clock	
distance and direction	
standard metric unit of force	
standard British unit of displacement	
a quantity of space	
standard metric unit of mass	
a push or a pull	
length and direction	
standard British unit of force	
standard metric unit of volume	
that which may affect motion	
weight is a measure of _?_	
resistance to a change in motion	
standard British unit of volume	
standard British unit of mass	
standard unit of time	
standard metric unit of displacement	
a quantity of material	
stuff	

#### CONVERSIONS

Based on the principles used in \_\_\_\_\_\_, and

exploit the rules used in "\_\_\_\_\_\_ - \_\_\_\_\_"

Example 1:

 $\frac{3}{4} \times \frac{1}{3} =$ 

Example 2:

 $\frac{a}{c} \times \frac{b}{a} =$ 

Example 3:

$$\frac{\circ}{\Box} \times \frac{\diamond}{\circ} =$$

Rationale:

## Applying method of multiplying fractions as a means of converting units (The "factor-labeling" method)

Example 1:

To convert <u>35 miles per hour</u> to <u>"x" feet per second</u> :

Step 1: Restate 35 MPH in fraction form:

35 miles

1 hour

Step 2: Set up multiplication problem in fraction form so that the terms you

\_\_\_\_\_

wish to change will be \_\_\_\_\_\_ - \_\_\_\_\_  $\frac{35 mi}{1 hour} \times \frac{hour}{mi} \times \frac{hour}{mi}$ 

Step 3: Replace terms with those you want:

 $\frac{35 \text{ mi}}{1 \text{ hour}} \times \frac{\text{feet}}{\text{mi}} \times \frac{\text{hour}}{\text{seconds}}$ 

Step 4: Inert correct mathematical equivalences:

$$\frac{35 \, mi}{1 \, hour} \, \mathrm{X} \, \frac{5.28 \, \mathrm{x} \, 10^3 \, feet}{1 \, mi} \, \mathrm{X} \, \frac{1 \, hour}{3.6 \, \mathrm{x} \, 10^3 sec}$$

\_\_\_\_\_

Step 5: Cross-cancel terms:

35 miles	$\frac{5.28  \mathrm{x}  10^3}{10^3} feet}{10^3}$	1 <u>hour</u>
1 <del>hour</del>	1 <del>mile</del>	$\frac{10^3}{3.6 \times 10^3}$ sec

Step 6: Restate with remaining terms:

35 x 5.28 feet 3.6 sec

\_\_\_\_\_

Step 7: Perform normal calculations one operation at a time until you reach an answer in the desired terms\*

\_\_\_\_\_

 $\frac{35 \times 5.28 \text{ feet}}{3.6 \text{ sec}} = \frac{184.8 \text{ feet}}{3.6 \text{ secs}} =$ 

\* ft/sec (final answer)

1 mile = 5.28 x 10 <sup>3</sup> ft       1 mile = 1.61 x 10 <sup>3</sup> meters       1 kilometer = 10 <sup>3</sup> meters       1 hour = 3.6 x 10 <sup>3</sup> seconds         Self -check: conversions       Answers:         Convert 400 MPH to ft/sec       Image: Second s
Self -check: conversions     Answers:       Convert 400 MPH to ft/sec
Convert 400 MPH to ft/sec
Convert 400 MPH to ft/sec
Convert 80 meters/sec to miles/hour
Convert 220 ft/sec to MPH
Convert 88 kilometers/hr to meters/sec

Field - shorthand method for algebraic equations (Navy "egg")





Ζ



"People, listen up! There is the Right Way, there is the Wrong Way, and then there is the Navy Way, **and you** <u>better</u> start learning the Navy Way!"

-Boatswain's Mate Second Class Donald Barger, USN, Navy Boot Camp Company Commander



Example 4:

Given: 
$$\frac{ab}{cde} = fg$$
 Solve for "d"  
Traditional solution:

Using the "egg"

$$\frac{ab}{cde} = fg, \text{ Solve for "d"}$$



Equation:	"Egg"	Solution ( "n" = ?)
F = ma		m =
$P = \frac{W}{T}$		T =
$2as = (V_f^2 - V_i^2)$		a =
$KE = \frac{1}{2}mv^{2}$ (Hint: $\frac{1}{2} = .5$ )		m =
$D = R \times T$		T =
PE = mgh		h =
$A = (\cos \theta)(H)$		H =
$a = \frac{V_f - V_i}{t}$		<i>t</i> =

Structure of atom - a key to understanding "mass"

Example 1:

Hydrogen:




Atom Model History
Democritus - Fifth century B.C.
1 . All matter is composed of
2. "Atom" : Greek for ""
John Dalton - 1803
1. Atom is a
(AKA the " model")
2. Each element was composed of
3. Different elements composed of
4. Compounds are composed of atoms in
5. Chemical reactions are of,
And mass is therefore
Joseph John Thompson - 1897
1. "Plum":
a. A sphere of diffuse electricity with
negative imbedded throughout
2. Discovered, and was awarded in 1906

