PHYS 110
TECHNICAL PHYSICS
STUDENT WORKBOOK

(3rd Edition revised Dec 2020)

Professor Kevin Kimball, B.S.

SMCC Physical Science Department

USN – retired

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.

For 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: $3x^2$ ____________

Scientific Notation: 3×10^2 ____________

The same rules pertaining to _______________ , __________________and _____________________ in Scientific Notation also apply in algebra.

Coefficient:

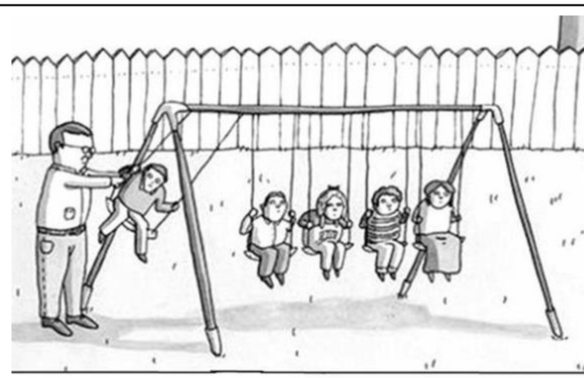
Base:

Exponent:

Oog, the Cave Man

Positive Exponents

Let’s start with the easy stuff - multiplication:



Why physics teachers should not be given playground duty

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^{st} power equals ___________________________

Standard Notation:

Lab exercises:

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

L R

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 _________________

"Cheater Rule" for Standard Notation:

Any number in standard notation can be expressed as _____________ times ___________

General Rule for correct scientific notation:

"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: Convert 873.463 into correct scientific notation	**Example 2:** Convert 0.00785 into correct scientific notation	**Example3:** Convert 56.98 x 10^{5} into correct scientific notation

Convert to correct scientific notation:

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

Convert to standard notation:

1.63×10^{3}	3.637×10^{-1}
2.94×10^{-6}	36.345×10^{2}

Operations in Scientific Notation

Multiplication Critical Rules:

Multiply _______________

Retain ________________

Add __________________

NOTE:
Adding a negative number is the same as __________________ a ________________ _______________
____

Example 1:

$(4.75 \times 10^3) \times (2.43 \times 10^7)$

____

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:

$(9.35 \times 10^{8}) \div (3.54 \times 10^{4})$

____

Example 2:

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

Addition/Subtraction Critical Rules:

Exponents ____________ ___________

Add/Subtract ____________________

Retain __________________________

Retain __________________________

Example 1:

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

Example 2 :

$(9.56 \times 10^{5}) - (8.47 \times 10^{4})$

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: $(2.56 \times 10^{\mathbf{3}})^{\mathbf{2}}$	Example 2: $(2.56 \times 10^{\mathbf{3}})^{\mathbf{3}}$
Example 3: $(3.12 \times 10^{\mathbf{-6}})^{\mathbf{2}}$	Example 4: $(3.12 \times 10^{\mathbf{-6}})^{\mathbf{3}}$

Square Roots/Cube Roots in Scientific 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: $\sqrt{9.46 \text{ x } 10^6}$	Example 2: $\sqrt[3]{9.46 \text{ x } 10^6}$
Example 3: $\sqrt{8.1 \text{ x } 10^5}$	Example 4: $\sqrt[3]{8.1 \text{ x } 10^5}$

$(3.93 \times 10^{7}) \times (5.37 \times 10^{6})$	Answer:
$(3.92 \times 10^{3}) \times (3.48 \times 10^{-5})$	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:

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

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

$\sqrt{2.36 \times 10^7}$ Change to : $\sqrt{23.6 \times 10^6}$ (exponent divisible by 2) $= 4.858 \times 10^3$	4.858×10^3
$(2.64 \times 10^7) - (1.37 \times 10^7)$ 2.64×10^7 -1.37×10^7 1.27×10^7	1.27×10^7
$(3.93 \times 10^7)^2$ $= 15.445 \times 10^{14}$ $= 1.5445 \times 10^{15}$	1.5445×10^{15}
$(5.37 \times 10^6)^3$ $= 154.854 \times 10^{18}$ $= 1.54854 \times 10^{20}$	1.5485×10^{20}
$\sqrt{8.26 \times 10^8}$ 2.874×10^4	2.874×10^4
$\sqrt[3]{5.06 \times 10^{16}}$ change to: $\sqrt[3]{50.6 \times 10^{15}}$ (exponent divisible by 3) $= 3.699 \times 10^5$	3.699×10^5

Metric System

Major advantage of the metric system:

It can be applied directly to ______________ ________________

Uses a system of __________ and ______________

Units relate to specific _____________ (“whatcha got”)

Prefixes are specific __________________ (“how many you got”)

Prefixes are mathematically ______________ with ___________ of ________

____

Examples of units:		Examples of prefixes:	
UNIT:	MEASUREMENT OF:	PREFIX:	EQUIVALENT:
Meter	________________	Centi	____________ or ______
Liter	________________	Milli	____________ or ______
Gram	________________	Kilo	____________ or ______

Hence:

8.5 centimeters = 8.5 x _______ meters

500 milliliters = 500 x ______ liters

6.75 kilograms = 6.75 x _______ grams

BOTTOM LINE:

Any prefix can be replaced or substituted with a _________ of _______

COMMONLY USED METRIC PREFIXES: (Required knowledge!)

Prefix:	Standard notation:	Fraction:	Power of ten:
giga			
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:

	Scientific Notation	Standard Notation
8.97 kilograms = ? grams		
6.5 centimeters = ? meters		
7.5 gigavolts = ? volts		
4.7 microFarads = ? Farads		
6.4 megawatts = ? watts		
9.87 mililiters = ? liters		

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

Conversion hack:

Convert 3.567×10^5 gigavolts to millivolts

Self - check

(Answer in correct scientific notation)

5.98 x 10^4 kilograms = _?_ grams	
8.34 x 10^{-1} meters = _?_ centimeters	
5.92 x 10^{-4} megawatts = _?_ watts	

(Answer in standard notation:)

500 millivolts = _?_ volts	
345 grams = _?_ kilograms	
6.73 x 10^5 centimeters = _?_ meters	
3.81 x 10^{-4} volts = _?_ microvolts	

(Answer in correct scientific notation:)

3.45 x 10^5 microvolts = _?_ kilovolts	
7.93 x 10^{-5} kilograms = _?_ milligrams	
5.78 x 10^3 millimeters = _?_ centimeters	
4.32 x 10^3 gigahertz = _?_ megahertz	

Physics terms

Displacement:

Definition(s):

1. _____________and ______________

2._____________ and______________

Symbol: ______

Standard units:

1. British ("U.S Standard"):______________

2. Metric: _____________

NOTE: In this context "displacement" does NOT refer to ____________

Force:

Definition(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 units:

1. British: _______________ (not __________)

2. Metric: ________/____ (not __________)

Volume:

Definition:

1. ____________________________

Standard units:

1. British: _______________ (__________)

2. Metric: _______________ (__________)*

* 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 ______________ __________ ___ __________"

- _______________ _______________

Standard unit: (both British and metric)

1. _____________ (NOT _______ or _____________)

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 ________________ _____________ , 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:

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

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:

$$\frac{35\ miles}{1\ hour}$$

Step 2: Set up multiplication problem in fraction form so that the terms you wish to change will be ___________ - ________________ :

$$\frac{35\ mi}{1\ hour} \text{ x } \frac{\square}{mi} \text{ x } \frac{hour}{\square}$$

Step 3: Replace terms with those you want:

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

Step 4: Inert correct mathematical equivalences:

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

Step 5: Cross-cancel terms:

$$\frac{\mathbf{35}\ \cancel{miles}}{1\ \cancel{hour}} \text{ x } \frac{\mathbf{5.28} \text{ x } \cancel{10^3}\ \boldsymbol{feet}}{1\ \cancel{mile}} \text{ x } \frac{1\ \cancel{hour}}{\mathbf{3.6} \text{ x } \cancel{10^3}\ \boldsymbol{sec}}$$

Step 6: Restate with remaining terms:

$$\frac{35 \text{ x } 5.28\ feet}{3.6\ sec}$$

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

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

______________ * **ft/sec** (final answer)

Conversion factors you should know:			
1 mile = 5.28 x 10^3 ft	**1 mile = 1.61 x 10^3 meters**	**1 kilometer = 10^3 meters**	**1 hour = 3.6 x 10^3 seconds**

Self -check: conversions

Answers:

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")

Example 1

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

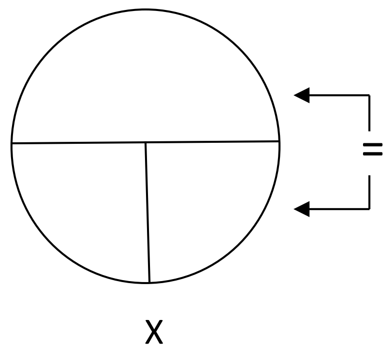
then:

$$\frac{12}{3} = 4$$

$$\frac{12}{4} = 3$$

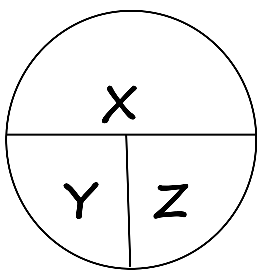
and $3 \times 4 = 12$

Or:



Example 2

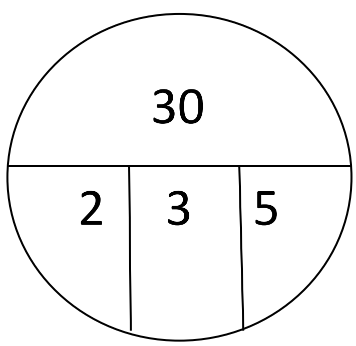
Given:



Then:

Example 3

Given:



Then: 30 = ____________________

2 = ____________________

3 = ____________________

5 = ____________________

"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

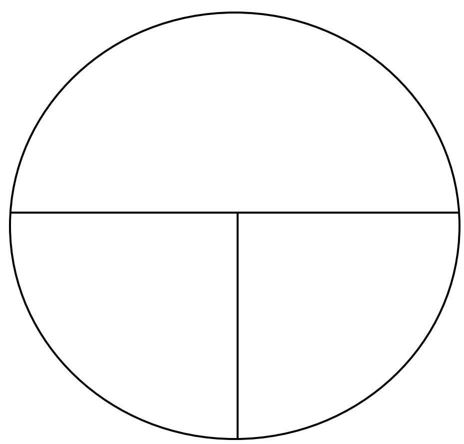
Example 4:

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

Traditional solution:

Using the "egg"

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



d = ________

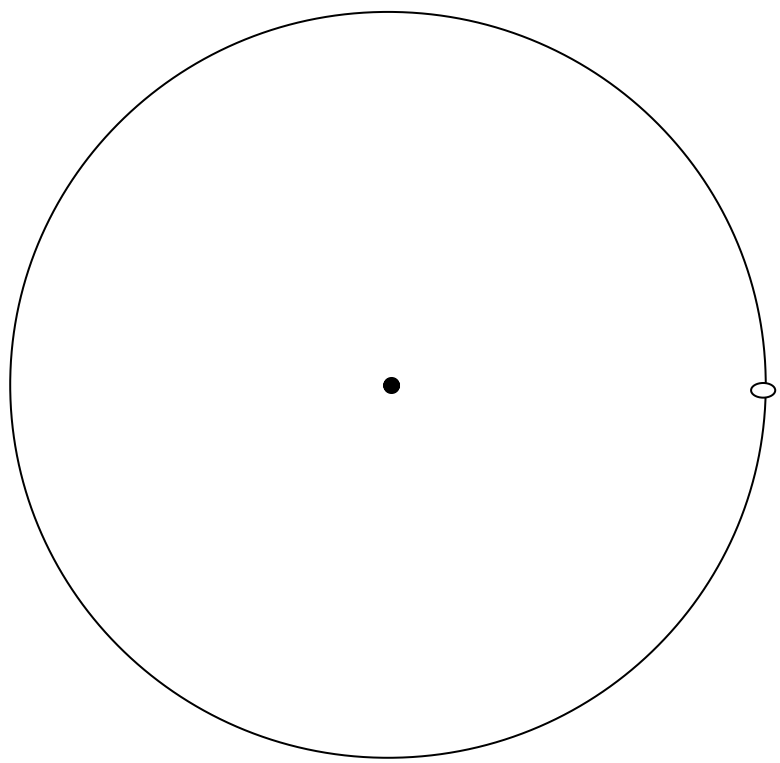
Self check:

Equation:	"Egg"	Solution ("n" = ?)
F = ma		m =
$P = \frac{W}{T}$		T =
$2as = (V_f^2 - V_i^2)$		a =
$KE = ½mv^2$ (Hint: ½ = .5)		m =
D = R x T		T =
PE = mgh		h =
A = (cos θ)(H)		H =
$a = \frac{V_f - V_i}{t}$		t =

Structure of atom - a key to understanding "mass"

Example 1:

Hydrogen:



Proton:

1 . _______________ charge

2. Has approximately ______________ times the mass of electron

Electron:

1. ______________charge

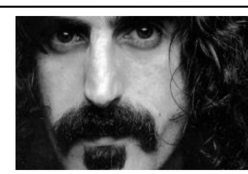
Hydrogen:

1. _________________ of all atoms

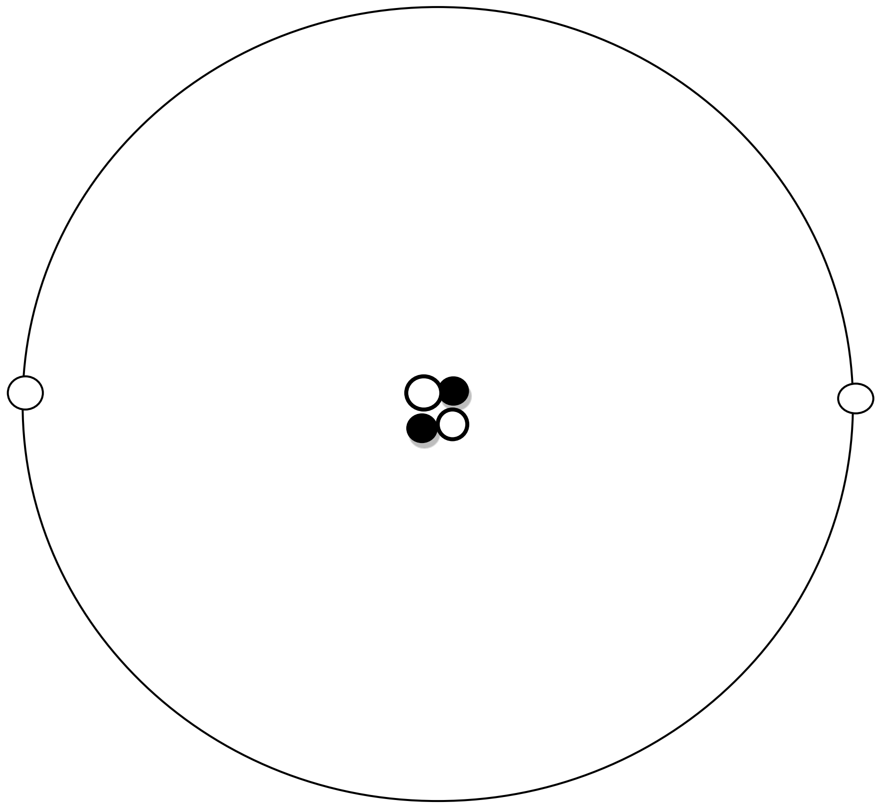
2. __________________________________ element in the universe

"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 ____________ and _____________

2. Accounts for _______ _____ of atom's mass

Neutron:

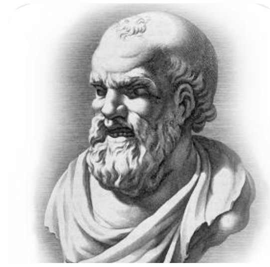
1. Slightly more _________ than a proton, hence it also has

   approximately __________ times the mass of electron

2. ___________ charge

By volume, an atom is over ____________ percent ________ __________

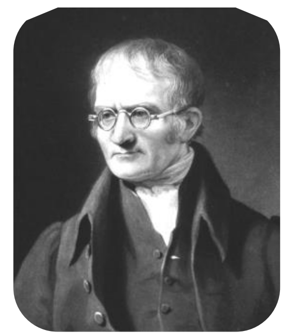
Atom Model History



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 _________________ .

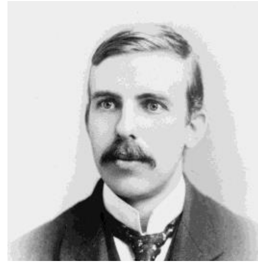
Joseph John Thompson - 1897

1. “Plum _____________ “ ____________ :

a. A sphere of diffuse ________________ electricity with

negative _______________ imbedded throughout

2. Discovered _______________, and was awarded ________ in 1906



The " Solar System" Model

Ernest Rutherford - 1911

1. Discovered that the atom is mostly __________ _________ with a

dense _______________ charged ________________ surrounded by

negative ___________________

Neils Bohr - 1913

1. Electrons travel in ___________________ ____________

2. Only ______________ ______________ allowed

3. Modern ___________ of the _______________

> *"Everything we call real is made of things that cannot be regarded as real."*

Electron Cloud Model - 1920's

1. **Erwin Schrodinger**[1] and **Werner Heisenburg**[2]

Developed ________________ functions to determine regions or clouds in

which ________________ are most likely to be found

2. Heisenberg: Developed the ________________ Principle : Impossible to

predict _______________ of single electron

1

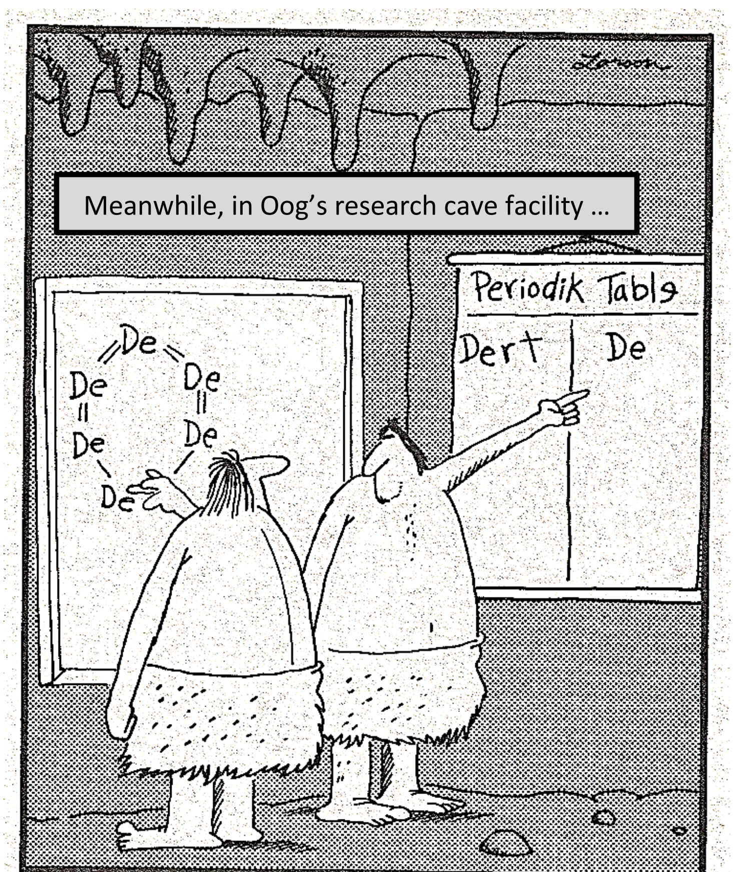
2

James Chadwick - 1932

1. British experimental physicist credited with discovering the __________

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.

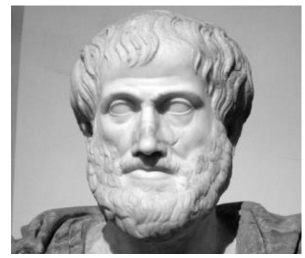
Aristotle

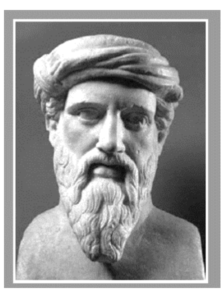
1.____

2.____

3. ____

4. ____





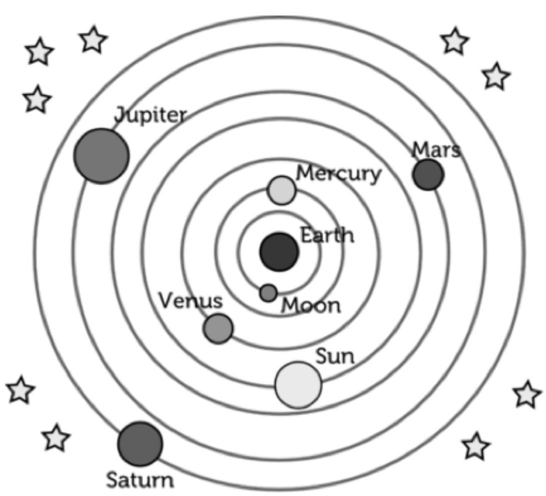
Pythagoras

____

____

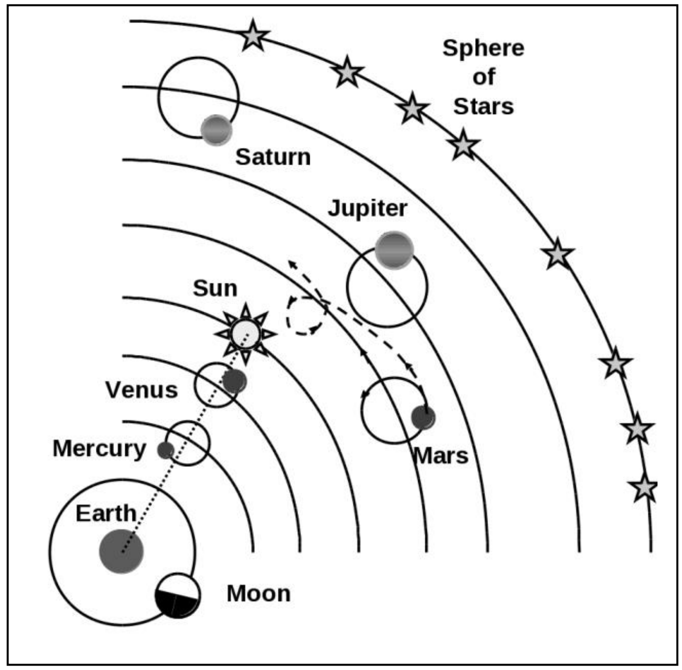
____

____



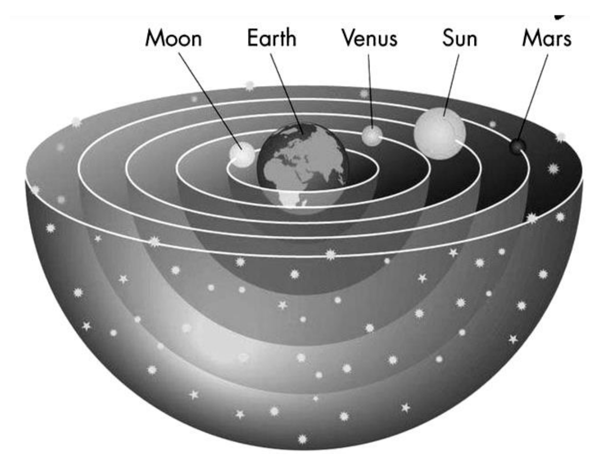
Earth at the Center

Ptolemy



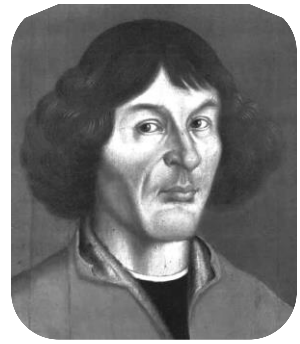
Epicycles

Deferents



Crystal Spheres

Copernicus

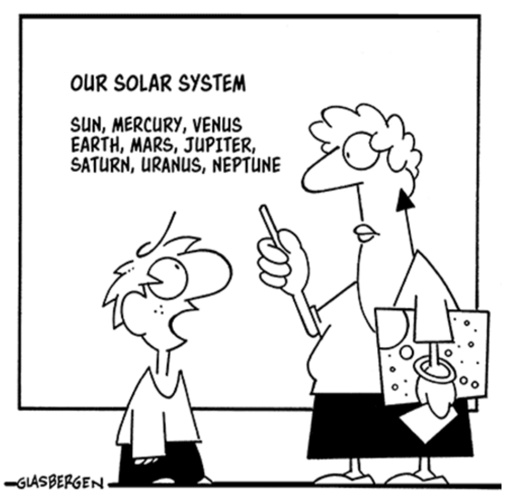


1. ____

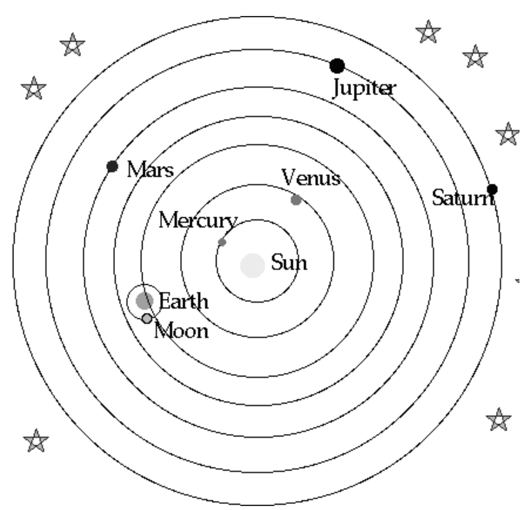
2. ____

3. ____

4. ____



"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 ____

2. Discovered the ________________ of ___________________________

3. Discovered the ________________ of ___________________________

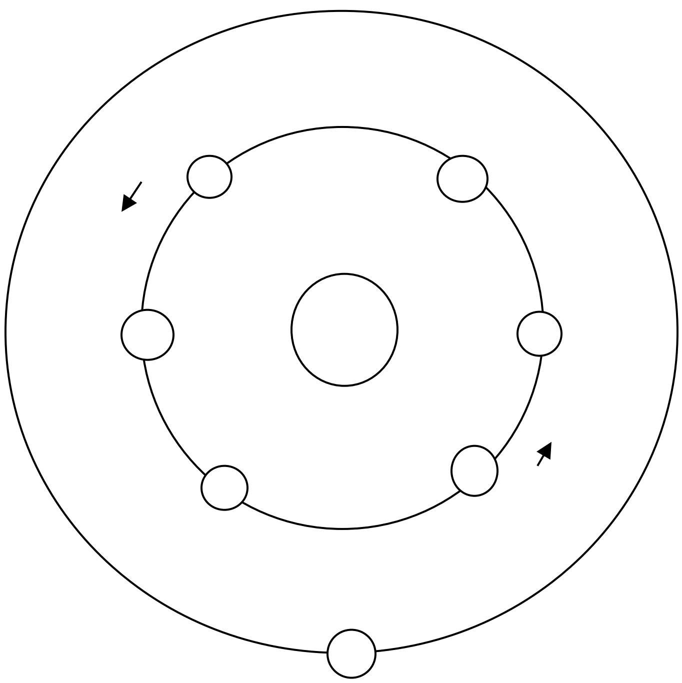
4. Discovered ____

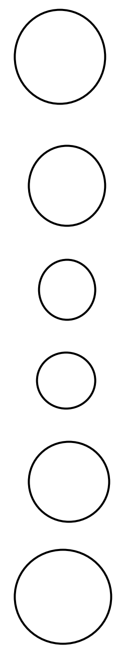
____

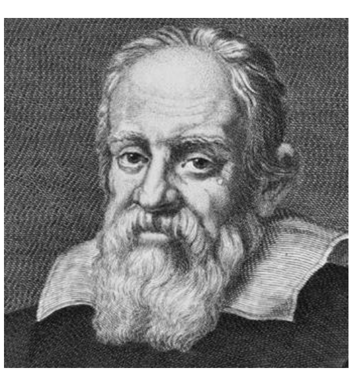
4. Prime author of the ____________________   ___________________

