# PHYS 110 TECHNICAL PHYSICS STUDENT WORKBOOK <br> (3 ${ }^{\text {rd }}$ Edition July 2020) <br> Kevin Kimball, B.S. <br> USN - retired <br> 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
$\qquad$ and $\qquad$
$\qquad$ numbers.

Based on an understanding of $\qquad$
$\qquad$

## *

and the $\qquad$
$\qquad$

Algebra:
Scientific Notation:



The same rules pertaining to $\qquad$ , and
$\qquad$ in Scientific Notation 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 $\qquad$ or a $\qquad$
"Zero" power: $\left(x^{0}\right)$
Any non-zero number to the "zero power" equals $\qquad$
Rationale:

First power: $\left(x^{1}\right)$
Any number to the $1^{\text {st }}$ power equals $\qquad$

Standard Notation:

Lab exercises:

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

R

## Converting numbers in standard notation to scientific notation

If the decimal point moves to the $\qquad$ , the exponent goes $\qquad$

If the decimal point moves to the $\qquad$ , the exponent goes $\qquad$

## Converting numbers in Scientific Notation to Standard Notation

If the exponent moves $\qquad$ , the decimal point moves $\qquad$

If the exponent moves $\qquad$ , the decimal point moves $\qquad$

## "Cheater Rule" for Standard Notation:

Any number in standard notation can be expressed as $\qquad$ times $\qquad$

General Rule for correct scientific notation:
"Only one $\qquad$ in the $\qquad$ to the $\qquad$ of the decimal"

## Very Important Exception:

It is often more convenient to ignore this rule during $\qquad$
$\qquad$
(In other words, don't get hung up on this and create more problems than necessary)

| Example 1: <br> Convert 873.463 into correct <br> scientific notation | Example 2: <br> Convert 0.00785 into correct <br> scientific notation | Example3: <br> Convert 56.98 $\times 10^{5}$ into correct <br> scientific notation |
| :--- | :--- | :--- |
|  |  |  |

## Convert to correct scientific notation:

| 186,000 | 0.0045 |
| :--- | :--- |
| 5280 | $34.78 \times 10^{3}$ |
| $783.487 \times 10^{-8}$ | 2.85 |
| $0.000859 \times 10^{-9}$ | $0.0835 \times 10^{6}$ |
| $0.0000386 \times 10^{12}$ | 73.96 |
| $1 / 4$ | .937 |

Convert to standard notation:

| $1.63 \times 10^{3}$ | $3.637 \times 10^{-1}$ |
| :--- | :--- |
|  |  |
| $2.94 \times 10^{-6}$ | $36.345 \times 10^{2}$ |

## Operations in Scientific Notation

## Multiplication Critical Rules:

Multiply $\qquad$

Retain $\qquad$

Add $\qquad$

NOTE:
Adding a negative number is the same as $\qquad$ a $\qquad$

Example 1:
$\left(4.75 \times 10^{3}\right) \times\left(2.43 \times 10^{7}\right)$

Example 2:
$\left.\left(3.72 \times 10^{7}\right) \times 1.67 \times 10^{-2}\right)$

## Division Critical Rules:

Divide

## Retain

$\qquad$

Subtract $\qquad$

NOTE:
Subtracting a negative number is the same as $\qquad$ a $\qquad$

Example 1:
$\left(9.35 \times 10^{8}\right) \div\left(3.54 \times 10^{4}\right)$

Example 2:
$\left(8.62 \times 10^{6}\right) \div\left(3.97 \times 10^{-3}\right)$

## Addition/Subtraction Critical Rules:

Exponents $\qquad$

Add/Subtract $\qquad$

Retain $\qquad$

Retain $\qquad$

Example 1:
$\left(6.72 \times 10^{3}\right)+\left(2.97 \times 10^{3}\right)$

Example 2 :
$\left(9.56 \times 10^{5}\right)-\left(8.47 \times 10^{4}\right)$

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

Square / Cube $\qquad$
Retain $\qquad$
Multiply $\qquad$ by $\qquad$ or $\qquad$
RECALL:
Multiplying unlike signs results in a $\qquad$
Multiplying like signs results in a $\qquad$


Square Roots/Cube Roots in Scientific Notation - Critical Rules
Exponent must be divisible by $\qquad$ or $\qquad$
Square/Cube root $\qquad$
Retain $\qquad$
Divide $\qquad$ by $\qquad$ or $\qquad$ RECALL:
Dividing unlike signs results in a $\qquad$
Dividing like signs results in a $\qquad$

| Example 1: |  |  |  |
| :--- | :--- | :--- | :--- |
|  |  | $\sqrt{9.46 \times 10^{6}}$ |  |
|  |  | $\sqrt[3]{9.46 \times 10^{6}}$ |  |
|  |  |  |  |
| Example 2: |  |  |  |
|  | $\sqrt{8.1 \times 10^{5}}$ | Example 4: |  |
|  |  |  |  |


| $\left(3.93 \times 10^{7}\right) \times\left(5.37 \times 10^{6}\right)$ | Answer: |
| :--- | :--- |
| $\left(3.92 \times 10^{3}\right) \times\left(3.48 \times 10^{-5}\right)$ |  |
| $\left(8.16 \times 10^{-5}\right) \div\left(4.89 \times 10^{6}\right)$ | Answer: |


| $\begin{array}{r} \left(3.93 \times 10^{7}\right) \times\left(5.37 \times 10^{6}\right) \\ 3.93 \times 10^{7} \\ 2.37 \times 10^{6} \\ 21.104 \times 10^{13} \\ =2.1104 \times 10^{14} \end{array}$ | $2.1104 \times 10^{14}$ |
| :---: | :---: |
| $\begin{array}{r} \begin{array}{r} \left.3.92 \times 10^{3}\right) \times\left(3.48 \times 10^{-5}\right) \\ 3.48 \times 10^{-5} \end{array} \\ \begin{aligned} 13.642 & \times 10^{-2} \end{aligned} \\ =1.364 \times 10^{-1} \end{array}$ | $1.364 \times 10^{-1}$ |
| $\begin{aligned} &\left(8.14 \times 10^{7}\right) \div\left(4.05 \times 10^{9}\right) \\ & \frac{8.14 \times 10^{7}}{4.05 \times 10^{9}} \\ &= 2.0098 \times 10^{-2} \end{aligned}$ | $2.0098 \times 10^{-2}$ |
| $\begin{aligned} &\left(8.16 \times 10^{-5}\right) \div\left(4.89 \times 10^{6}\right) \\ & \frac{8.16 \times 10^{-5}}{4.89 \times 10^{6}} \\ &= 1.669 \times 10^{-11} \end{aligned}$ | $1.669 \times 10^{-11}$ |