The " Solar System" Model			Page 34
Ernest Rutherford - 1911		RA	
1. Discovered that the a	itom is mostly		with a
dense	charged	su	rrounded by
negative			Section to
Neils Bohr - 1913			8-5-
1. Electrons travel in			
2. Only		allowed	
3. Modern	_of the		"Everything we call real is made of things
Electron Cloud Model - 1920's	5		that cannot be regarded as real. "
1. Erwin Schrodinger <sup>1</sup>	and Werner Heisen	burg <sup>2</sup>	~Niels Bohr
Developed	functions to	determine re	egions or clouds in
which	_ are most likely to	be found	
2. Heisenberg: Develop	ed the	Princi	ple : Impossible to
predict	_ of single electron		
James Chadwick - 1932	Y		

1. British experimental physicist credited with discovering the \_\_\_\_\_

Particle	Approx. Radius
	10 <sup>-9</sup> meters
	10 <sup>-10</sup> meters
	10 <sup>-15</sup> - 10 <sup>-14</sup> meters
	10 <sup>-15</sup> meters
	10 <sup>-18</sup> meters

Particles and average radii:



# More History: How We Got Here

The 3-legged stool of understanding is held up by history, languages, and mathematics. Equipped with these three you can learn anything you want to learn. But if you lack any one of them you are just another ignorant peasant with dung on your boots.

- Robert A. Heinlein, author, engineer, U.S. Naval Academy graduate, curmudgeon.

# Aristotle 1.\_\_\_\_\_ 2. \_\_\_\_\_ 3. \_\_\_\_\_ 4.\_\_\_\_\_ **Pythagoras** ☆ ☆ ☆ ☆ ☆ Jupiter Mai Mercury Venus Sun ☆ ☆

Saturn Earth at the Center ☆

☆







Epicycles

Ptolemy

Deferents

**Crystal Spheres** 









"Until I see evidence to the contrary, I will continue to believe that *I* am the center of the universe."

### Galileo



TO THE CHURCH

### Sir Isaac Newton:

L. Wrote	
. Discovered	
. Established the link	
. Sought to	
. Emphasized A , , ,	results@
. Invented	
7. Derived planetary motions	





"Physicists are conservative revolutionaries. They do not give up tried and tested principles until experimental evidence - or an appeal to logical and conceptual simplicity - forces them into a new and sometimes revolutionary viewpoint. Such conservatism is at the core of the critical structure of inquiry. Pseudoscientists lack that commitment to existing principles, preferring instead to introduce all sorts of ideas from the outside."
Dr. Heinz R. Pagels, "The Cosmic Code"
If it walks like duck, swims like duck, quacks like duck . . . it's probably not an elephant."
Chief Petty Officer Ralph Caraway, Master Instructor, USN-retired, explaining the overarching theory of acoustic intelligence analysis.
You can observe a lot just by watching."

The Scientific Method is a remarkably adaptable tool that allows us "mere mortals" to pursue the most profound truths. Its strength lies in both its beautifully articulated process and its flexibility.

We keep the Scientific Method around because it works, and most importantly, it has **never failed**. Not even once. Its self-correcting nature prohibits failure.

Now that's a pretty bold if not outrageous statement, so let's bring the topic into sharper focus by stipulating a distinction between the "Scientific Method" and "Science" itself:

While the Scientific Method does not fail, Science often does. It happens all the time, and is a normal, entirely expected part of the business. The Scientific Method gives us the means to (1) recognize and deal with these failures and (2) establish the credibility of successes through a rigorous, clearly defined vetting process.

In short, the Scientific Method is how we police the business of Science.

Though frequently viewed as an esoteric, intellectual protocol, it also has very practical, down-to-earth applications. One beautiful example of this (I believe) is the grand experiment of American Democracy. People a lot smarter and more credentialed than me have long argued that it's no coincidence that the architects of the American government were also products of the Galilean/Newtonian revolution of scientific rationale (think Thomas Jefferson and Benjamin Franklin, both well-established scientists, inventors, and philosophers in their own right). Look closely, and you will see a remarkable similarity between the Scientific Method and our constitutional system of informed candid debate, peer review, accountability and a formal regimen of "checks and balances."

Both protocols are ultimately beholden to unvarnished reality, and survive the most rigorous challenges to their very existence because they are specifically engineered as fluid, adaptive processes of deliberative, critical analysis and self-correction.

"Galileo was one of the first people to practice what we recognize today as the scientific process (or "method"): the dynamic interplay between experience (in the form of experiments and observations)

and thought (in the form of creatively constructed theories and hypotheses). This notion that scientists

learn not from authority or from inherited beliefs but rather from experience and rational thought is what makes Galileo's work, and science itself, so powerful and enduring.

"Galileo's methods have been crucial to science ever since. They included:

- Experiments, designed to test specific hypotheses
- Idealizations of real-world conditions, to eliminate (at least in ones's mind) any side
   effects that might obscure the main effects
- Limiting the scope of inquiry by considering only one question at a time. For example,
- Galileo separated horizontal from vertical motion, studying only one of them at a time.
- · *Quantitative methods*. Galileo went to great lengths to measure the motion of bodies.
- · He understood that a theory capable of making quantitative predictions was more
- powerful than one that could make only descriptive predictions, because quantitative predictions were more specific and could be experimentally tested in greater detail

"Observation refers to the data gathering process. A measurement is a quantitative observation, and an **experiment** is an observation that is designed and controlled by humans, perhaps in a laboratory.