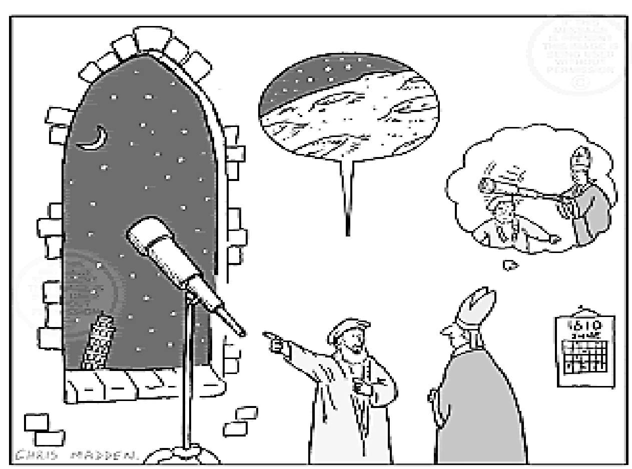
5. Was tried for ____

____









GALILEO DESCRIBES HIS DISCOVERIES
TO THE CHURCH

Sir Isaac Newton:

1. Wrote ____

____

2. Discovered ____

____

____

3. Established the link ____

____

4. Sought to ____

____

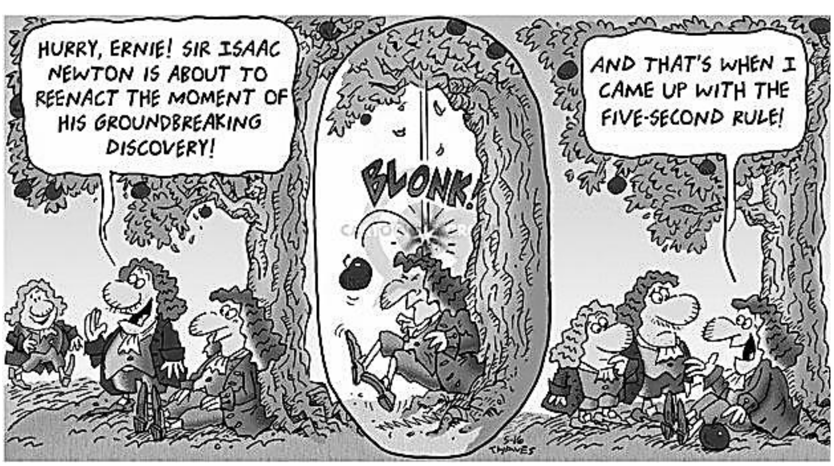
5. Emphasized A_____________________ , ______________________ results@

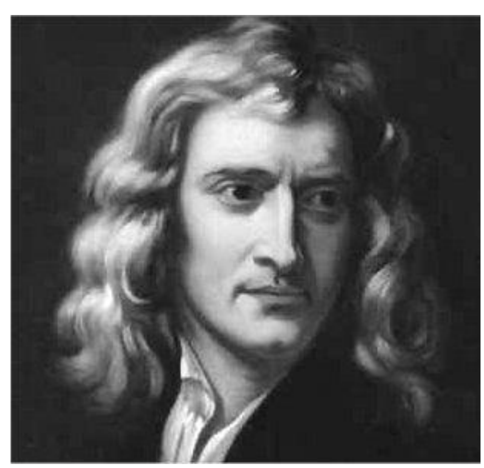
6. Invented ____

7. Derived planetary motions ____

____

____





The Scientific Method

"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."

-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.

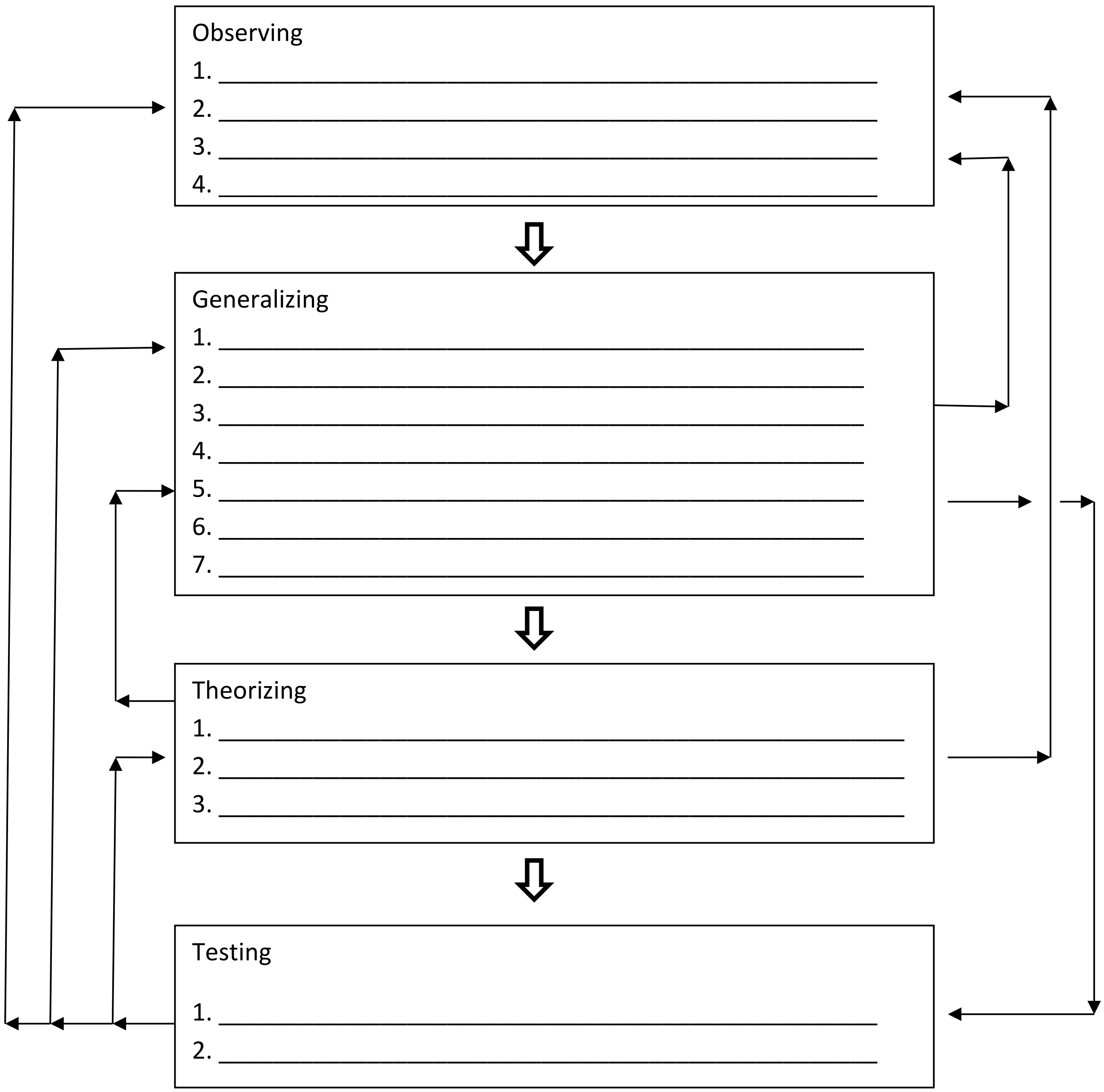
· *Quantitative methods*. Galileo went to great lengths to measure the motion of bodies.
· He understood that a theory capable of making quantitative predictions was more
· powerful than one that could make only descriptive predictions, because quantitative predictions were more specific and could be 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:

2. Hypothesis:

3. Idealizations (Galileo):

4. Limiting the Scope of Inquiry (Galileo):

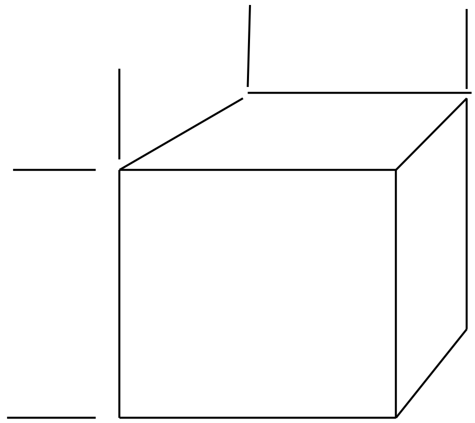
5. Quantitative methods (Galileo):

6. Creating a model:

7. Repeatable, predictable results/outcomes (Newton):

8. Fact-based rather than authority-based knowledge:

Volume:



Volume = length x height x width

= ________ x ________ x _________ = ________   _________

and also = ________ x ________ x _________ = ________   _________

Therefore, ________ M^3 is equivalent to ___________ or _____ cm^3

Additionally:

1 M^3 = _________ or _______ liters (L)

1 liter = ________ or _______ milliliters (mL)

Using "factor-labeling" conversion method to determine # mL in 1 M^3:

1 M^3 x 10^3 Liters x 10^3 milliliters = _____________ milliliters
1 1 M^3 1 Liter

Since 1 M^3 equals ________ cm^3 and also _________ mL ,

_______cm^3 = _______ mL; a cm^3 is also referred to as a "________"

Mass Density Calculations

Mass Density (D_m) (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^3

Solution:

Use factor-labeling to convert grams/cm^3 to Kilograms/M^3

1. Restate the raw data as fraction:

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

2. Add conversion factors for cancellation:

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

3. Restate with remaining terms and perform necessary calculations:

$$\frac{67.5\ \boldsymbol{x}\ 10^3 Kg}{30\ m^3} \quad = \quad \_\_\_\_\_\_\_\_\_\_\_ \text{Kg/m}^3$$

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

Example 2:

<u>Predicting the mass of a sample of known material</u>

Given a 50 cm³ sample of lead, predict the mass

Solution: Set up a proportionality equation using the known D_m of lead

Step 1:

State the known D_m of lead

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

Step 2:

Set up as equivalent to given sample

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

Step 3:

Convert all quantities to like terms (grams, cm^3, since this is a small sample)

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

Review: Cross-multiplying

$$\frac{a}{b} = \frac{c}{d} \quad \Downarrow \quad a \times d = b \times c$$

$$\frac{2}{3} = \frac{12}{18} \quad \Downarrow \quad 2 \times 18 = 3 \times 12$$

Step 4: Cross-multiply

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

Now the equation becomes:

_________________ x _______________ = ______________ x ______________

After canceling like terms, the equation becomes

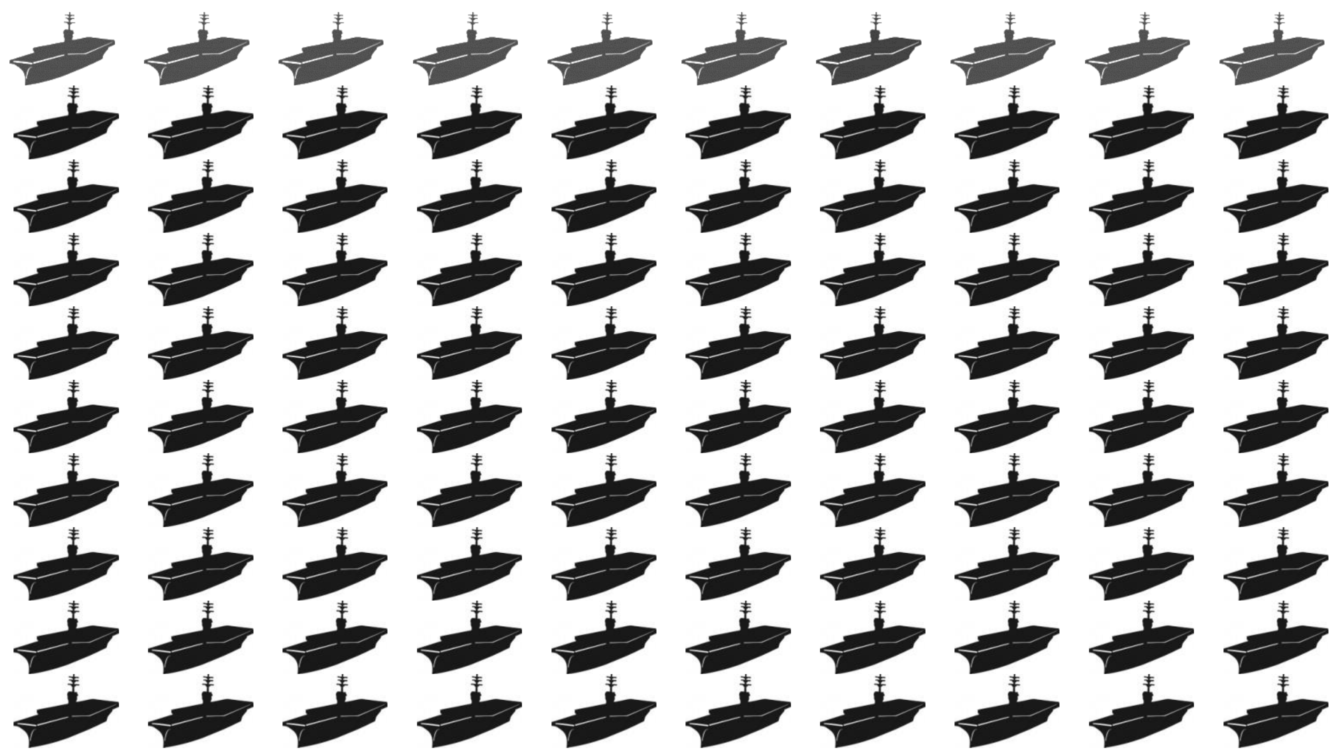
_________ x ________ = ______

Thus, a 50 cm³ 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.