| $\sqrt{2.36 \times 10^{7}}$ |  |
| :--- | :--- |
| $\left(2.64 \times 10^{7}\right)\left(1.37 \times 10^{7}\right)$ |  |
| $\left(3.93 \times 10^{7}\right)^{2}$ |  |
| $\sqrt{8.26 \times 10^{8}}$ |  |
| $\left(5.37 \times 10^{6}\right)^{3}$ |  |


| $\sqrt{2.36 \times 10^{7}}$ $\text { Change to: } \begin{aligned} & \sqrt{23.6 \times 10^{6}} \text { (exponent divisible by 2) } \\ & =4.858 \times 10^{3} \end{aligned}$ | $4.858 \times 10^{3}$ |
| :---: | :---: |
| $\begin{aligned} &\left(2.64 \times 10^{7}\right)-\left(1.37 \times 10^{7}\right) \\ & 2.64 \times 10^{7} \\ & \frac{-1.37 \times}{} \times 10^{7} \\ & \hline 1.27 \times 10^{7} \end{aligned}$ | $1.27 \times 10^{7}$ |
| $\begin{aligned} \left(3.93 \times 10^{7}\right)^{2} & \\ & =15.445 \times 10^{14} \\ & =1.5445 \times 10^{15} \end{aligned}$ | $1.5445 \times 10^{15}$ |
| $\begin{aligned} \left(5.37 \times 10^{6}\right)^{3} & =154.854 \times 10^{18} \\ & =1.54854 \times 10^{20} \end{aligned}$ | $1.5485 \times 10^{20}$ |
| $\sqrt{8.26 \times 10^{8}}$ $2.874 \times 10^{4}$ | $2.874 \times 10^{4}$ |
| $\begin{aligned} & \sqrt[3]{5.06 \times 10^{16}} \\ & \text { change to: } \begin{array}{r} \sqrt[3]{50.6 \times 10^{15}} \text { (exponent divisible by 3) } \\ =3.699 \times 10^{5} \end{array} \end{aligned}$ | $3.699 \times 10^{5}$ |

## Metric System

Major advantage of the metric system:

It can be applied directly to $\qquad$

Uses a system of $\qquad$ and $\qquad$

Units relate to specific $\qquad$ ("whatcha got")

Prefixes are specific $\qquad$ ("how many you got")

Prefixes are mathematically $\qquad$ with $\qquad$ of $\qquad$ Examples of units:

Examples of prefixes:

UNIT: MEASUREMENT OF: PREFIX: EQUIVALENT:

8.5 centimeters $=8.5 \mathrm{x}$ $\qquad$ meters

500 milliliters $=500 x$ $\qquad$ liters
6.75 kilograms $=6.75 x$ $\qquad$ grams

## BOTTOM LINE:

Any prefix can be replaced or substituted with a $\qquad$ of $\qquad$

COMMONLY USED METRIC PREFIXES: (Required knowledge!)
Prefix:

| giga | / Standard notation: | / Fraction: |  |
| :--- | :--- | :--- | :--- |
| mega |  |  |  |
| kilo |  |  |  |
| centi |  |  |  |
| milli |  |  |  |
| micro |  |  |  |

self check:

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

## Informal Lab Exercise:

| 8.97 Kilograms $=\ldots \quad$ Scientific Notation | Standard Notation |  |
| :--- | :--- | :--- |
| 6.5 centimeters $=\ldots \ldots$ meters |  |  |
| 7.5 gigavolts $=\ldots$ volts |  |  |
| 4.7 microFarads $=\ldots \ldots$ Farads |  |  |
| 6,7 megawatts $=\ldots$ watts |  |  |
| 9.87 milliliters $-\ldots$ liters |  |  |


| Quantity |
| :--- |
| 5483 grams  <br> 0.0268 meters  <br> $9,700,000,000$ volts  <br> 0.0000056 Farads  <br> 0.0045 liters  <br> $4,300,000$ watts  |

Conversion hack:

Convert $3.567 \times 10^{5}$ gigavolts to millivolts

| $5.98 \times 10^{4}$ kilograms =_?_grams |  |
| :--- | :--- |
| $8.34 \times 10^{-1}$ meters =_?_ centimeters |  |
| $5.92 \times 10^{-4}$ megawatts =_?_ watts |  |

(Answer in standard notation:)

| 500 millivolts =_?_ volts |  |
| :--- | :--- |
| 345 grams =_?_ kilograms |  |
| $6.73 \times 10^{5}$ centimeters =_?_ meters |  |
| $3.81 \times 10^{-4}$ volts =_?_ microvolts |  |

(Answer in correct scientific notation:)

| $3.45 \times 10^{5}$ microvolts =_?_ kilovolts |  |
| :--- | :--- |
| $7.93 \times 10^{-5}$ kilograms = _?_milligrams |  |
| $5.78 \times 10^{3}$ millimeters = _?_ centimeters |  |
| $4.32 \times 10^{3}$ gigahertz =_?_ megahertz |  |

## Physics terms

## Displacement:

Definition(s):

1. $\qquad$ and $\qquad$
2. $\qquad$ and $\qquad$

Symbol: $\qquad$

Standard units:

1. British ("U.S Standard"): $\qquad$
2. Metric: $\qquad$

NOTE: In this context "displacement" does NOT refer to $\qquad$

## Force:

Definition(s):

1. $\qquad$ or a $\qquad$
2. That which may $\qquad$
$\qquad$

Symbol: $\qquad$ (Weight is a measure of $\qquad$

Standard units:

1. British ("English"): $\qquad$
2. Metric: $\qquad$
NOTE:
Since a $\qquad$ is a unit of force, then it is NOT a measure of $\qquad$ .