" A scientific **theory** is a well- confirmed framework of ideas that explain what we observe. A **model** is a theory that can be visualized, and a **principle** or **law** is one idea within a more general theory. The word *law* can be misleading because it sounds so certain. As we will see, scientific ideas are never absolutely certain.

"Note that a theory is a well-confirmed framework of ideas. It's a misconception to think that a scientific theory is mere guesswork, as nonscientists occasionally do when they refer to some idea as 'only a theory'. Some people who disliked Copernican theory [heliocentric system] argued that it was a 'mere theory' that need not be taken seriously. Today, people who dislike the theory of biological evolution attack it on similar grounds. Theories - well-confirmed explanations of what we observe – are what science is all about and are as certain as any idea can be in science.

"The correct word for a reasonable but unconfirmed scientific suggestion (or guess) is **hypothesis**. For example, Kepler's first unconfirmed suggestion that the planets might move in elliptical orbits was a hypothesis. Once the data of Brahe and others confirmed Kepler's suggestion, elliptical orbits took on the status of theory rather than mere hypothesis."

- Dr. Art Hobson, "Physics -concepts and connections"

# **Scientific Method Flow Chart**



### **IMPORTANT:**

"Communication": Common to \_\_\_\_\_\_ of the Scientific Method

# Key Points in the lingo and protocol of science and the Scientific Method

1. Theory:
2. Hypothesis:
3. Idealizations (Galileo):
4. Limiting the Scope of Inquiry (Galileo):
5. Quantitative methods (Galileo):
6. Creating a model:
7. Repeatable, predictable results/outcomes (Newton):
8. Fact-based rather than authority-based knowledge:

Volume:





### **Mass Density Calculations**

Mass Density (D<sub>m</sub>) (also referred to simply as "density")

is measured in \_\_\_\_\_\_ per \_\_\_\_\_ or \_\_\_\_/\_\_\_\_

Example 1:

Determine the  $D_m$  of a 67.5 gram sample of material with a volume of 30 cm<sup>3</sup>

Solution:

Use factor-labeling to convert grams/cm<sup>3</sup> to Kilograms/M<sup>3</sup>

1. Restate the raw data as fraction:

 $\frac{67.5 \ grams}{30 \ cm^3}$ 

2. Add conversion factors for cancellation:

$$\frac{67.5 \text{ grams}}{30 \text{ cm}^3} \times \frac{1 \text{ Kg}}{10^3 \text{ grams}} \times \frac{10^6 \text{ 10}^3 \text{ cm}^3}{1m^3}$$

3. Restate with remaining terms and perform necessary calculations:

$$\frac{67.5 \ x \ 10^3 Kg}{30 \ m^3} = \underline{Kg/m^3}$$

NOTE:

Determining the  $D_m$  of a material can serve as an indicator of the chemical identity of the material.

# Example 2:

# Predicting the mass of a sample of known material

Given a  $50 \text{ cm}^3$  sample of lead, predict the mass Solution: Set up a proportionality equation using the known D<sub>m</sub> of lead

Step 1:

State the known  $\mathsf{D}_\mathsf{m}$  of lead

$$\frac{11.3 \times 10^3 Kg}{m^3}$$

Step 2:

Set up as equivalent to given sample

$$\frac{11.3 \times 10^3 Kg}{m^3} = \frac{x g}{50 \ cm^3}$$

Step 3:

Convert all quantities to like terms (grams, cm<sup>3</sup>, since this is a small sample)

$\frac{11.3 \times 10^6 g}{10^6 cm^3} = \frac{x g}{50 cm^3}$	Review: Cross-multiplying		
Step 4: Cross-multiply $\frac{11.3 \times 10^{6} g}{10^{6} cm^{3}} = 50 cm^{3}$	$\frac{a}{b} = \frac{c}{d}$ $a \times d = b \times c$	$\frac{2}{3} = \frac{12}{18}$ $\bigcirc$ 2 x 18 = 3 x 12	

Now the equation becomes:

\_\_\_\_\_\_x \_\_\_\_\_ = \_\_\_\_\_\_x \_\_\_\_\_

After canceling like terms, the equation becomes

\_\_\_\_\_x \_\_\_\_ = \_\_\_\_

Thus, a 50 cm<sup>3</sup> sample of lead has a mass of \_\_\_\_\_ grams

# Neutron Stars: The ultimate in mass density:

If a star has sufficient mass (that is to say, 8 to 20 times more than our own Sun)

when it goes \_\_\_\_\_\_\_, the atoms of the remaining material in the core are ripped apart by the extreme \_\_\_\_\_\_ and the extreme \_\_\_\_\_\_\_. During this process electrons combine with protons to form \_\_\_\_\_\_\_. Since the volume of a normal atom is over \_\_\_\_\_\_ empty space, this once-empty volume is now filled with neutrons. The result is a material so dense that a teaspoon of this substance can weigh \_\_\_\_\_\_, or the same as \_\_\_\_\_\_\_ aircraft carriers.