=



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 cm^3 sample of iron	answer:

Vectors:

Two types of measurement used in Physics; they are

1.________________measures

b. Indicate _______________ only

2.________________ measures

a. Indicate ___________________ and _______________

Examples:

Scalar	Vector
____________________	_________________________
____________________	_________________________
____________________	_________________________

Since vector measures include the component of ___________________ then that component must be taken into consideration during ______________________ .

Example 1: Two bungee cords pulling in opposite directions:

Example 1a:

●

Net force:_________________

Example 1b:

●

Net force: _________________

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

●

Net force:___________________

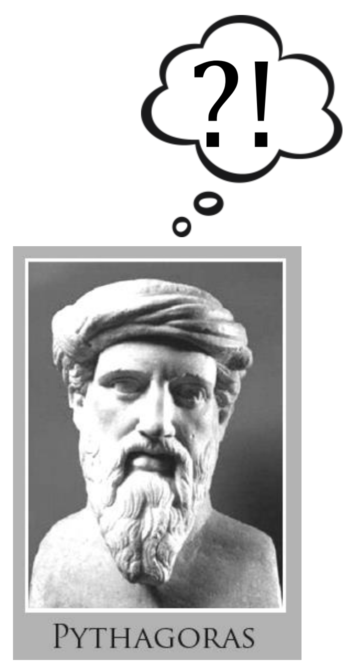
Note:

At this point you should see the ______________ of net forces, or

the “________________ - _________________”

Example 3: Two bungee cords pulling at a 90^o angle relative to one another

Solution: Use "___________ to ___________ " schematic



The sum of these two vectors is called a "_______________"

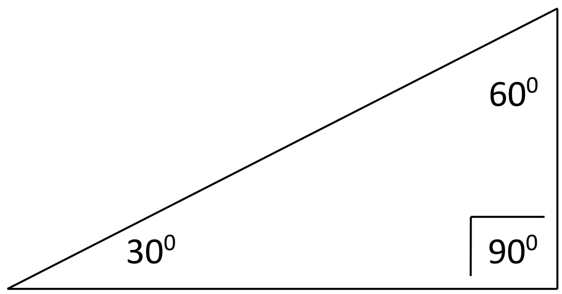
BUT,
The Pythagorean Theorem will solve ____________________ only

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 30^0** as an example.

Method 1:

1. Hit [sin]
2. enter "**30**"
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 "**2nd**" 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"**

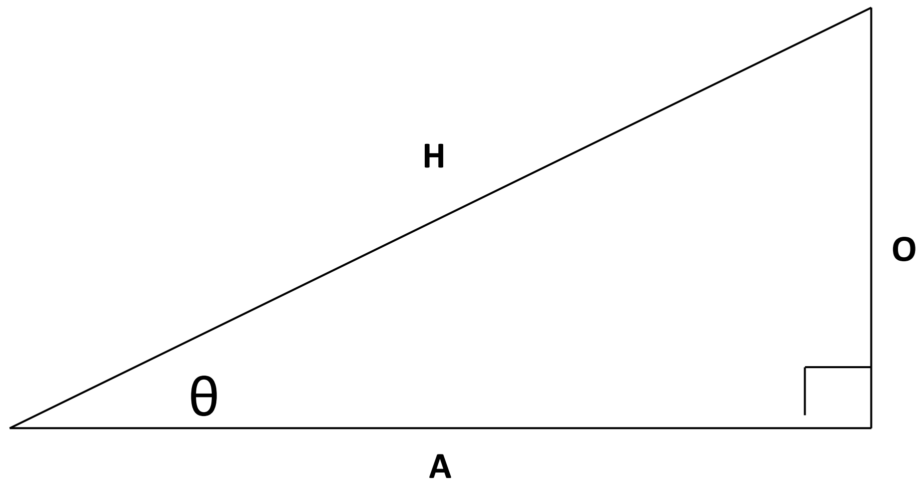
Method 2 (more common on simpler, less expensive calculators):

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



θ ("Theta"): ____

Hypotenuse: ____

Opposite: ____

Adjacent: ____

Sine θ (sin θ) :

the ratio of the _______________ side over the _____________

Cosine θ (cos θ):

the ratio of the _______________ side over the _____________

Tangent θ (tan θ)

the ratio of the _____________side over the _____________side

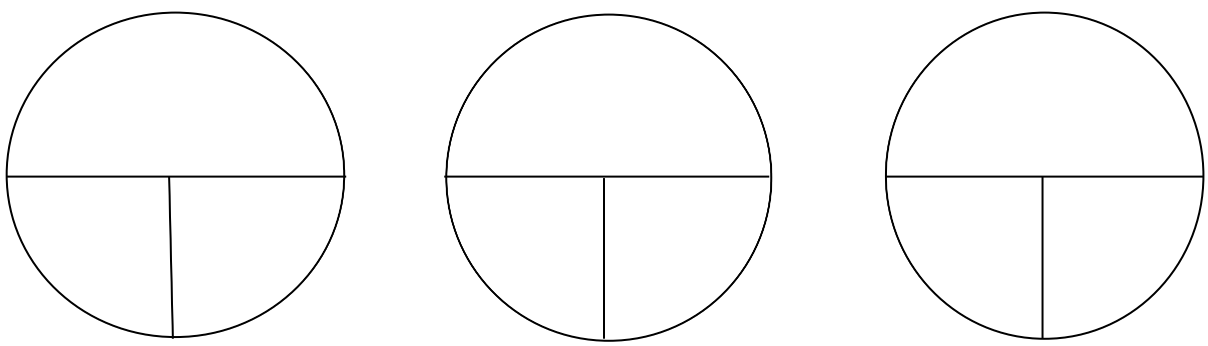
Stated more simply:

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

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

$\tan\theta = \frac{O}{A}$

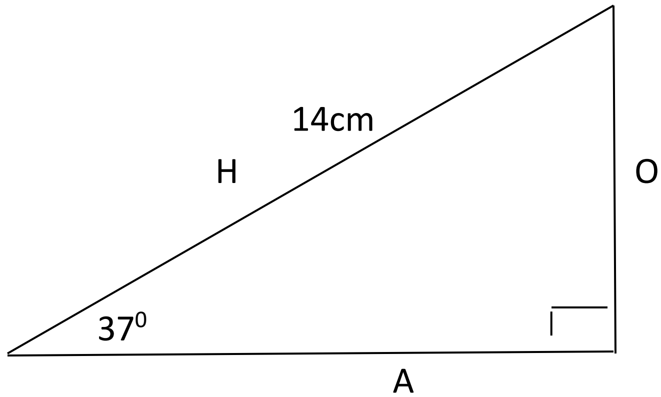
Stated yet another way:



Sin θ =	Cos θ =	Tan θ =
O =	A =	O =
H =	H =	A =

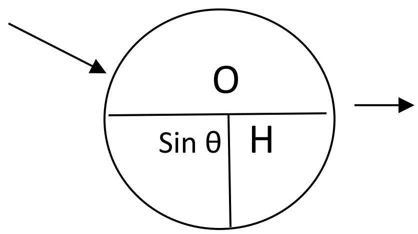
Using Trig

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)**

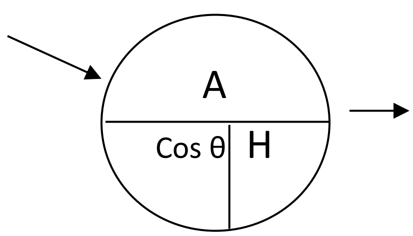


$O = (\text{Sin } 37^0) \times H$

= (   ) x (14)

= ______________

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

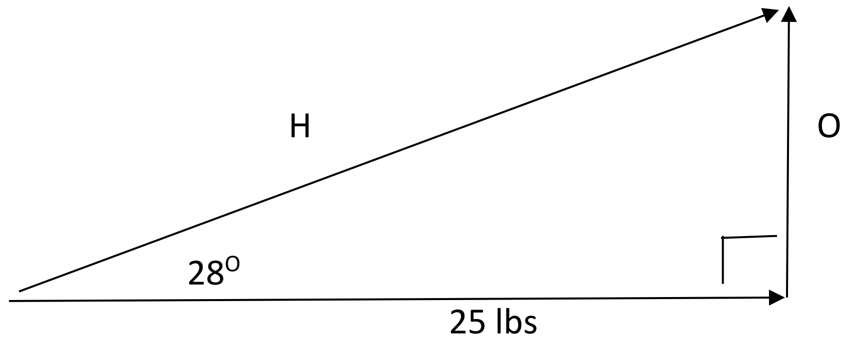


$A = (\text{Cos } 37^0) \times H$

= (   ) x (14)

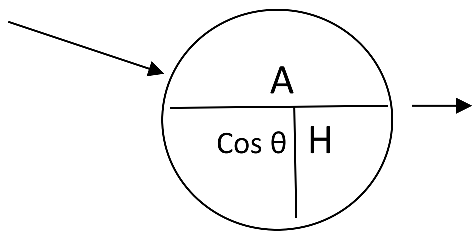
= ______________

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)**

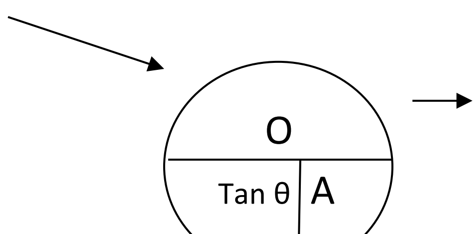


$$H = \frac{A}{\text{Cos } 28^0}$$

$$= \frac{25}{\quad}$$

= ______________

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

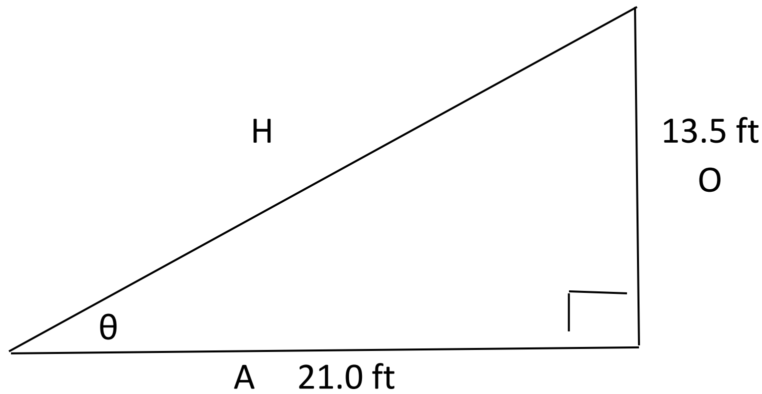


$O = (\text{Tan } 28^o) \times A$

$= (\qquad\qquad) \times (25)$

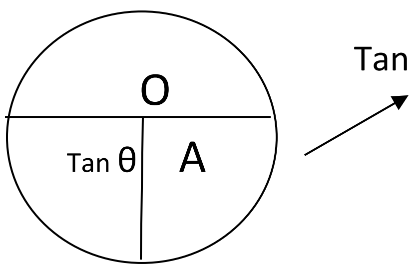
= ______________

Example 3:



Determine length of "H" and the value of "θ"

1. Begin by determining "θ". Since "O" and "A" are known, use "Tan".



$\text{Tan } \theta = \frac{O}{A} = \frac{13.5}{21.0} = $ ____________

Tan^{-1} ________________ → ________________
(reciprocal function)

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 30^0 is 0.5**, we'll start there.

Method 1:

1. Hit "**Shift**" or " **2^{nd}** "
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^{nd}** "
3. Hit [sin]
4. Your answer should be **"30"**

Practice using other trig functions:

$\cos^{-1} .866 \rightarrow 30^0$

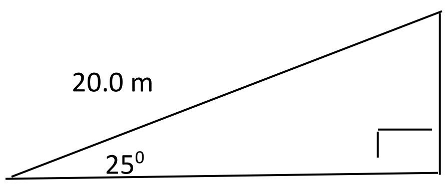
$\tan^{-1} .577 \rightarrow 30^0$

Informal Lab: Practice problems

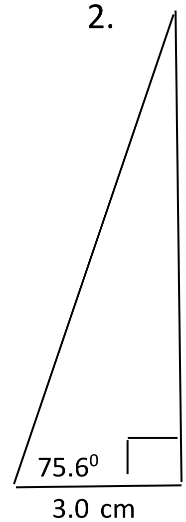
ASSIGNMENT: Solve for unknown sides and angles using trigonometry
plus additional instructions below:

1. Do **NOT** Pythagorean Theorem!
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!***

1.

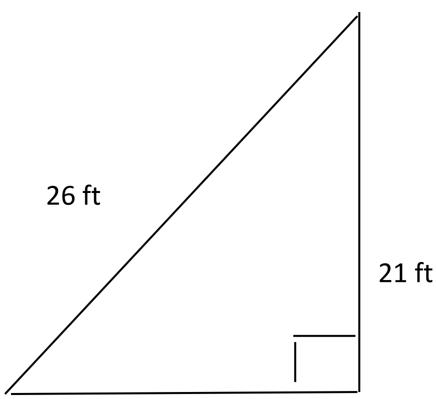


2.

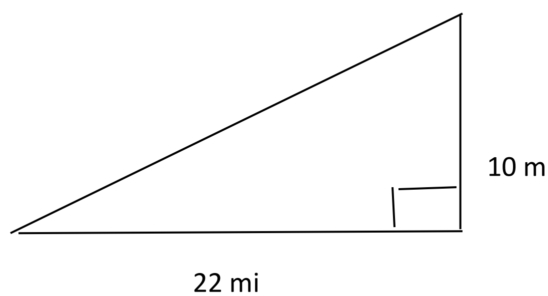


Hint:
Do **not**
"rotate"
this one!