## Mass:

Definition(s):

1. $\qquad$
2. $\qquad$
3. $\qquad$


Standard units:

1. British: $\qquad$ (not $\qquad$ )
2. Metric: $\qquad$ (not $\qquad$ )

## Volume:

Definition:

$$
1 .
$$

$\qquad$

Standard units:

1. British: $\qquad$ 1 $\qquad$ )
2. Metric: $\qquad$ 1 $\qquad$ )*

* NOTE: "_ "_ are also frequently used to measure volume in metric terms, but are no longer considered as "standard units."

Time:
Definition:

1. "That which we $\qquad$
$\qquad$ ___ _ _

Standard unit: (both British and metric)

1. $\qquad$ ( NOT $\qquad$ or $\qquad$
self check:
Answers:

| 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 $\qquad$
$\qquad$ , and
exploit the rules used in " $\qquad$ - _"___

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

Example 2:
$\frac{a}{c} \times \frac{b}{a}=$

Example 3:

$$
\frac{\bigcirc}{\square} \times \frac{\Delta}{\bigcirc}=
$$

Rationale:

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

## Example 1:

To convert 35 miles per hour to " $x$ " feet per second:

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 $\qquad$ - $\qquad$ :
$\frac{35 m i}{1 \text { hour }} \times \frac{}{m i} \times \frac{\text { hour }}{}$

Step 3: Replace terms with those you want:

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

Step 4: Inert correct mathematical equivalences:

$$
\frac{35 \mathrm{mi}}{1 \text { hour }} \times \frac{5.28 \times 10^{3} \text { feet }}{1 \mathrm{mi}} \times \frac{1 \text { hour }}{3.6 \times 10^{3} \mathrm{sec}}
$$

Step 5: Cross-cancel terms:


Step 6: Restate with remaining terms:
$35 \times 5.28$ feet
3.6 sec

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

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

| Conversion factors you should know: |  |  |  |  |
| :--- | :--- | :--- | :--- | :---: |
| 1 mile $=5.28 \times 10^{3} \mathrm{ft}$ | 1 mile $=1.61 \times 10^{3}$ meters | 1 kilometer $=10^{3}$ meters | 1 hour $=3.6 \times 10^{3}$ seconds |  |

Self -check: conversions
Answers:

| Convert 400 MPH to ft/sec |  |
| :--- | :--- |

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

Example 1

Given: "12", "3", and "4"
then:

$$
\begin{aligned}
& \frac{12}{3}=4 \\
& \frac{12}{4}=3
\end{aligned}
$$

and $3 \times 4=12$
Or:

X

## Example 2 <br> Given: <br>  <br> Then:

Example 3

Given:


Then: $30=$ $\qquad$
$2=$ $\qquad$

3 = $\qquad$
$5=$ $\qquad$
"People, listen up!
There is the Right Way, there is the Wrong Way, and then there is the Navy Way, and you better start learning the Navy Way!"
-Boatswain's Mate Second Class Donald Barger, USN, Navy Boot Camp Company Commander


Example 4:
Given: $\quad \frac{a b}{c d e}=f g \quad$ Solve for " d "
Traditional solution:

Using the "egg"
$\frac{a b}{c d e}=f g$, Solve for " d "

$d=$

Self check:


Structure of atom - a key to understanding "mass"
Example 1:
Hydrogen:


Proton:

1. $\qquad$ charge
2. Has approximately $\qquad$ times the mass of electron Electron:
3. $\qquad$ charge

Hydrogen:

1. $\qquad$ of all atoms
2. $\qquad$ element in the universe
"There is more stupidity than hydrogen in the universe, and it has a longer shelf life."

- Frank Zappa


Example 2 - Helium atom

(NOT to scale! )

## Nucleus:

1. Contains $\qquad$ and $\qquad$
2. Accounts for $\qquad$ of atom's mass

Neutron:

1. Slightly more $\qquad$ than a proton, hence it also has approximately $\qquad$ times the mass of electron
2. $\qquad$ charge

By volume, an atom is over $\qquad$ percent $\qquad$
$\qquad$

## Atom Model History

Democritus - Fifth century B.C.

1. All matter is composed of $\qquad$
2. "Atom" : Greek for " $\qquad$ "

John Dalton - 1803

1. Atom is a $\qquad$
$\qquad$

## (AKA the "

$\qquad$
$\qquad$ model")
2. Each element was composed of $\qquad$

3. Different elements composed of $\qquad$
4. Compounds are composed of atoms in $\qquad$
5. Chemical reactions are $\qquad$ of $\qquad$ ,

And mass is therefore $\qquad$ .

## Joseph John Thompson - 1897

1. "Plum $\qquad$ " $\qquad$ :
a. A sphere of diffuse $\qquad$ electricity with

2. Discovered $\qquad$ and was awarded $\qquad$ in 1906

The " Solar System" Model

Ernest Rutherford - 1911

1. Discovered that the atom is mostly $\qquad$
$\qquad$ with a dense $\qquad$ charged $\qquad$ surrounded by negative $\qquad$

## Neils Bohr - 1913

1. Electrons travel in $\qquad$
$\qquad$

2. Only $\qquad$ allowed
3. Modern $\qquad$ of the $\qquad$

## Electron Cloud Model-1920's

## 1. Erwin Schrodinger ${ }^{1}$ and Werner Heisenburg ${ }^{2}$

Developed $\qquad$ functions to determine regions or clouds in which $\qquad$ are most likely to be found
2. Heisenberg: Developed the $\qquad$ Principle : Impossible to predict $\qquad$ of single electron

## James Chadwick - 1932




1. British experimental physicist credited with discovering the $\qquad$

Particles and average radii:

| Particle | Approx. Radius |
| :--- | :--- |
|  | $10^{-9}$ meters |
|  | $10^{-10}$ meters |
|  | $10^{-15}-10^{-14}$ meters |
|  | $10^{-15}$ meters |
|  | $10^{-18}$ meters |



Early chemists describe the first dirt molecule.