Determine the D <sub>m</sub> of a 273 gram sample of material with a volume of 35 mL	answer:
Determine the mass of a 95 cm <sup>3</sup> sample of iron	answer:
Determine the mass of a 95 cm <sup>3</sup> sample of iron	answer:
Determine the mass of a 95 cm <sup>3</sup> sample of iron	answer:
Determine the mass of a 95 cm <sup>3</sup> sample of iron	answer:
Determine the mass of a 95 cm <sup>3</sup> sample of iron	answer:
Determine the mass of a 95 cm <sup>3</sup> sample of iron	answer:
Determine the mass of a 95 cm <sup>3</sup> sample of iron	answer:
Determine the mass of a 95 cm <sup>3</sup> sample of iron	answer:
Determine the mass of a 95 cm <sup>3</sup> sample of iron	answer:
Determine the mass of a 95 cm <sup>3</sup> sample of iron	answer:
Determine the mass of a 95 cm <sup>3</sup> sample of iron	answer:

# Vectors:

Two types of measurement used in Physics; they are

		_measures		1
	only		b. Indicate _	
		_ measures		2
	 and		a. Indicate	
				Examples:
	Vector		Scalar	
en that	 ponent of	clude the con	r measures in	Since vecto
e	and Vector	clude the con	a. Indicate	Examples:

component must be taken into consideration during \_\_\_\_\_\_.

Example 1: Two bungee cords pulling in opposite directions:

Example 1a:	
Example 1b:	• Net force:
Example 2: Two bunge	Net force: ee cords pulling in the same direction:
●	Net force:
Note: At this point you shoul	ld see the of net forces, or
the "	_ "

# Example 3: Two bungee cords pulling at a 90° angle relative to one another

Solution: Use "\_\_\_\_\_\_to \_\_\_\_\_" schematic The sum of these two vectors is called a "\_\_\_\_\_ " BUT, The Pythagorean Theorem will solve \_\_\_\_\_\_ only What about direction?



### **Basic Right-Angle Trigonometry**

(Invented by \_\_\_\_\_\_)

Given: a 30-60-90 triangle



One of the unique characteristics of a 30-60-90 triangle is that

the side \_\_\_\_\_ the 30° angle

is always \_\_\_\_\_\_ - \_\_\_\_\_ the length of the \_\_\_\_\_\_.

In other words, given the \_\_\_\_\_ angle,

the \_\_\_\_\_\_ of the \_\_\_\_\_\_ side over the \_\_\_\_\_\_

will always be \_\_\_\_\_\_, or \_\_\_\_\_,

In Right-Angle Trigonometry, this ratio is called

the \_\_\_\_\_ of the \_\_\_\_\_

Thus, we can state that the "\_\_\_\_\_ of 30° is \_\_\_\_\_"

# Trig on a calculator:

Depending on what model calculator you are using, you will do trig functions in one of two ways. We will use the **Sine (sin) of 30<sup>0</sup>** as an example.

# Method 1:



11.Repeat steps 1 -3, your answer should now be "0.5"

Method 2 (more common on simpler, less expensive calculators):

- 1. Enter "30"
- 2. Hit sin
- 3. Your answer should be "0.5"

Practice using other trig functions: Cosine  $30^0 = .866$ Tangent  $30^0 = .577$ 

H O O A
θ ("Theta"):
Hypotenuse:
Opposite:
Adjacent:
<b>Sine θ</b> (sin $\theta$ ):
the ratio of the side over the
<b>Cosine</b> $\boldsymbol{\theta}$ (cos $\boldsymbol{\theta}$ ):
the ratio of the side over the
Tangent θ (tan θ)
the ratio of the side over the side

Page 55

Stated more simply:

 $\sin \theta = \frac{O}{H}$  $\cos \theta = \frac{A}{H}$  $\tan \theta = \frac{O}{A}$ 

Stated yet another way:



Using Trig Example 1.



Determine the lengths of sides "O" and "A"

To determine "O" use "Sin", which uses the known angle and the known hypotenuse (H)



2. To determine "A" use "Cos", which uses the known angle and the known hypotenuse (H)



Example 2.



Determine the lengths of sides "H" and "O"

To determine "H" use "Cos", which uses the known angle and the known adjacent (A)



To determine "O" use "Tan", which uses the known angle and the known adjacent (A)



Example 3:



Determine length of "H" and the value of " $\theta$  "

1. Begin by determining " $\theta$ ". Since "O" and "A" are known, use "Tan".



2. Determine "H" by using either **Sine** or **Cosine** 

$$H = \frac{O}{\sin \theta}$$

$$H = \frac{A}{\cos \theta}$$

Using the **"reciprocal function"** on the calculator

Since we know that the **Sine of 30<sup>0</sup> is 0.5**, we'll start there.