3.



4.



Practical principles:

1. The sine, cosine, and tangent of any/every angle between _______ and ________ is ____________ to that angle alone.

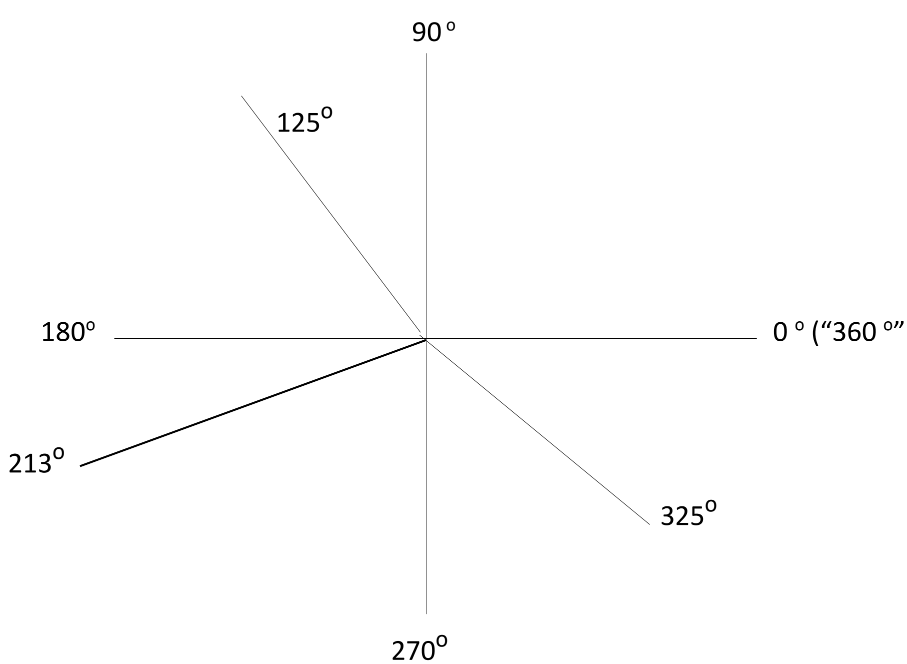
2. Thus, if we know the sine, cosine and/or tangent of an angle, then we have the means to _____________ the original angle.

3. NOTE:
This course will take the "old-school trig" approach in analyzing angles, and therefore <u>all</u> angles ("vectors") will be evaluated as if their measures are between _____ and _____ .

Example 1:
125^{o} will be evaluated as ______ (180^{o} - 125^{o}) (measure from x-axis)

Example 2:
213^{o} will be evaluated as ______ (213^{o} -180^{o}) (measure from x-axis)

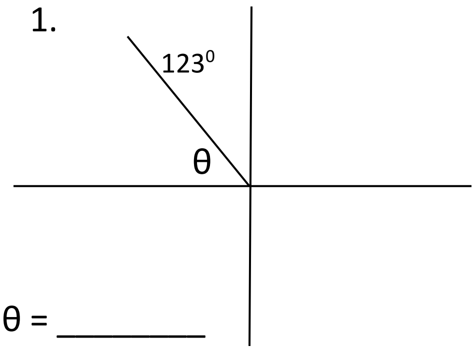
Example 3:
325^{o} will be evaluated as ______ (360^{o} - 325^{o}) (measure from x-axis)



Informal Lab: Practice evaluating angles

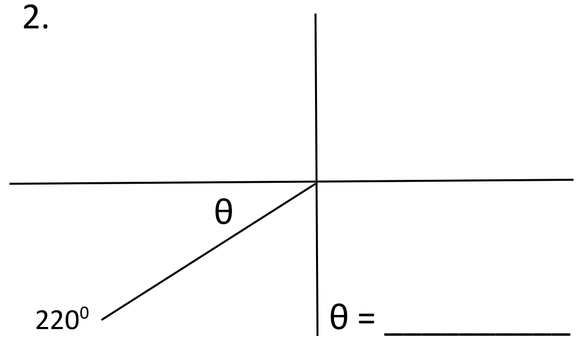
Hint: **Always** measure from the **closest horizontal** (“*x* – axis”)

1.



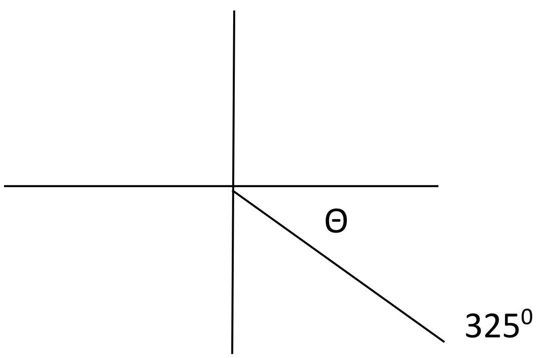
θ = _________

2.



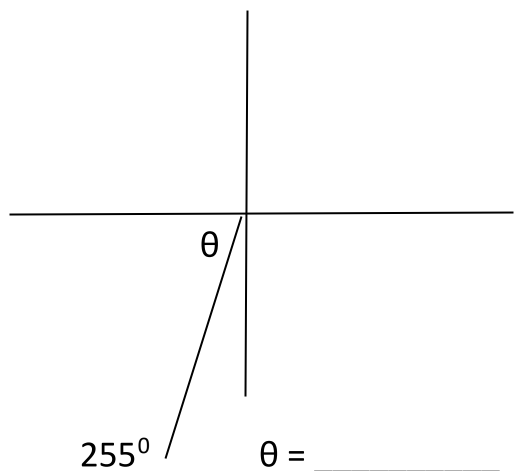
θ = ___________

3.



θ = ___________

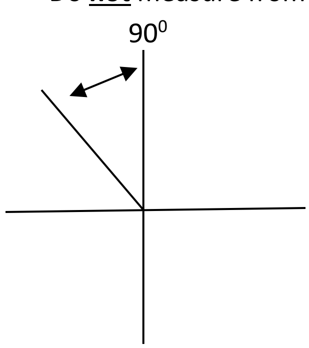
4.

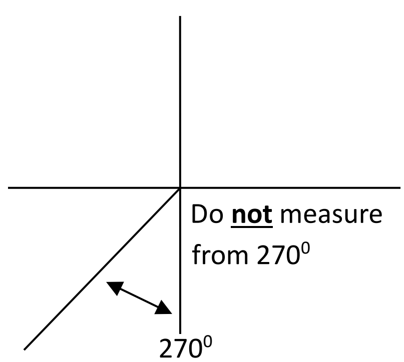


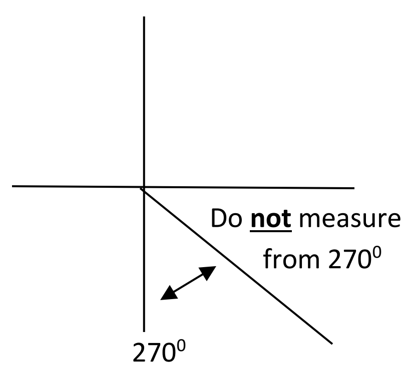
θ = ___________

Common mistakes:

Do **not** measure from







ANSWERS: 1. 57^0 (180 – 123) **2.** 40^0 (220-180) **3.** 35^0 (360-325) **4.** 75^0 (255-180)

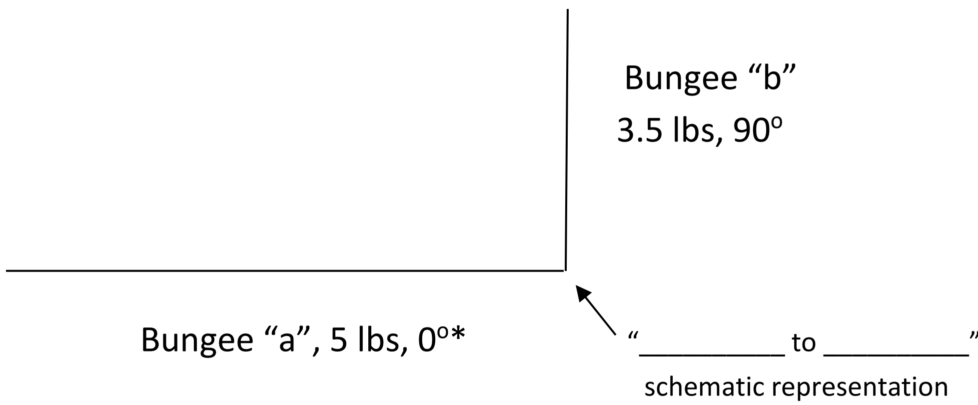
Back to the beginning of this topic:

Given:

1. Two bungee cords attached at a common point.
2. Bungee “a” pulls with 5 pounds of force at 0^o
3. Bungee “b” pulls with 3.5 pounds of force at 90^o
4. What is the sum of the forces of the two bungee cords?

Solution:

Draw *:



*** NOTE: <u>Always</u> draw ________________________ vector <u>first</u>**
<u>beginning</u> with the ________________________

1. Calculate the tangent of the unknown angle “____” : tan = ——— = ___________
2. $\tan^{-1}$ ___________ → _________________
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,

H = ——————— = ——————— = _____________ (solution)

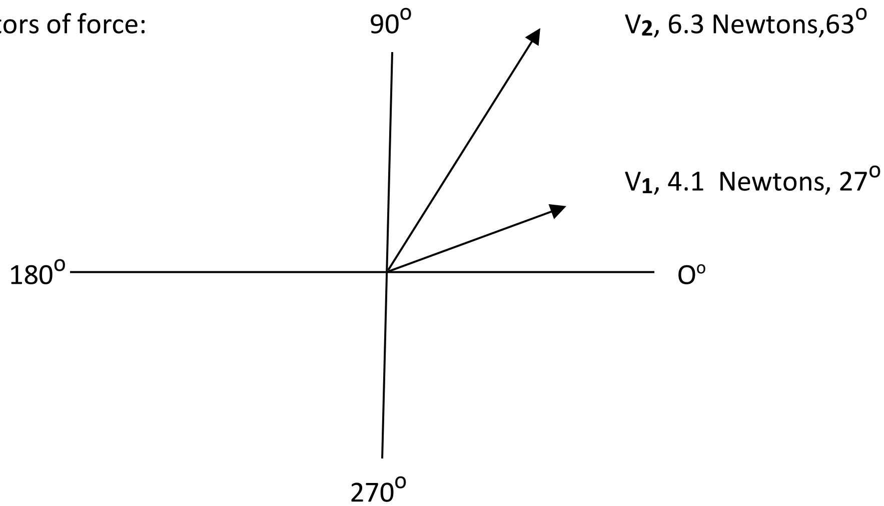
Thus, the sum (__________________) of the forces of the two bungee

cords is _____________ at ____________ degrees

Adding Vectors:

Example 1:

Given the following vectors of force:



Determine the sum of $V_1 + V_2$

Solution:

① Draw each vector individually, and label accordingly

② Add component vectors and label accordingly

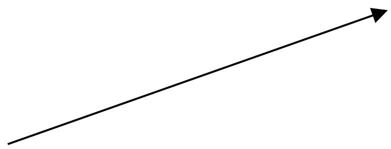
③ Use trig to solve for components

④ Add components

⑤ Construct new vector ("resultant") using component sums

⑥ Use trig to evaluate resultant

V_1, 4.1 Newtons, 27°

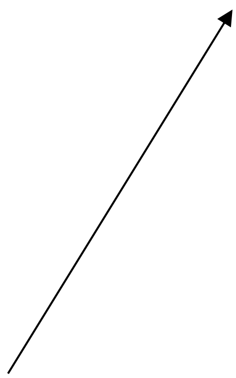


A1 = (__________)x(________)
= __________ x ________
= ______________________

A_2 = (__________)x(________)
= __________ x _________
= ______________

O_1 = (__________)x(________)
= __________ x _________
= ______________

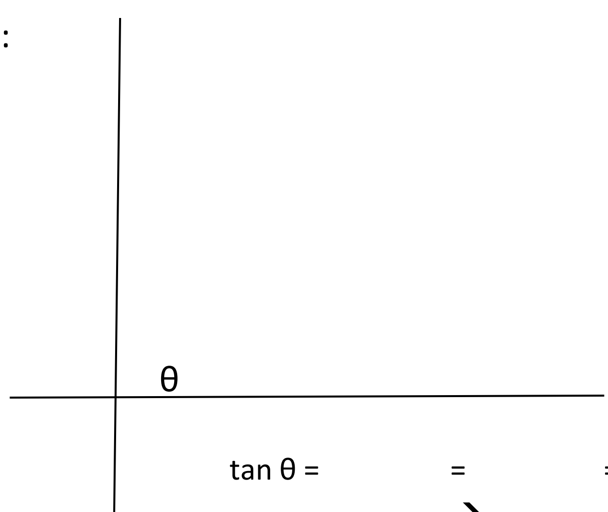
V_2, 6.3 Newtons,63°



O_2 = (__________)x(________)
= __________ x _________
= ______________

A_1 ________	O_1 _________
$+A_2$ ________	$+ O_2$ _________
A_{total}	O_{total}

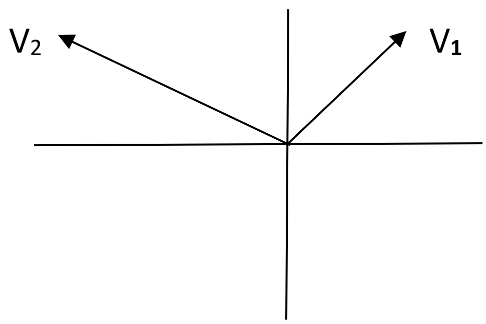
Construct/draw in order:
A_{total}
O_{total}
Resultant



tan θ = = = ________
$\tan^{-1}$ ________ → ________

Resultant (H) = = = ________

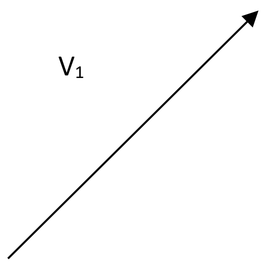
Example 2:

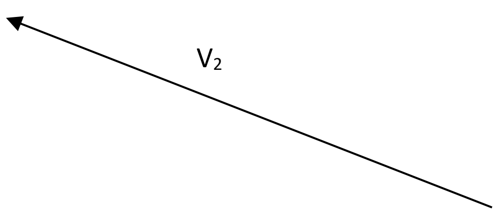


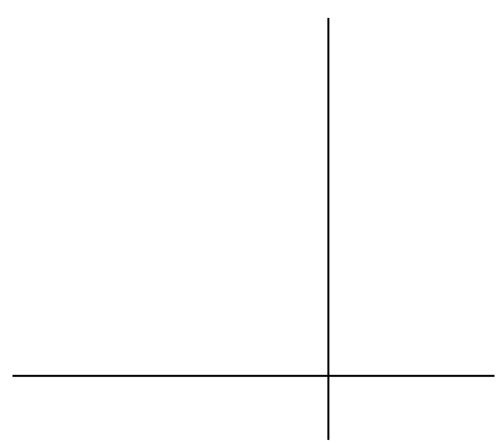
V_1: 48°, 50 meters/sec

V_2: 147°, 75 meters/sec

A_1	O_1
A_2	O_2
A_t	O_t



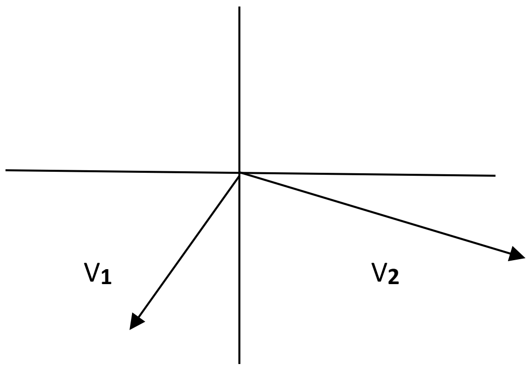




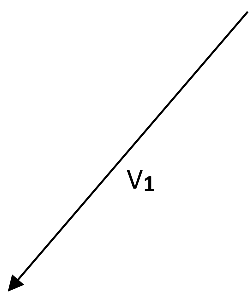
Example 3:

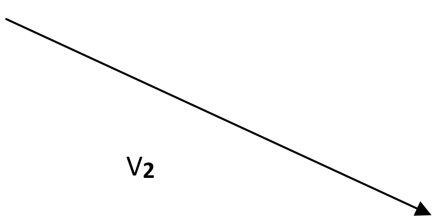
V_1: 245^o, 36 N

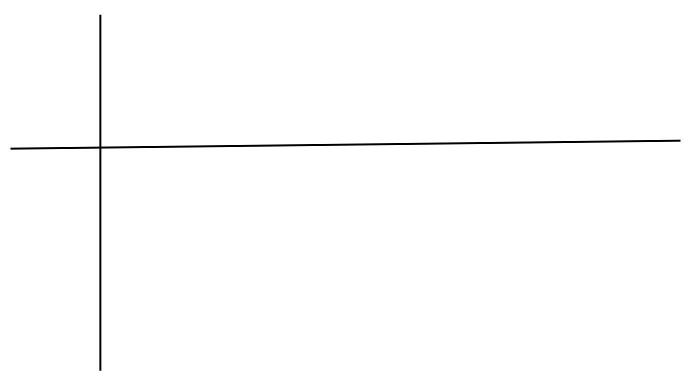
V_2: 337^o, 68 N



A_1	0_1
A_2	O_2
A_t	O_t

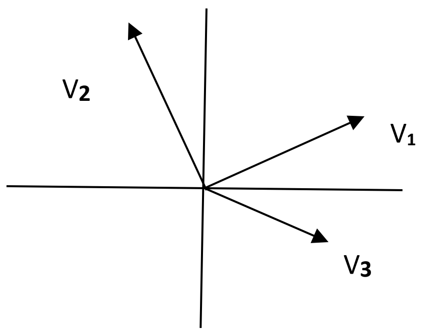






Forces in Equilibrium

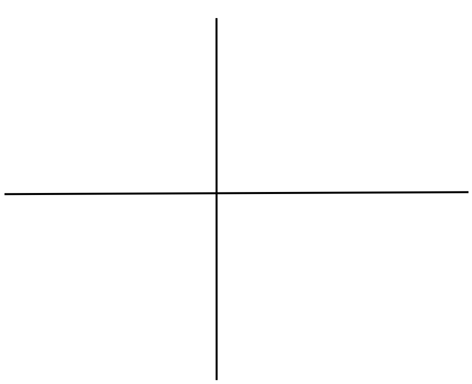
Given:



V_1

V_2

V_3



$V_1 : 33^{o}$, 3.1 N

$V_2 : 103^{o}$, 2.0 N

$V_3 : 338^{o}$, 1.6 N

<u>Calculations:</u>

A_1	O_1
A_2	O_2
A_3	O_3
A_t	O_t

Resultant calculations:

Tan θ____________

Tan-1 ____________ = __________

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

Calculate the vector that will cancel the resultant

Equilibrium Vector (V_{eq})calculations

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

MOTION

1. Velocity:

   a. __________ measurement

   b. __________ and ____________

   c. ____________ over__________ (   )

   d. Measured in:

      1. _______ per________ (____/ _____) (British)

      2. _______ per ________ (____/ _____) (Metric)

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:

a. ______________ measurement

b. A ___________ in ____________ * over ___________

*("V_Δ" or "__________ V ")

("Δ" = "___________")

c. Measured in:

1. _________ per ________ per________ (_____ /_____)
(British)

2. _________ per ________ per________ (_____ /_____)
(Metric)

Explanation of units of Acceleration:

("ft/sec^2 = feet per second per second")

("m/sec^2 = meters per second per second")

Acceleration (continued):

1. The acceleration of gravity (a_g)

CAUTION:

Gravity is acceleration,

BUT

Not all acceleration is gravity!

On Earth:

a. _____ ft/sec^2 (British)

b. _____m/sec^2 (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

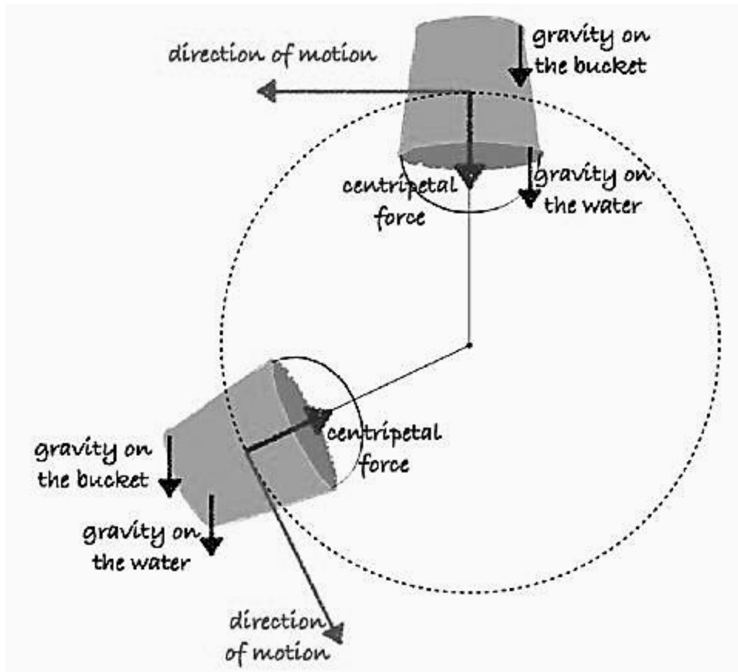
a _________ in __________ ,

and velocity is defined as

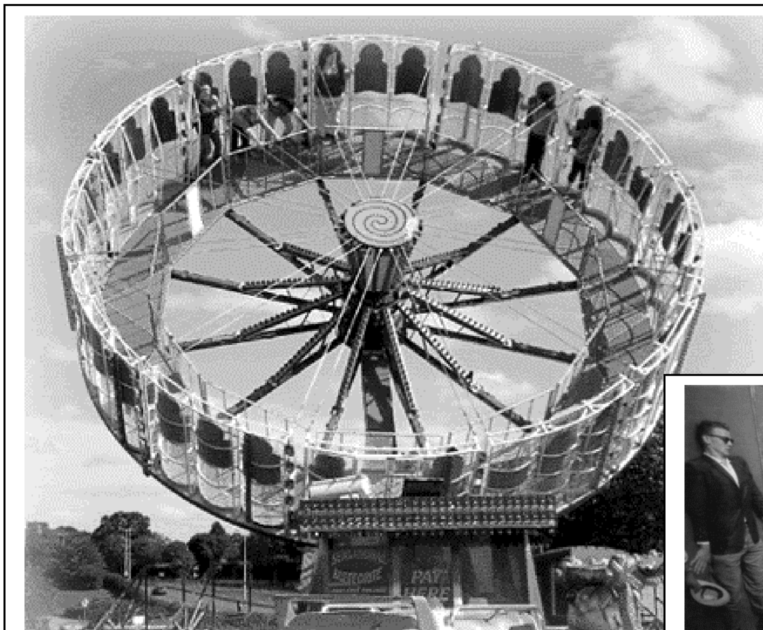
__________ and _____________ ,

then a ________ in ____________ results in ______________.

Example 1: Beach Bucket



Example 2: The “Gravitron”



Critical Factors in Acceleration Calculations:

1. V_i :
2. V_f :
3. a :
4. s :
5. t :

" Three outa five ain't bad!"

Given any __________ of the above factors,
the remaining _________ factors may be calculated

Basic Formulas Used in Acceleration Problems:

V_i	V_f	a	s	t	basic formula:

Acceleration Formula Cheat Sheet

$t = \otimes$			
$a = \frac{V_{f^2} - V_{i^2}}{2s}$	$s = \frac{V_{f^2} - V_{i^2}}{2a}$	$V_f = \sqrt{V_{i^2} + 2as}$	$V_i = \sqrt{V_f - 2as}$
$s = \otimes$			
$V_f = at + V_i$	$V_i = V_f - at$	$a = \frac{V_f - V_i}{t}$	$t = \frac{V_f - V_i}{a}$
$a = \otimes$			
$s = .5(V_f + V_i)t$	$t = \frac{s}{.5(V_f + V_i)}$	$V_f = \frac{s}{.5t} - V_i$	$V_i = \frac{s}{.5t} - V_f$
$V_f = \otimes \quad V_i = 0$			
$s = .5at^2$	$a = \frac{s}{.5t^2}$	$t = \sqrt{\frac{s}{.5a}}$	
$V_f = \otimes \quad V_i \neq 0$			
$s = V_i t + .5at^2$	$t = \frac{-V_i \pm \sqrt{V_{i^2} + 2ac}}{a}$	$v_i = \frac{.5at^2}{t}$	$a = \frac{s - v_i t}{.5t^2}$

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 $+(-s) \qquad +(-s)$

④ $V_i\, t + .5at^2 + (-s) = 0$

⑤ $.5at^2 + V_i\, t + (-s) = 0$

⑥

⑥

Change symbol from	to

Informal Lab: Working through acceleration problems

Example 1:

<u>How long</u> will it take an object to <u>drop</u> <u>4 feet</u>?

①　　　　　　　　　　　　　②　③

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

Step 2: Inventory

② V_i

V_f

② a

③ s

① t

Step 3: What is the question?

Step 4: **Look for the "odd man out" (⊗)**

Step 5: **Look for ⊗ 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 ft/sec. How far will the ball have travelled after 2 sec.?

V_i

V_f

a

s

t

Oog conducts early experiments with gravity

Example 4.

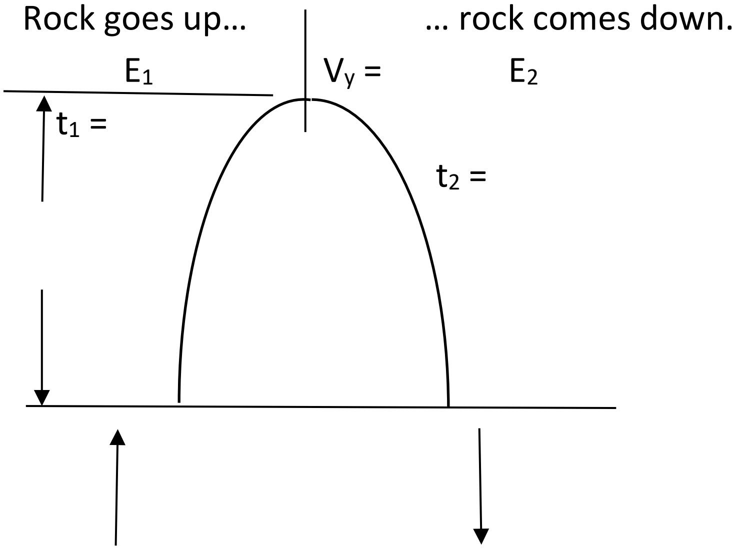
A rocket boosts from the launch pad at 48 ft/sec^2. How high is the rocket after 5 sec.?

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!**)



Q1: What is the initial velocity (V_i)of the rock going up?

V_i
V_f
a
s
t

V_i =

Q2: How long does it take the rock to reach max height?

V_i
V_f
a
s
t

t =

Q 3: How long does it take the rock to come back down?

V_i
V_f
a
s
t

t =

Q4: What is the final velocity of the rock at the return point?