## 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. $\qquad$
2. $\qquad$
3. $\qquad$
4. $\qquad$


## Pythagoras


$\qquad$
$\qquad$


Earth at the Center

Ptolemy
$\qquad$
$\qquad$
$\qquad$
$\qquad$
$\qquad$
$\qquad$
$\qquad$
$\qquad$
$\qquad$

$\qquad$
$\qquad$
$\qquad$
$\qquad$

$\qquad$

Epicycles

Deferent


Crystal Spheres

## Copernicus

1. $\qquad$
2. $\qquad$
3. $\qquad$
4. $\qquad$

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

## Galileo

1. First to use the $\qquad$
2. Discovered the $\qquad$ of $\qquad$
3. Discovered the $\qquad$ of $\qquad$
4. Discovered $\qquad$
5. Prime author of the $\qquad$
6. Was tried for $\qquad$


GALILEO DESCRIBES HIS DISCOVERIES
TO THE CHGRCH

1. Wrote $\qquad$
$\qquad$
2. Discovered $\qquad$
$\qquad$
$\qquad$
3. Established the link $\qquad$
4. Sought to $\qquad$
$\qquad$
5. Emphasized A $\qquad$ , $\qquad$ results@
6. Invented $\qquad$
7. Derived planetary motions $\qquad$
$\qquad$
$\qquad$


## The Scientific Method


#### Abstract

"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."


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- Dr. Heinz R. Pagels, "The Cosmic Code"
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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."
-Yogi Berra, American philosopher

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

Volume:


Volume $=$ length x height x width

$$
={ }_{C}
$$

and also = $\qquad$ $x$ $\qquad$ x $\qquad$
$\qquad$
$\qquad$

Therefore, $\qquad$ $M^{3}$ is equivalent to $\qquad$ or $\qquad$ $\mathrm{cm}^{3}$

Additionally:
$1 \mathrm{M}^{3}=$ $\qquad$ or $\qquad$ liters (L)

1 liter = $\qquad$ or $\qquad$ milliliters (mL)

Using "factor-labeling" conversion method to determine \# mL in $1 \mathrm{M}^{3}$ :

$$
\begin{array}{cccc}
1 \mathrm{M}^{3} & \times 10^{3} \text { Liters } & \times 10^{3} \text { milliliters } & = \\
1 & 1 \mathrm{M}^{3} & 1 \text { Liter }
\end{array} \text { milliliters }
$$

Since $1 \mathrm{M}^{3}$ equals $\qquad$ $\mathrm{cm}^{3}$ and also $\qquad$ mL ,
$\qquad$ mL ; $\mathrm{acm}^{3}$ is also referred to as a " $\qquad$

## Mass Density Calculations

Mass Density ( $\mathrm{D}_{\mathrm{m}}$ ) ( also referred to simply as "density")
is measured in $\qquad$ per $\qquad$ or $\qquad$

## Example 1:

Determine the $\mathbf{D}_{\mathrm{m}}$ of a 67.5 gram sample of material with a volume of $30 \mathrm{~cm}^{\mathbf{3}}$

Solution:

Use factor-labeling to convert grams $/ \mathrm{cm}^{3}$ to Kilograms/ $\mathrm{M}^{3}$

1. Restate the raw data as fraction:

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

2. Add conversion factors for cancellation:

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

3. Restate with remaining terms and perform necessary calculations:

$$
\frac{67.5 \times 10^{3} \mathrm{Kg}}{30 \mathrm{~m}^{3}}=\ldots \mathrm{Kg} / \mathrm{m}^{3}
$$

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 $50 \mathrm{~cm}^{3}$ sample of lead, predict the mass
Solution: Set up a proportionality equation using the known $D_{m}$ of lead
Step 1:
State the known $\mathrm{D}_{\mathrm{m}}$ of lead

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

Step 2:
Set up as equivalent to given sample

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

Step 3:
Convert all quantities to like terms (grams, $\mathrm{cm}^{3}$, since this is a small sample)

$$
\frac{11.3 \times 10^{6} \mathrm{~g}}{10^{6} \mathrm{~cm}^{3}}=\frac{x g}{50 \mathrm{~cm}^{3}}
$$

Step 4: Cross-multiply

$$
\frac{11.3 \times 10^{6} \mathrm{~g}}{10^{6} \mathrm{~cm}^{3}} \stackrel{\leftrightarrow}{\leftrightarrows} \longleftrightarrow \frac{x \mathrm{~g}}{50 \mathrm{~cm}^{3}}
$$

| Review: Cross-multiplying |  |
| :---: | :---: |
| $\frac{a}{b}=\frac{c}{d}$ | $\frac{2}{3}=\frac{12}{18}$ |
| $a \times d=b \times c$ | $2 \times 18=3 \times 12$ |

Now the equation becomes:
$\qquad$ x $\qquad$ = $\qquad$ x $\qquad$

After canceling like terms, the equation becomes
$\qquad$ $x$ $\qquad$ $=$ $\qquad$
$\qquad$ 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 $\qquad$ the atoms of the remaining material in the core are ripped apart by the extreme $\qquad$ and the extreme
$\qquad$ . During this process electrons combine with protons to
form $\qquad$ . Since the volume of a normal atom is over $\qquad$ 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
$\qquad$
$\qquad$ , or the same as $\qquad$ aircraft carriers.

Self check:

| Determine the $D_{m}$ of a 273 gram sample of material with a volume of 35 mL | answer: |
| :--- | :--- | :--- |
| Determine the mass of a $95 \mathrm{~cm}^{3}$ sample of iron |  |

## Vectors:

Two types of measurement used in Physics; they are

1. measures
b. Indicate $\qquad$ only
2. $\qquad$ measures
a. Indicate $\qquad$ and $\qquad$

Examples:
Scalar
Vector
$\qquad$
$\qquad$
$\qquad$
$\qquad$

Since vector measures include the component of $\qquad$ then that component must be taken into consideration during $\qquad$ .