# Method 1:

- 1. Hit "Shift" or " 2<sup>nd</sup> "
- 2. Hit sin
- 3. Enter " .5 "
- 4. Hit " = "
- 5. Your answer should be "30"

Method 2 (for simpler, less expensive calculators):

- 1. Enter " **.5** "
- 2. Hit "Shift" or " 2<sup>nd</sup> "
- 3. Hit sin
- 4. Your answer should be "30"

Practice using other trig functions:  $\cos^{-1} .866 \rightarrow 30^{0}$  $\tan^{-1} .577 \rightarrow 30^{0}$ 

# Informal Lab: Practice problems

**ASSIGNMENT**: Solve for unknown sides and angles using trigonometry

- plus additional instructions below:
- 1. Do NOT Pythagorean Theorem!
- DRAW these in larger scale on a separate paper use a straight-edge if it helps. The idea is to get you used to drawing, *as Galileo recommends!*



Practical principles:





Informal Lab: Practice evaluating angles Hint: **Always** measure from the <u>closest horizontal</u> ("x - axis")



### Back to the beginning of this topic:

Given:

- 1. Two bungee cords attached at a common point.
- 2. Bungee "a" pulls with 5 pounds of force at  $0^{\circ}$
- 3. Bungee "b" pulls with 3.5 pounds of force at  $90^{\circ}$
- 4. What is the sum of the forces of the two bungee cords?

Solution:

Draw \*: Bungee "b" 3.5 lbs, 90° Bungee "a", 5 lbs,  $0^{\circ*}$ to schematic representation \* NOTE: <u>Always</u> draw \_\_\_\_\_\_ vector <u>first</u> beginning with the \_\_\_\_\_ 1. Calculate the tangent of the unknown angle "\_\_\_\_\_" : tan = ----- = \_\_\_\_\_ 2. tan<sup>-1</sup> \_\_\_\_\_→\_\_\_\_ 3. Calculate the hypotenuse ( or "\_\_\_\_\_ ") Using trig, we know that H =  $\frac{O}{\sin \theta}$  and/or  $\frac{A}{\cos \theta}$ Selecting the first trig formula, \_\_\_\_\_ = (solution) H = ------Thus, the sum ( \_\_\_\_\_\_ ) of the forces of the two bungee cords is \_\_\_\_\_ at \_\_\_\_ degrees

### **Adding Vectors:**



Determine the sum of  $V_1 + V_2$ 

Solution:

- 0 Draw each vector individually, and label accordingly
- <sup>②</sup> Add component vectors and label accordingly
- ③ Use trig to solve for components
- ④ Add components
- ⑤ Construct new vector ("resultant") using component sums
- <sup>©</sup> Use trig to evaluate resultant





Example 2:



Example 3:


#### Forces in Equilibrium

Given:

 $V_1$ 

 $V_2$ 

V<sub>3</sub>





V<sub>1</sub>: 33<sup>°</sup>, 3.1 N V<sub>2</sub>: 103<sup>°</sup>, 2.0 N

V<sub>3</sub>: 338<sup>0</sup>, 1.6 N

A <sub>1</sub>	0 <sub>1</sub>
A <sub>2</sub>	0 <b>2</b>
A <sub>3</sub>	0 <b>3</b>
A <sub>t</sub>	Ot

Resultant calculations:

Tan θ\_\_\_\_\_ Tan-1 \_\_\_\_\_ = \_\_\_\_\_

Calculate the vector that will cancel the resultant Equilibrium Vector (  ${\rm V}_{\rm eq}$  )calculations

Note: What is the sum of all component force vectors in a system in equilibrium?

### MOTION



2. Average Velocity ( $V_{avg}$ )

Averages \_\_\_\_\_\_ in velocity over a given period of time. Example: Driving from Portland to Boston

3. Uniform Velocity:

Velocity that does not \_\_\_\_\_\_ (Example: " \_\_\_\_\_\_ - \_\_\_\_\_"

#### 4. Acceleration:



( "m/sec<sup>2</sup> = meters per second per second" )

#### Acceleration (continued):

1. The acceleration of gravity ( $a_g$ )

On Earth:

- a. \_\_\_\_\_ ft/sec<sup>2</sup> (British)
- b. \_\_\_\_\_m/sec<sup>2</sup> (Metric)
- c. Thus, one "g" = \_\_\_\_\_ or \_\_\_\_\_
- 2. Key words:
  - a. "Boost":
  - b. "Retro-burn"
  - c. Negative g's
- 3. Acceleration due to a change in direction:

Since acceleration is defined as

a \_\_\_\_\_\_ in \_\_\_\_\_,

and velocity is defined as

\_\_\_\_\_ and \_\_\_\_\_ ,

then a \_\_\_\_\_ in \_\_\_\_\_ results in \_\_\_\_\_\_.



Law of Gravity Strictly Enforced!

#### Example 1: Beach Bucket



Example 2: The "Gravitron"



V<sub>i</sub>:
 V<sub>f</sub>:
 a:
 s:
 s:
 t:

# <u>"Three outa five ain't bad!</u>"

Given any \_\_\_\_\_\_ of the above factors,

the remaining \_\_\_\_\_\_ factors may be calculated

## **Basic Formulas Used in Acceleration Problems:**

Vi	$V_{\rm f}$	а	S	t	basic formula:

# **Acceleration Formula Cheat Sheet**

$$t = \bigotimes$$

$$a = \frac{v_{f^2} - v_{f^2}}{2s} \quad t = \frac{v_{f^2} - v_{f^2}}{2a} \quad V_f = \sqrt{V_{i^2} + 2as} \quad V_i = \sqrt{2as - V_{f^2}}$$

$$s = \bigotimes$$

$$V_f = at + V_i \quad V_i = V_f - at \quad a = \frac{v_f - v_i}{t} \quad t = \frac{v_f - v_i}{a}$$

$$a = \bigotimes$$

$$s = .5(V_f + V_i)t \quad t = \frac{s}{.5(V_f + V_i)} \quad V_f = \frac{s}{.5t} - V_i \quad V_i = \frac{s}{.5t} - V_f$$

$$V_f = \bigotimes \quad V_i = o$$

$$s = .5at^2 \quad a = \frac{s}{.5t^2} \quad t = \frac{\sqrt{s}}{.5a}$$

$$V_f = \bigotimes \quad V_i \neq o$$

$$s = V_i t + .5at^2 \quad t = \frac{-v_i \pm \sqrt{v_i^2 + 2ac}}{a} \quad v_i = \frac{.5at^2}{t} \quad a = \frac{s - v_i t}{.5t^2}$$

# Points to ponder

Given this formula:  $s = V_i t + \frac{1}{2}at^2$ 

# Solve for t

1) 
$$s = V_i t + .5at^2$$
  
2)  $V_i t + .5at^2 = s$   
3)  $+(-s) + (-s)$   
4)  $V_i t + .5at^2 + (-s) = 0$   
5)  $.5at^2 + V_i t + (-s) = 0$ 

6 Change symbol from to

6

#### Page 77

### Informal Lab: Working through acceleration problems

Example 1:

How long will it take an object to drop 4 feet?

1

2

Step 1: Does this question involve gravity and /or acceleration? If so, then go to: Step 2: Inventory

 $(\mathfrak{T})$ 

2	$V_i$
	$V_{\rm f}$
2	а
3	S
ന	t

Step 3: What is the question?

Step 4: Look for the "odd man out" (  $\otimes$  )

Step 5: Look for  $\otimes$  on the Cheat Sheet

Step 6: Select formula corresponding to "?"

Step 7: Insert correct values in formula and solve

- Be sure to use correct standard units! Convert if necessary.



Example 2:

(Part 1)

A rock is <u>dropped</u> from a bridge. It takes <u>1.35 seconds</u> for the rock to strike the water below. <u>How high</u> (in ft) is the bridge above the water?

Vi			
$V_{f}$			
а			
S			
t			

(Part 2) <u>How fast</u> is the rock travelling at impact?

V<sub>i</sub> V<sub>f</sub> a

a

S

t

Example 3.

A ball is thrown straight down from a cliff. The velocity of the ball as it leaves the thrower's hand is 60 ft/sec. How far will the ball have travelled after 2 sec.?

- V<sub>i</sub> V<sub>f</sub>
- а
- S

t



## Example 4.

A rocket boosts from the launch pad at 48 ft/sec<sup>2</sup>. How high is the rocket after 5 sec.?



Example 5.

A car goes from 55MPH to 70 MPH in 10 sec. What is its rate of acceleration? (Hint: convert to standard units **first**)

Example 6.

An aircraft with a landing speed of 180 MPH lands on an aircraft carrier by catching the arresting wire and coming to a complete stop in 2 sec. How many G's does the pilot experience? (**Be sure to convert to correct units first!**)











You know, I used to like this hobby. ... But shoot! Seems like everybody's got a rock collection."



#### **Informal Lab Problems:**

- 1. A bullet is fired vertically with an initial velocity Of 250 m/sec. Discounting air resistance,
  - a. How high does it go?
  - b. How long does it take to reach max height?



- 2. A bullet is fire vertically and reaches a max height of 700 ft Discounting air resistance,
  - a. What is its initial velocity?
  - b. How long does it take to reach max height?

## **Kinematics: Motion in Two Dimensions**

Example 1:



## Calculations/measurements:

- 1. S<sub>x</sub> \_\_\_\_\_
- 2. S<sub>y</sub>\_\_\_\_\_
- 3. t =

4.  $V_{muzzle} =$ 





(only when elevation is set at 0°)

# Predicting range of angled shot based on known $V_{\rm m}$



# Sound:





Frequency, wavelength, velocity:



#### The role of the medium in a mechanical wave

The medium determines \_\_\_\_\_\_ of a wave

The Doppler Effect:



#### Where:

- $v_s$  = Velocity of the Source v = Velocity of wave f = Real frequency
- f' = Apparent frequency

Equation to determine velocity of source:

$$V_{\rm s} = \frac{V(f'-f)}{f'}$$

A sonar analyst detects an underwater sound at a frequency of 319.63 HZ.

He knows from prior intelligence that sound is actually propagated at 318.00 hz.

- 1. Is the sound source approaching or receding?
- 2. What is the speed of the source in Knots (nautical miles per hour)?

Data:

- 1. Speed of sound in water  $\sim~4900$  ft/sec
- 2. 1 Nautical mile  $\sim$  6000 ft.



U.S. P-3 Orion and Soviet submarine

# Structure of the atom and the nature of light



# Wile E. Coyote's Last Hurrah!





#### **Hubble Law**

Hubble's law or Hubble—Lemaître's law is the name for the observation that:

- 1. All objects observed in deep space (extragalactic space, ~ 10 Mpc or more) have a doppler shiftmeasured velocity relative to Earth, and to each other;
- 2. The doppler-shift-measured velocity of galaxies moving away from Earth, is proportional to their distance from the Earth and all other interstellar bodies.