V_i
V_f
a
s
t

V_f =

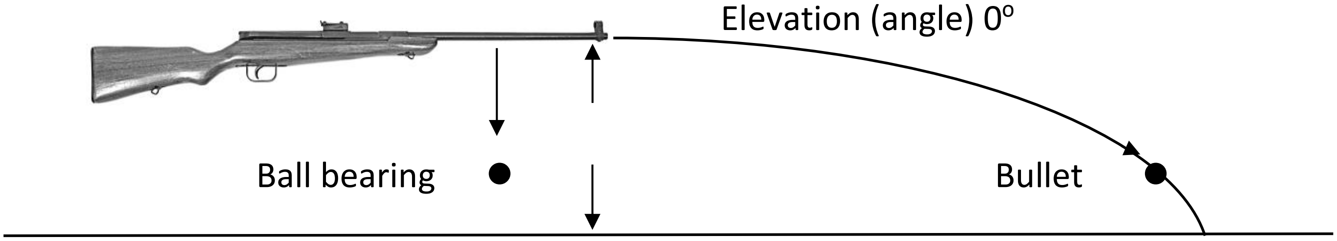
Informal Lab Problems:

1. A bullet is fired vertically with an initial velocity 0f 250 m/sec. Discounting air resistance,
   a. How high does it go?
   b. How long does it take to reach max height?

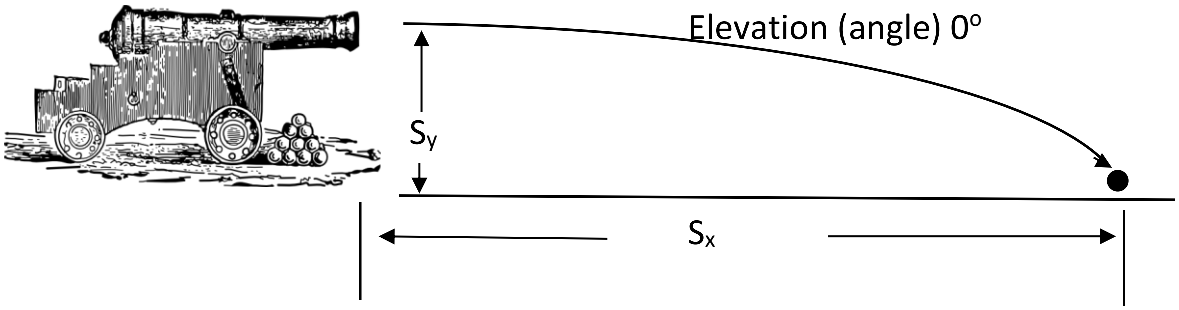
2. A bullet is fire vertically and reaches a max height of 700 ft
   Discounting air resistance,
   a. What is its initial velocity?
   b. How long does it take to reach max height?

Kinematics: Motion in Two Dimensions

Example 1:



Example 2:



Using a level shot to determine Muzzle Velocity (V_{muzzle})

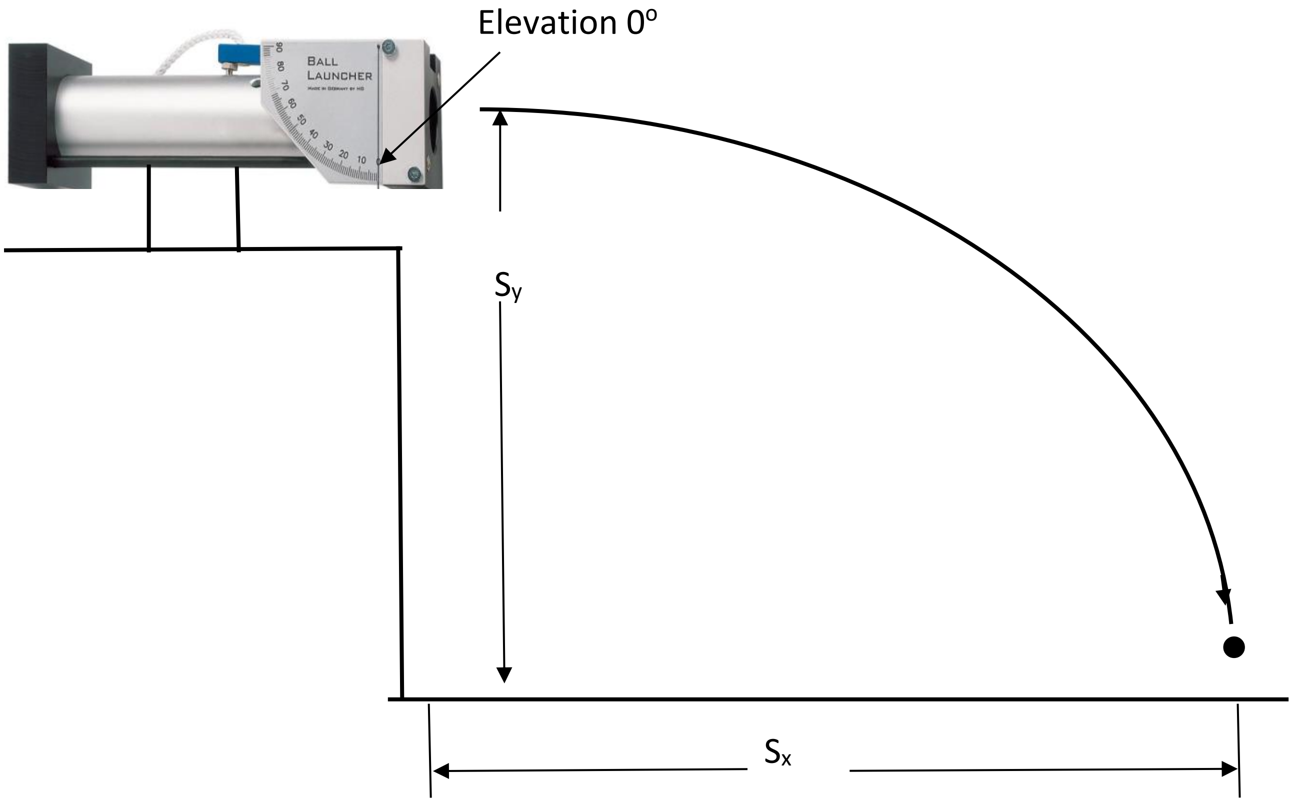
Theory:

1. Definition of velocity: (——)
2. V_x is stipulated as ________________________ ("idealization")
3. V_{muzzle} is set at 0^o elevation and is therefore _________________ to V_x
4. "S" is measured as _______________
5. "t" is calculated using _____________

Calculations/measurements:

1. S_x ____________________
2. S_y ____________________
3. t =
4. V_{muzzle} =

Determining Muzzle Velocity



S_y = ________________ (as measured)

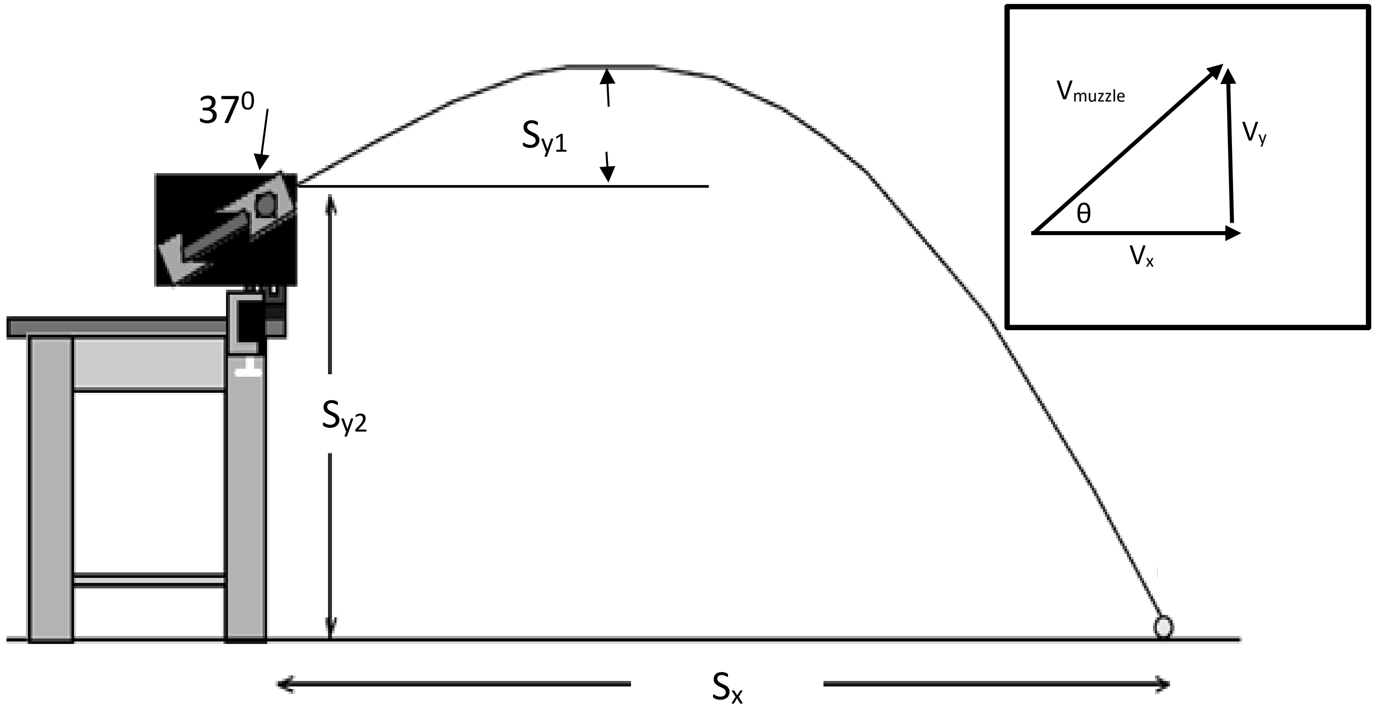
S_x = __________________ (as measured)

$$t = \sqrt{\frac{S_y}{.5a}} = \sqrt{\frac{\qquad}{.5a}} = \sqrt{\qquad} = \_\_\_\_\_\_\_\_\_\_$$

$$V_x = \frac{S_x}{t} = \frac{\qquad}{\qquad} = \_\_\_\_\_\_\_\_\_\_ \; V_{muzzle}$$

(**only when elevation is set at 0º**)

Predicting range of angled shot based on known V_m



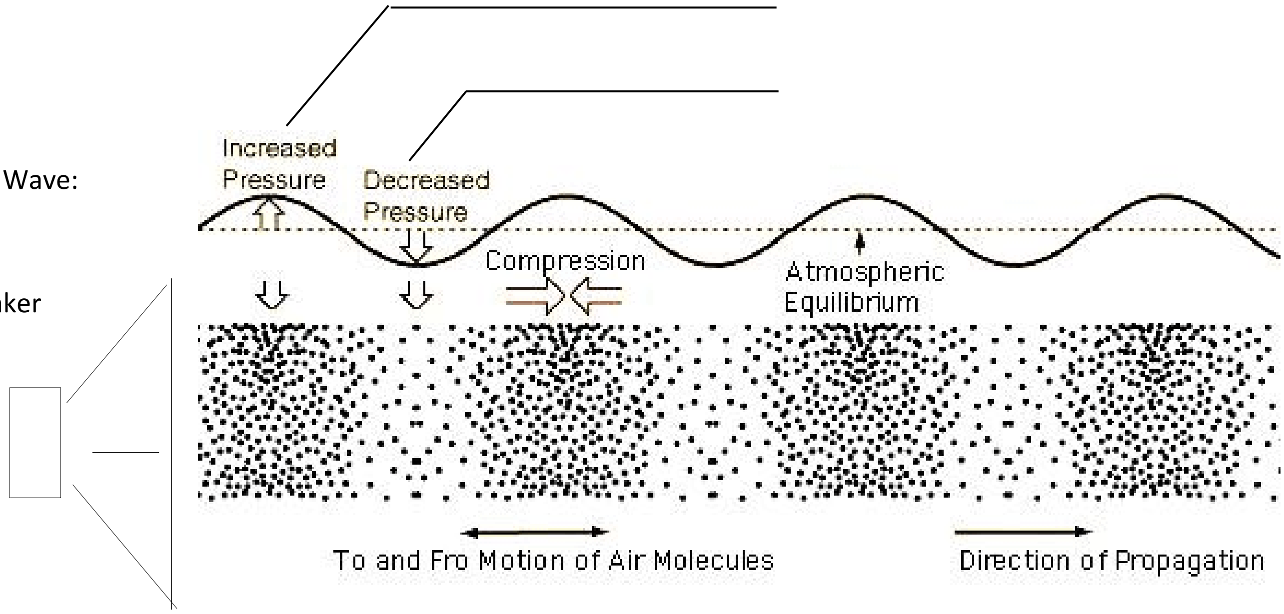
OBJECTIVE: Predict S_x given known V_{muzzle}

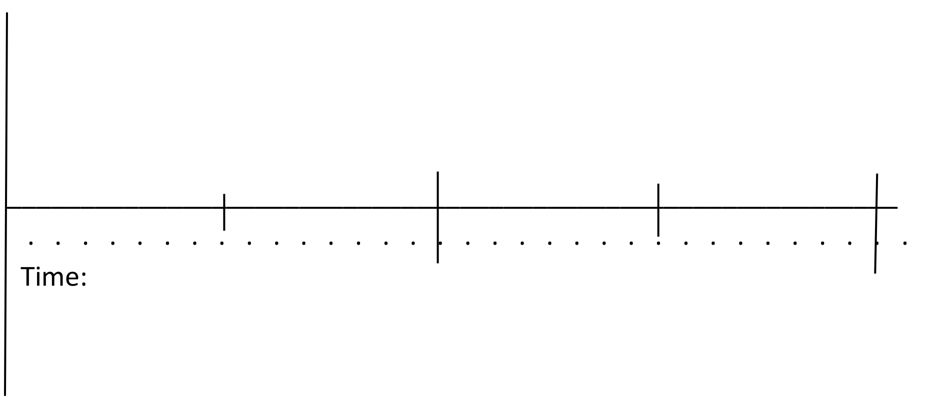
1. Proposition: $S_x = V_x \times t_{total,} \longrightarrow (t_{total} = [(t_1) + (t_2)]$ = ( ) x [( )+( )] = ____________________	
3. V_x =	4. V_y =
5. t_1 =	6. S_{y1} =
6. T_2 =	

Sound:

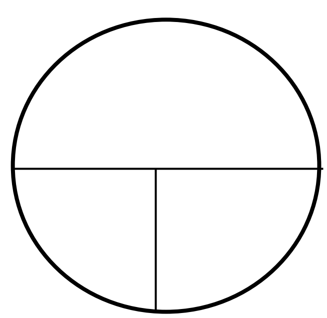
Sine Wave:

Speaker





Frequency, wavelength, velocity:



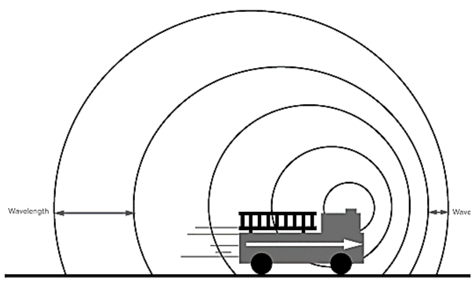
The role of the medium in a mechanical wave

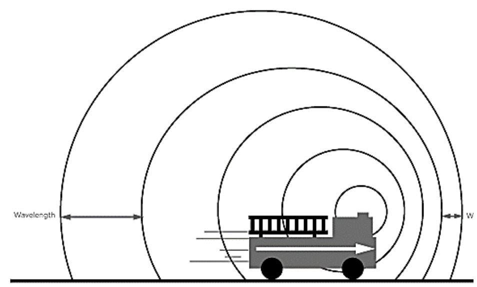
The medium determines ____________________ of a wave

The Doppler Effect:

____
____
____

?