Example 1: Two bungee cords pulling in opposite directions:

Example 1a:

Net force: $\qquad$

Example 1b:

Net force: $\qquad$

Example 2: Two bungee cords pulling in the same direction:

Net force: $\qquad$

Note:
At this point you should see the $\qquad$ of net forces, or the " $\qquad$ -

Example 3: Two bungee cords pulling at a $90^{\circ}$ angle relative to one another

Solution: Use " $\qquad$ to $\qquad$ " schematic

The sum of these two vectors is called a " $\qquad$

BUT,
The Pythagorean Theorem will solve $\qquad$ only

What about direction?


## Basic Right-Angle Trigonometry

(Invented by $\qquad$ )

Given: a 30-60-90 triangle


One of the unique characteristics of a 30-60-90 triangle is that
the side $\qquad$ the $30^{\circ}$ angle
is always $\qquad$ - $\qquad$ the length of the $\qquad$ .

In other words, given the $\qquad$ angle,
the $\qquad$ of the $\qquad$ side over the $\qquad$
will always be $\qquad$ - $\qquad$ or $\qquad$ .

In Right-Angle Trigonometry, this ratio is called the $\qquad$ of the $\qquad$

Thus, we can state that the " $\qquad$ of $30^{\circ}$ is $\qquad$

## 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 ( $\mathbf{s i n}$ ) of $\mathbf{3 0 ^ { \circ }}$ as an example.

Method 1:

1. Hit $\sin$
2. enter " $\mathbf{3 0}$ "
3. Hit " = "
4. Your answer should be "0.5."
5. If not, you're probably in "radian mode" and using a graphing calculator.
6. Go to mode (you may need to use "shift" or "2 $2^{\text {nd " }}$ to get there)
7. You should see a screen showing both"degree" and "radian."
8. Select "degree"
9. enter
10. clear
11.Repeat steps $1-3$, your answer should now be " 0.5 "

Method $\mathbf{2}$ (more common on simpler, less expensive calculators):

1. Enter " $\mathbf{3 0}$ "
2. Hit

3. Your answer should be "0.5"

## Practice using other trig

 functions:Cosine $30^{\circ}=.866$
Tangent $30^{\circ}=.577$

$\theta$ ("Theta"): $\qquad$

Hypotenuse: $\qquad$

Opposite: $\qquad$

Adjacent: $\qquad$

Sine $\boldsymbol{\theta}(\sin \theta):$
the ratio of the $\qquad$ side over the $\qquad$

Cosine $\boldsymbol{\theta}(\cos \theta):$
the ratio of the $\qquad$ side over the $\qquad$

Tangent $\theta \quad(\tan \theta)$
$\qquad$ side over the $\qquad$ side

Stated more simply:

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

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

Stated yet another way:


## Using Trig

Example 1.


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

1. 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 "

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

$\rightarrow H=\frac{A}{\operatorname{Cos} 28^{0}}$
$=\xrightarrow{25}$ $=$ $\qquad$
2. To determine " $\mathbf{O}$ " 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
$H=\frac{0}{\sin \theta}$
$H=\frac{A}{\cos \theta}$

Using the "reciprocal function" on the calculator

Since we know that the Sine of $\mathbf{3 0}{ }^{\circ}$ is $\mathbf{0 . 5}$, we'll start there.

Method 1:

1. Hit "Shift" or " $\mathbf{2}^{\text {nd } "}$
2. Hit $\sin$
3. Enter ". 5 "
4. Hit" ="
5. Your answer should be " $\mathbf{3 0}$ "

Method $\mathbf{2}$ ( for simpler, less expensive calculators):

1. Enter " . 5 "
2. Hit "Shift" or " $\mathbf{2 d}^{\text {nd }}$
3. Hit $\sin$
4. Your answer should be " $\mathbf{3 0}$ "

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

## Informal Lab: Practice problems

ASSIGNMENT: Solve for unknown sides and angles using trigonometry plus additional instructions below:

1. Do NOT Pythagorean Theorem!
2. 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!
3. 


3.

4.


1. The sine, cosine, and tangent of any/every angle between $\qquad$ and $\qquad$
is $\qquad$ to that angle alone.
2. Thus, if we know the sine, cosine and/or tangent of an angle, then we have the means to $\qquad$ the original angle.
3. NOTE:

This course will take the "old-school trig" approach in analyzing angles, and therefore all angles ("vectors") will be evaluated as if their measures are between $\qquad$ and $\qquad$ .

Example 1:

$$
125^{\circ} \text { will be evaluated as ___ }\left(180^{\circ}-125^{\circ}\right) \text { (measure from } x \text {-axis) }
$$

Example 2: $213^{\circ}$ will be evaluated as ___ $\left(213^{\circ}-180^{\circ}\right)$ (measure from x-axis)
Example 3: $325^{\circ}$ will be evaluated as ___ $\left(360^{\circ}-325^{\circ}\right)$ (measure from x-axis)


## Informal Lab: Practice evaluating angles

Hint: Always measure from the closest horizontal (" $x$-axis")

2.

3.

$\theta=$ $\qquad$
4.


## Common mistakes:

Do not measure from




## 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"
$3.5 \mathrm{lbs}, 90^{\circ}$

Bungee "a", $5 \mathrm{lbs}, 0^{\circ}$ * $\qquad$ to $\qquad$
schematic representation

## * NOTE: Always draw <br> $\qquad$ vector first beginning with the <br> $\qquad$

1. Calculate the tangent of the unknown angle " $\qquad$ $": \tan =$ - $=$ $\qquad$
2. $\tan ^{-1}$ $\qquad$ $\rightarrow$ $\qquad$
3. Calculate the hypotenuse ( or " $\qquad$ ")

Using trig, we know that $\mathrm{H}=\frac{0}{\sin \theta}$ and/or $\frac{\mathrm{A}}{\cos \theta}$
Selecting the first trig formula,

$$
\mathrm{H}=\square=\square=\square \text { (solution) }
$$

Thus, the sum ( $\qquad$ ) of the forces of the two bungee
cords is $\qquad$ at $\qquad$ degrees