In effect, the space-time volume of the observable universe is expanding and Hubble's law is the direct physical observation of this. It is the basis for believing in the **expansion of the universe** and is evidence often cited in support of the Big Bang model.

Although widely attributed to Edwin Hubble, the law was first derived from the General Relativity equations by Georges Lemaître in a 1927 article. There he proposed that the Universe is expanding, and suggested a value for the rate of expansion, now called the **Hubble constant**. Two years later Edwin Hubble confirmed the existence of that law and determined a more accurate value for the constant that now bears his name. The recession velocity of the objects was inferred from their redshifts, many measured earlier by Vesto Slipher in 1917 and related to velocity by him.

The law is often expressed by the equation  $v = H_0D$ , with  $H_0$  the constant of proportionality (the **Hubble constant**) between the "proper distance" *D* to a galaxy and its velocity *v* (see *Uses of the proper distance*).  $H_0$  is usually quoted in (km/s)/Mpc, which gives the speed in km/s of a galaxy 1 megaparsec ( $3.09 \times 10^{19}$  km) away. The reciprocal of  $H_0$  is the Hubble time.



Example:

Astronomers observe a galaxy 7 billion light years away.

- 1. How fast is the galaxy moving away from us?
- 2. How long has it been travelling?

.....

"The most beautiful thing we can experience is the mysterious. It is the source of all true art and science."

-Albert Einstein

**Michelson – Morley Experiment** 



Page 97

Lorentz Factor: 
$$\sqrt{1-rac{V^2}{c^2}}$$
 or  $\gamma$  ("Gamma")

Where



## **Relativity Toolbox**

Where:		
Τ <sub>Δ</sub> =		
T =		
C =		
V =		
L <sub>Δ</sub> =		
L =		
Relativistic Velocities (	)	
	/	
"Gamma" ( $\gamma$ ) is the factor that all	ows us to compute	in both
and	given a specific velo	city; these effects are most
evident at	,	but occur at any and all
velocities.		

# **Einstein's Two Postulates of Special Relativity:**

1. The laws of physics	 	
2. The speed of light	 	

## **Quotes by Albert Einstein:**

# **On Relativity:**

"When you are courting a nice girl, an hour seems like a second. When you sit on a red - hot cinder, a second seems like an hour. That's relativity."

# On virtue:

"As far as I'm concerned, I prefer silent vice to ostentatious virtue."

# On traffic safety:

"Any man who can drive safely while kissing a pretty girl is simply not giving the kiss the attention it deserves."

# On nationalism:

"Nationalism is an infantile disease. It is the measles of mankind."



To understand why Relativity is necessary we have to look at the practical problems resulting from a Cosmic Speed Limit (The speed of light: "c")

(C= 186,000 mi/sec, 300,000 km/sec, and/or 3.0 x 10<sup>8</sup> m/sec)

We'll start with a ridiculous imaginary clock:



### **Relativity Example 1.**

A spacecraft passes NASA Ground Control at .9c.

A video camera monitors the clock inside the cabin and transmits the image to an observer in Ground Control. The observer has his own clock adjacent to the console video screen displaying the shipboard clock. fig 2. Ground Control observer's console







Question 1: The Ground Controller observes the image of the Ship's clock second hand as it completes 1 rotation (60 sec). How much time has elapsed on the Ground Control clock?



Question 2: What is the length of the spacecraft from the perspective of the observer?



#### **Relativity and the Muon**

Evidence supporting Einstein's theory of Special Relativity is found in the analysis of the behavior of *muons*.

Muons are subatomic particles that are created in Earth's upper atmosphere when cosmic rays (typically protons) collide with the nuclei of air molecules; muons have a velocity of .998c and a "life span" of  $2.2 \times 10^{-6}$  seconds (*at rest*), after which they disintegrate into other particles.

Scientists conducted an experiment in which they detected the presence of muons at the top of Mount Washington, New Hampshire.

After recording their results, they then moved their detection equipment to a New England beach ("sea level").

Given the altitude of Mt. Washington (**approximately 2000 meters**), and the velocity (V) and "life span" (T) of muons, ( and discounting the effects of Relativity ) there should have been no muons detected at sea level, since :

(V) x (T) = (Distance)  

$$\downarrow$$
  $\downarrow$   $\downarrow$  (.998c) x (2.2 x 10<sup>-6</sup>) = (2.994 x 10<sup>8</sup> m/sec) (2.2 x 10<sup>-6</sup> sec) = 658.68 meters

In other words, <u>according to classical Newtonian principles</u> the muons should have disintegrated a little over a third of the distance down from the top of the mountain.

Yet, when the detection equipment was activated at sea level, muons were clearly and abundantly present! How come?

#### Solution:

1. Calculate "Gamma" for .998c

2. Calculate  $T_{\Delta}$ 

3. Calculate  $L_{\Delta}$  from the perspective of the muon:

### Famous quotes by baseball legend and American philosopher Yogi Berra:

#### On the Scientific Method:

"You can observe a lot just by watching."

#### **On Relativistic Time:**

"This is the earliest I've ever been late!"

### On the Uncertainty Principle of Quantum Physics:

"When you come to a fork in the road, take it."