## Adding Vectors:

Example 1:
Given the following


Determine the sum of $\mathrm{V}_{\mathbf{1}}+\mathrm{V}_{\mathbf{2}}$

Solution:
(1) Draw each vector individually, and label accordingly
(2) Add component vectors and label accordingly
(3) Use trig to solve for components
(4) Add components
(5) Construct new vector ("resultant") using component sums
(6) Use trig to evaluate resultant
$V_{2}, 6.3$ Newtons, $63^{\circ}$

$A_{2}=$
 ) $\times(\ldots \quad$ _ $)$ $\begin{array}{ll}= \\ = & \mathrm{X}\end{array}$
$\mathrm{O}_{1}=($
 ) $\times(\ldots$ ___ $)$
$\qquad$ X $\qquad$
$V_{1}$, 4.1 Newtons, $27^{\circ}$
$=$
$\mathrm{O}_{2}=($ $\qquad$ ) $\times(\ldots \quad$ ) $=\ldots \quad \times$ $=$


Construct/draw in order:
$A_{\text {total }}$
$\mathrm{O}_{\text {total }}$
Resultant

$\qquad$

Example 2:


$$
\begin{aligned}
& \mathrm{V}_{1}: 48^{\circ}, 50 \text { meters } / \mathrm{sec} \\
& \mathrm{~V}_{\mathbf{2}}: 147^{\circ}, 75 \text { meters } / \mathrm{sec}
\end{aligned}
$$

| $\mathrm{A}_{1}$ | $\mathrm{O}_{1}$ |
| :--- | :--- |
| $\mathrm{~A}_{2}$ | $\mathrm{O}_{2}$ |
| $\mathrm{~A}_{\mathrm{t}}$ | $\mathrm{O}_{\mathrm{t}}$ |



Example 3:



Forces in Equilibrium

## Given:


$V_{1}$
$V_{2}$
$V_{3}$
$V_{1}: 33^{\circ}, 3.1 \mathrm{~N}$
$\mathrm{V}_{2}: 103^{\circ}, 2.0 \mathrm{~N}$
$V_{3}: 338^{\circ}, 1.6 \mathrm{~N}$

## Calculations:

| $A_{1}$ | $O_{1}$ |
| :--- | :--- |
| $A_{2}$ | $O_{2}$ |
| $A_{3}$ | $O_{3}$ |
| $A_{t}$ | $O_{t}$ |

Resultant calculations:
$\operatorname{Tan} \theta$
Tan-1 $\qquad$ $=$ $\qquad$

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

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

## MOTION

1. Velocity:
a. $\qquad$ measurement
b. $\qquad$ and $\qquad$
c. $\qquad$ over $\qquad$ ( )
d. Measured in:
2. $\qquad$ per___ $\square$ (British)
3. $\qquad$ per $\qquad$ (___ $\qquad$ ) (Metric)
4. Average Velocity ( $\mathrm{V}_{\text {avg }}$ )

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

## 3. Uniform Velocity:

Velocity that does not $\qquad$
(Example: " $\qquad$ - ___
4. Acceleration:
a. $\qquad$ measurement
b. A $\qquad$ in $\qquad$ * over $\qquad$ * ( " $\mathrm{V}_{\Delta}$ " or " $\quad \mathrm{V}$ ") (" $\Delta^{\prime \prime}=$ " " $)$
c. Measured in:

1. $\qquad$ per $\qquad$ per___ $\qquad$ (British)
2. $\qquad$ per $\qquad$ per___( (_____ ) (Metric)
Explanation of units of Acceleration: ( $" \mathrm{ft} / \mathrm{sec}^{2}=$ feet per second per second") ( "m/sec ${ }^{2}$ = meters per second per second")

Acceleration (continued):

1. The acceleration of gravity ( $\mathrm{ag}_{\mathrm{g}}$ )

On Earth:
a. $\qquad$ $\mathrm{ft} / \mathrm{sec}^{2}$ (British)
b. $\qquad$ $\mathrm{m} / \mathrm{sec}^{2}$ (Metric)

## CAUTION:

Gravity is acceleration,
BUT
Not all acceleration is gravity!
c. Thus, one " g " = $\qquad$ or $\qquad$
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 $\qquad$ in $\qquad$ ,
and velocity is defined as
$\qquad$ and $\qquad$
then a $\qquad$ in $\qquad$ results in $\qquad$ .

Example 1: Beach Bucket


Example 2: The "Gravitron"


## Critical Factors in Acceleration Calculations:

1. $V_{i}$ :
2. $V_{f}$ :
3. $a:$
4. $\mathrm{s}:$
5. t :

## " Three outa five ain't bad!"

Given any $\qquad$ of the above factors, the remaining $\qquad$ factors may be calculated

## Basic Formulas Used in Acceleration Problems:

| $\mathrm{V}_{\mathrm{i}}$ | $\mathrm{V}_{\mathrm{f}}$ | a | s | t | basic formula: |
| :--- | :--- | :--- | :--- | :--- | :--- |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

## Acceleration Formula Cheat Sheet



## Points to ponder

Given this formula: $s=V_{i} t+\frac{1}{2} a t^{2}$
Solve for $t$
(1) $s=V_{i} t+.5 a t^{2}$
(2) $V_{i} t+.5 a t^{2}=s$
(3) $+(-s)+(-s)$
(4) $V_{i} t+.5 a t^{2}+(-s)=0$
(5) $.5 a t^{2}+V_{i} t+(-s)=0$
(6)

| Change symbol |  |
| :--- | :---: |
| from | to |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

## Informal Lab: Working through acceleration problems

## Example 1:

How long will it take an object to drop 4 feet?
(1)
(2)
(3)

Step 1: Does this question involve gravity and /or acceleration? If so, then go to:
Step 2: Inventory
(2) $\mathrm{V}_{\mathrm{i}}$
$V_{f}$
(2) a
(3) S
(1) 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 dropped from a bridge. It takes 1.35 seconds for the rock to strike the water below. How high (in ft) is the bridge above the water?
$V_{i}$
$V_{f}$
a

S
t

## (Part 2)

How fast is the rock travelling at impact?
$V_{i}$
$V_{f}$
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 $60 \mathrm{ft} / \mathrm{sec}$. How far will the ball have travelled after 2 sec.?
$V_{i}$
$V_{f}$
a

S
t


## Example 4.

A rocket boosts from the launch pad at $48 \mathrm{ft} / \mathrm{sec}^{2}$. How high is the rocket after 5 sec .?