#### **The Twins Paradox**

One of pair of identical twins is selected to be a crew member of a deep-space expedition to a star eleven light-years distant.

The other twin will remain on Earth.

The vessel will travel at .998c

Discounting the time spent exploring the star system, determine the ages of each twin upon the vessel's return to Earth



#### **Gamma Chart For Relativistic Velocities**

v	v <sup>2</sup>	1-v <sup>2</sup>	√( 1-v <sup>2</sup> )
			(" <b>Y</b> ")
.9c (.1 or one-tenth under "c")	.81	.19	.44
.99c (.01 or one-hundredth under "c")	.980	.02	.14
.999c (.001 or one-thousandth under "c")	.998	.002	.045
.9999c (.0001 or one-ten thousandth under "c")	.9998	.0002	.014
.99999c (.00001 or one-hundred thousandth under"c")	.99998	.00002	.0045
.999999c (.000001 or one-millionth under "c")	.999998	.000002	.0014
.9999999c (.0000001 or one-ten millionth under "c")	.9999998	.0000002	.00045
.99999999c (.00000001 or one-hundred millionth under "c")	.99999998	.0000002	.00014
.999999999c (.000000001 or one-billionth under "c")	.999999998	.00000002	.000045
.999999999990 (.000000001 or one-ten billionth under "c")	.9999999998	.000000002	.000014
# Further Problems with Relativistic Travel Example 1:

A crew of astronauts leaves Earth to explore deep space.

Given:

- 1. From the crew's perspective, they will experience one year of shipboard time travelling within a billionth of "c".
- 2. "Gamma" for their velocity is 0.00001 (See "Gamma Chart", previous page)

Determine how much time will have elapsed on Earth when they return.

## Example 2:

Given: A space vessel traveling at .9c collides with an small object with a mass of grain of salt, approximately 5.86 x 10<sup>-8</sup> Kg

How much kinetic energy (KE) is released at impact?

(Comparison: 1 ton of TNT =  $4.2 \times 10^9$  Joules)

Formula for Kinetic Energy  $KE = \frac{1}{2}mv^2$ or  $KE = .5mv^2$ 

#### Example 3:

Given: A space vessel traveling at .9c collides with an small object with a mass of 2.5 grams ( roughly the mass of a penny )

How much kinetic energy (KE) is released at impact?

# The effects of acceleration on the path of a photon





Path of photon relative to spacecraft

## An Einstein "Thought Experiment"

If the Sun was to suddenly vanish, would the Earth break from its orbit at the instance of the Sun's disappearance?

Newton's View\_\_\_\_\_

Einstein's view: \_\_\_\_\_

Proof of gravity affecting light during solar eclipse:









# **Another Thought Experiment:**

Escape Velocity:\_\_\_\_\_

Data:  

$$V_{esc} = \sqrt{\frac{2GM}{r}}$$
  
G= 60672 x 10<sup>-11</sup>  
M = 6.0 x 10<sup>24</sup> Kg  
r<sub>earth</sub> 6.37 x 10<sup>6</sup> m

Now let's super- shrink the Earth and reduce the radius to 7.8 mm (7.8 x  $10^{-3}$  m) and calculate the new escape velocity.

\*\*\*\*\*



The Most Famous Equation in the World:

 $E = mc^2$ 

To get a handle on this, let's first take a look at a lesser known version:

 $E = \Delta mc^2$ 

Where:	Data:
E = "Binding Energy"	Mass of a proton =1.67262 x 10 $^{-27}$ Kg
$\Delta m$ = "mass defect" C <sup>2</sup> = speed of light squared (3.0 x 10 <sup>8</sup> ) <sup>2</sup>	Mass of a neutron = 1.67493 x 10 <sup>-27</sup> Kg Mass of an electron = 9.1094 x 10 <sup>-31</sup> Kg

$^4_2\text{H}$ compared to $^{235}_{92}\text{U}$
Top # =
Bottom # =

We'll start by constructing a Helium atom and predicting its mass based on the known masses of its constituent parts. Remember, a Helium atom contains

2 protons, 2 neutrons, and 2 electrons



 $E = \Delta mc^2$ 



Page 112

Now compare the mass – energy conversion factor:



# Finally:

$$E = mc^2$$

Alternate way of reading the formula:

#### "

#### Question:

"

How much TOTAL energy is contained in 1 Kilogram of material (like the Laboratory Rock)?

# Epilogue: Where do we go from here?

	The Four Fundame	ntal Forces:
В.В.		
0 sec 10 <sup>-43</sup> sec	•	Described by:
	1	:
	2	:
	3	:
$\longleftrightarrow  \longleftrightarrow$	<b>4</b>	:
Conflict: The existence o	f	
	·	
String Theory – possible	solution?	
All "matter" is		
Original model called for	the existence of	
0		
Problems developed bec	ause of mathematic	al
Anomalies resolved by _		
Strength of String Theory	y:	
Weakness of String Theo	)rv:	
		AND HOWEVER DIFFICULT LIFE MAY SEEM, THERE IS ALWAYS SOMETHING YOU CAN DO, AND SUCCEED AT. IT MATTERS THAT YOU DON'T JUST GIVE UP."
		1942 - 2018