## Example 5.

A car goes from 55 MPH 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!)


like everybody's got a rock collection."

| Q1: What is the initial velocity $\left(\mathrm{V}_{\mathrm{i}}\right)$ of the rock going up? <br> $V_{i}$ <br> $V_{f}$ <br> a <br> s <br> t | Q2: How long does it take the rock to reach max height? <br> $V_{i}$ <br> $V_{f}$ <br> a <br> s <br> t |
| :---: | :---: |
| $\mathrm{V}_{\mathrm{i}}=$ | $\mathrm{t}=$ |
| Q 3: How long does it take the rock to come back down? <br> $V_{i}$ <br> $V_{f}$ <br> a <br> s <br> t | Q4: What is the final velocity of the rock at the return point? <br> $V_{i}$ <br> $V_{f}$ <br> a <br> s <br> t |
| $\mathrm{t}=$ | $\mathrm{V}_{\mathrm{f}}=$ |

## Informal Lab Problems:

1. A bullet is fired vertically with an initial velocity $0 f 250 \mathrm{~m} / \mathrm{sec}$.

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:


Example 2:


Using a level shot to determine Muzzle Velocity ( $\mathrm{V}_{\text {muzzle }}$ )
Theory:

1. Definition of velocity: $(-)$
2. $V_{x}$ is stipulated as $\qquad$ ("idealization")
3. $V_{\text {muzzle }}$ is set at $0^{\circ}$ elevation and is therefore $\qquad$ to $\mathrm{V}_{\mathrm{x}}$
4. " S " is measured as $\qquad$
5. " t " is calculated using $\qquad$

## Calculations/measurements:

1. $S_{x}$ $\qquad$
2. $S_{y}$ $\qquad$
3. $t=$
4. $\mathrm{V}_{\text {muzzle }}=$

Determining Muzzle Velocity

$S_{y}=$ $\qquad$ (as measured)
$S_{x}=$ $\qquad$ ( as measured)

$$
t=\sqrt{\frac{S_{y}}{.5 a}}=\sqrt{\frac{.5 a}{.5 a}}=\sqrt{ }=
$$

$$
V_{x}=\frac{S_{x}}{t}=\square=\square V_{m u z z l e}
$$

(only when elevation is set at $0^{\circ}$ )

Predicting range of angled shot based on known $\mathrm{V}_{\mathrm{m}}$


OBJECTIVE: Predict $S_{x}$ given known $V_{\text {muzzle }}$

1. Proposition: $\quad S_{x}=\frac{V_{x}}{\downarrow} \times \mathrm{t}_{\text {total }} \longrightarrow\left(\mathrm{t}_{\text {total }}=\frac{\left[\left(\mathrm{t}_{1}\right)+\left(\mathrm{t}_{2}\right)\right]}{\swarrow}\right.$

$$
=(\quad) \times[(\quad)+(\quad)]=
$$

$\qquad$
3. $V_{x}=$
4. $\mathrm{V}_{\mathrm{y}}=$
5. $\mathrm{t}_{1}=$
6. $S_{y 1}=$
6. $\mathrm{T}_{2}=$

## Sound:



Frequency, wavelength, velocity:


The role of the medium in a mechanical wave
The medium determines $\qquad$ of a wave

The Doppler Effect:


## Where:

$\mathrm{v}_{\mathrm{s}}=$ Velocity of the Source
$\mathrm{v}=$ Velocity of wave
$\mathrm{f}=$ Real frequency
$f^{\prime}=$ Apparent frequency

Equation to determine velocity of source:

$$
V_{s}=\frac{V\left(f^{\prime}-f\right)}{f^{\prime}}
$$

## Doppler Effect Real World Example:

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 $\sim 4900 \mathrm{ft} / \mathrm{sec}$
2. 1 Nautical mile $\sim 6000 \mathrm{ft}$.

U.S. P-3 Orion and Soviet submarine

Structure of the atom and the nature of light

Recall:


De Broglie Wavelength


## 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, $\sim 10 \mathrm{Mpc}$ 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 $v=H_{0} D$, 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 $(\mathrm{km} / \mathrm{s}) / \mathrm{Mpc}$, which gives the speed in $\mathrm{km} / \mathrm{s}$ of a galaxy 1 megaparsec $\left(3.09 \times 10^{19} \mathrm{~km}\right)$ away. The reciprocal of $H_{0}$ is the Hubble time.

Hubble law: $V=H_{0} D$
Where:
$V=$ velocity in Km/sec
Ho = Hubble Constant $=\frac{71 \mathrm{Km} / \mathrm{sec}}{\mathrm{Mpc}}$
$\mathrm{D}=$ distance in parsecs (pc)
1 parsec (pc) = 3.26 LY



Einstein and LeMaitre


## 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

Albert Michelson

1. $\qquad$
2. $\qquad$

Luminiferous Ether (Aether) (the "Ether")

1. $\qquad$
2. $\qquad$

Michelson-Morley Experiment

- As the earth moves through the ether, the "wind" will act like the river current, affecting the motion of the light waves.
- Rotating the experiment will cause interference fringes to change, proving the existence of the ether.


George Fitzgerald $\qquad$

Hendrik Lorentz : $\qquad$


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

Time: $T_{\Delta}=\frac{\mathrm{T}}{\sqrt{1-\frac{\mathrm{V}^{2}}{\mathrm{c}^{2}}}} \quad$ Length: $\mathrm{L}=\mathrm{L}_{\Delta} \times \sqrt{1-\frac{\mathrm{V}^{2}}{\mathrm{c}^{2}}}$


## Relativity Toolbox

Where:
$\mathrm{T}_{\Delta}=$ $\qquad$
$\mathrm{T}=$ $\qquad$
$\mathrm{C}=$ $\qquad$
$\mathrm{V}=$ $\qquad$
$\mathrm{L}_{\Delta}=$ $\qquad$
$\mathrm{L}=$ $\qquad$

Relativistic Velocities ( $\qquad$ )

Non-Relativistic Velocities $\qquad$
"Gamma" $(\gamma)$ is the factor that allows us to compute $\qquad$ in both
$\qquad$ and $\qquad$ given a specific velocity; these effects are most evident at $\qquad$
$\qquad$ , but occur at any and all velocities.

## Einstein's Two Postulates of Special Relativity:

1. The laws of physics $\qquad$
2. The speed of light $\qquad$
$\qquad$

## 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 ")

$$
\text { ( } C=186,000 \mathrm{mi} / \mathrm{sec}, 300,000 \mathrm{~km} / \mathrm{sec} \text {, and } / \text { or } 3.0 \times 10^{8} \mathrm{~m} / \mathrm{sec} \text { ) }
$$

We'll start with a ridiculous imaginary clock:


After 1.0 sec of travel :


## 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. 1

fig 2. Ground Control observer's console

(camera image)
Ship's clock


Ground Control clock

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?

Step 1: Calculate "Gamma" $(\gamma)$
$\gamma=\sqrt{1-\frac{V^{2}}{c^{2}}}$

Step 2: Solve for $\mathrm{T}_{\Delta}$
$\mathrm{T}_{\Delta}=\frac{\mathrm{T}}{\gamma}$

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

$$
\mathrm{L}=\mathrm{L}_{\Delta} \times \gamma
$$

## 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 .998 c and a "life span" of $\mathbf{2 . 2 \times 1 0 ^ { - 6 }}$ 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 :


In other words, according to classical Newtonian principles 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 l'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 | $v^{2}$ | $1-v^{2}$ | $\begin{aligned} & \sqrt{\left(1-v^{2}\right)} \\ & \left(" \mathbf{Y}^{\prime \prime}\right) \\ & \hline \end{aligned}$ |
| :---: | :---: | :---: | :---: |
| (. 1 or one-tenth under " c ") | . 81 | . 19 | . 44 |
| (. 01 or one-hundredth under " c ") | . 980 | . 02 | . 14 |
| .999c <br> (. 001 or one-thousandth under "c") | . 998 | . 002 | . 045 |
| $\begin{array}{r} .9999 \mathrm{c} \\ \begin{array}{r} \text { (.0001 or one-ten thousandth } \\ \text { under "c") } \end{array} \\ \hline \end{array}$ | . 9998 | . 0002 | . 014 |
|  | . 99998 | . 00002 | . 0045 |
|  | . 999998 | . 000002 | . 0014 |
| .9999999c <br> (. 0000001 or one-ten millionth under " c ") | . 9999998 | . 0000002 | . 00045 |
| .99999999c <br> (. 00000001 or one-hundred millionth under " c ") | . 99999998 | . 00000002 | . 00014 |
|  | . 999999998 | . 000000002 | . 000045 |
| $\begin{array}{r} .9999999999 \text { c } \\ \text { (.0000000001 or one-ten billionth } \\ \text { under " } c \text { ") } \end{array}$ | . 9999999998 | . 0000000002 | . 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 $5.86 \times 10^{-8} \mathrm{Kg}$

Formula for Kinetic Energy

$$
\begin{gathered}
K E=\frac{1}{2} m v^{2} \\
\text { or } \\
K E=.5 m v^{2}
\end{gathered}
$$

## 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?

Comparison: The energy released by atomic bomb detonated over Hiroshima was approximately $6.5 \times 10^{13}$ Joules, or $65,000,000,000,000$ or 65 thousand billion Joules

The effects of acceleration on the path of a photon


## 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 $\qquad$

Einstein's view: $\qquad$

Proof of gravity affecting light during solar eclipse:


## Another Thought Experiment:

Escape Velocity: $\qquad$

Data:
$V_{e S C}=\sqrt{\frac{2 G M}{r}}$
$\mathrm{G}=60672 \times 10^{-11}$
$M=6.0 \times 10^{24} \mathrm{Kg}$
$r_{\text {earth }} 6.37 \times 10^{6} \mathrm{~m}$

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


The Most Famous Equation in the World:

$$
E=m c^{2}
$$

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

$$
\mathrm{E}=\Delta \mathrm{mc}^{2}
$$

Where:
$\mathrm{E}=$ "Binding Energy"
$\Delta \mathrm{m}=$ "mass defect"
$C^{2}=$ speed of light squared $\left(3.0 \times 10^{8}\right)^{2}$

## Data:

Mass of a proton $=1.67262 \times 10^{-27} \mathrm{Kg}$ Mass of a neutron $=1.67493 \times 10^{-27} \mathrm{Kg}$
Mass of an electron $=9.1094 \times 10^{-31} \mathrm{Kg}$

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
${ }_{2}^{4} \mathrm{H}$ compared to ${ }_{92}^{235} \mathrm{U}$

Top \# = $\qquad$

Bottom \# = $\qquad$

2 protons = $\qquad$ Kg


Predicted total $=$
 Kg
Actual total $=6.6463 \times 10^{-27} \mathrm{~kg}$
Difference: $\qquad$ Kg
(Missing mass or " ")

$$
\begin{aligned}
& \mathrm{E}=\Delta \mathrm{mc}^{2} \\
& \text { = } \\
& \text { X } \\
& \text { = } \\
& \text { X } \\
& \text { = } \\
& \text { Joules }
\end{aligned}
$$

Now compare the mass - energy conversion factor:


Note the exponential difference

Finally:

$$
E=m c^{2}
$$

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 Fundamental Forces:
B.B.

0 sec $10^{-43}$ sec
Described by:


Conflict: The existence of $\qquad$
$\qquad$
$\qquad$
String Theory - possible solution?
All "matter" is $\qquad$
Original model called for the existence of $\qquad$
$\qquad$
Problems developed because of mathematical $\qquad$

Anomalies resolved by $\qquad$
Strength of String Theory: $\qquad$
Weakness of String Theory: $\qquad$