Wavelength compressed relative to observer

observer

Wavelength expanded relative to observer

Longer __________________ = lower ______________________

Shorter __________________ = higher _____________________

Doppler equation: $f' = f\left(\frac{V}{V \pm V_s}\right)$

Where:

v_s = Velocity of the Source

v = Velocity of wave

f = Real frequency

f' = Apparent frequency

Equation to determine velocity of source:

$$V_s = \frac{V\,(f' - f)}{f'}$$

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)?

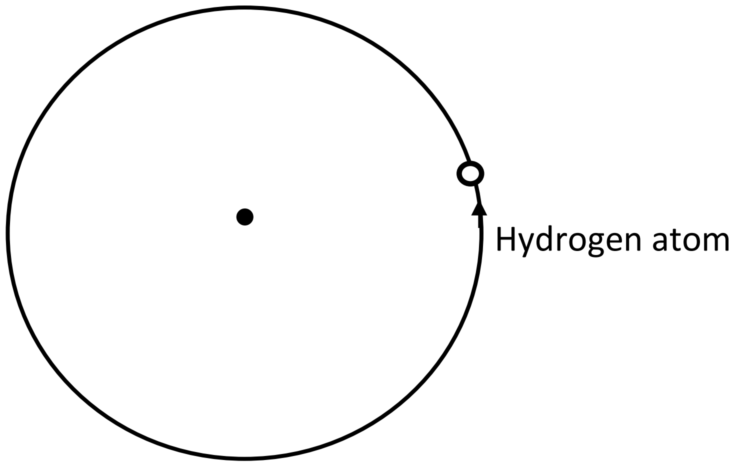
Data:

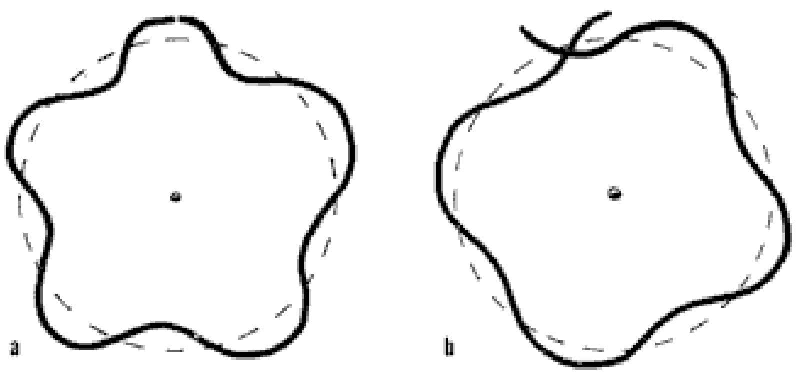
1. Speed of sound in water ~ 4900 ft/sec
2. 1 Nautical mile ~ 6000 ft.

Soviet submarine with US Navy P-3 Orion
anti-submarine surveillance aircraft
(My old alma mater – Patrol Squadron Eight!)

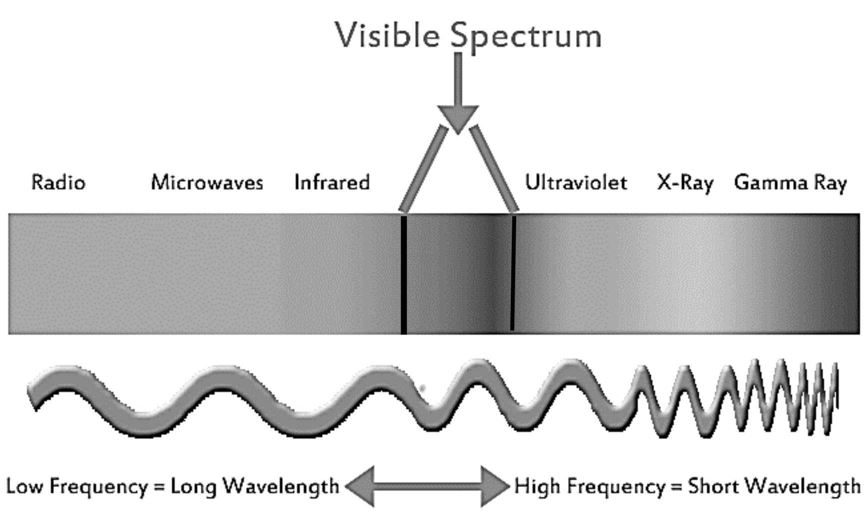
Structure of the atom and the nature of light

Recall:

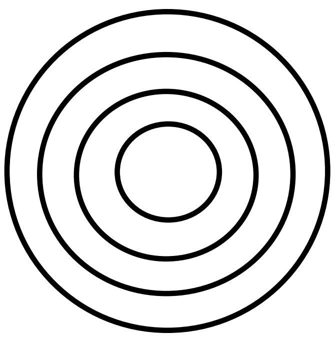




De Broglie Wavelength



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, ~ 10 Mpc or more) have a doppler shift-measured 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 (3.09×10^{19} km) away. The reciprocal of H_0 is the Hubble time.

Hubble law: $V = H_oD$

Where:

V = velocity in Km/sec

Ho = Hubble Constant = $\frac{71 \text{ Km/sec}}{\text{Mpc}}$

D = distance in parsecs (pc)

1 parsec (pc) = 3.26 LY

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?

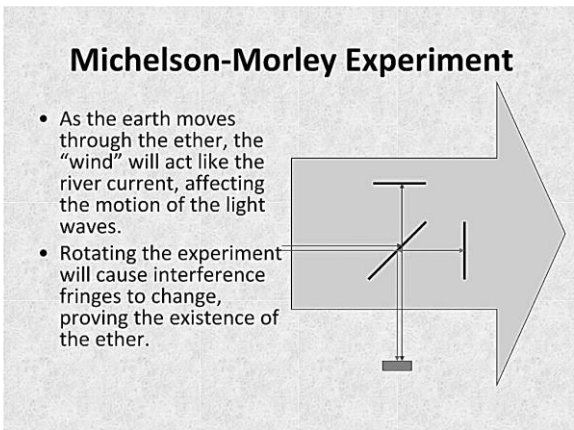
Michelson – Morley Experiment

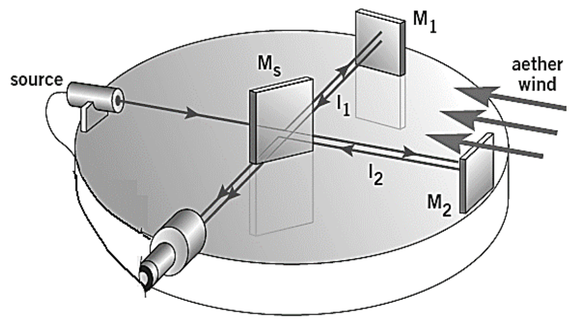
Albert Michelson

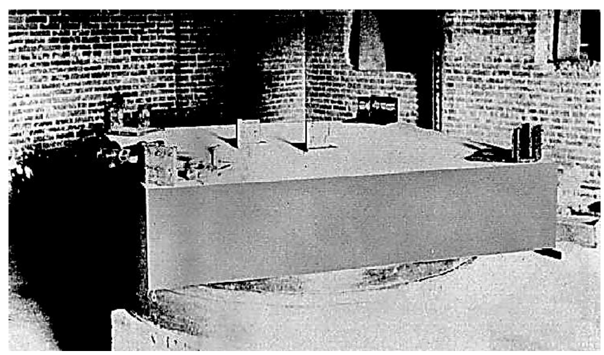
1. ______________________________
2. ______________________________

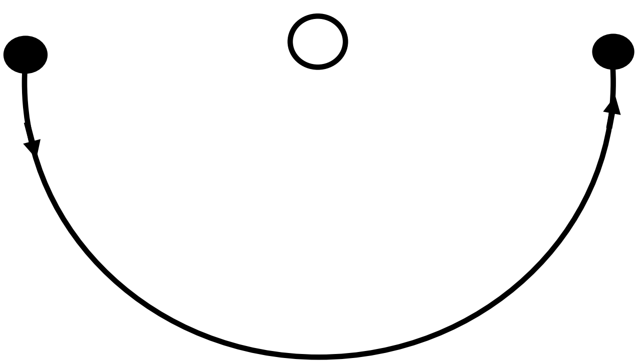
Luminiferous Ether (Aether) (the "Ether")

1. ____
2. ____

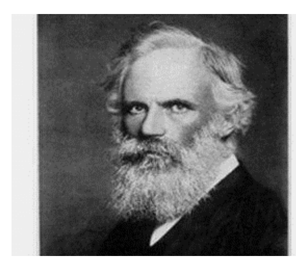




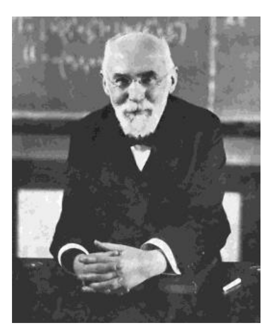




George Fitzgerald ____________________________



Hendrik Lorentz : _______________



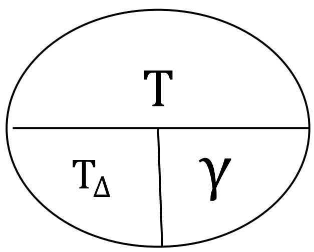
Page 97

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

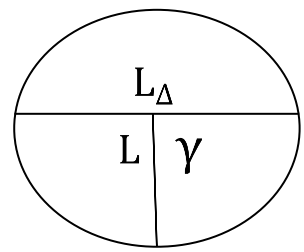
Where

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

or $T_\Delta = \frac{T}{\gamma}$



or $L_\Delta = L \times \gamma$



Relativity Toolbox

Where:

T_Δ = ____

T = ____

C = ____

V = ____

L_Δ = ____

L = ____

Relativistic Velocities (_____________)

____

Non-Relativistic Velocities (______________)

"Gamma" (γ) is the factor that allows us to compute _______________ in both _______________ and _______________ given a specific velocity; 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."

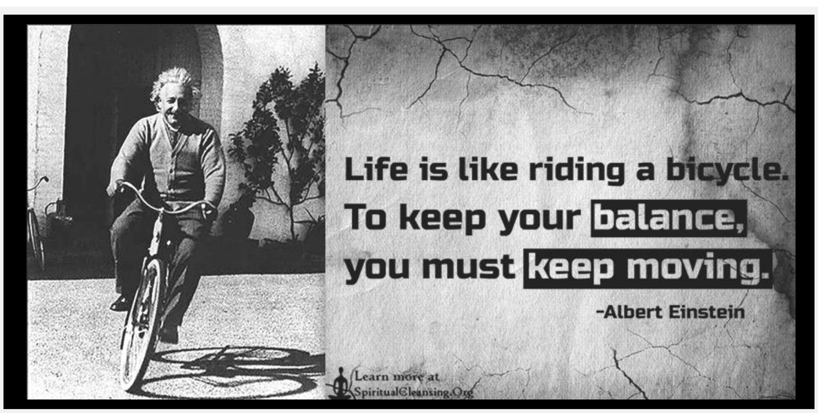
On virtue:

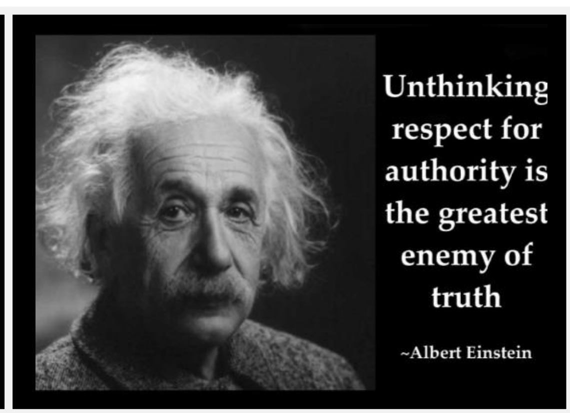
"As far as I'm concerned, I prefer silent vice to ostentatious virtue."

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."

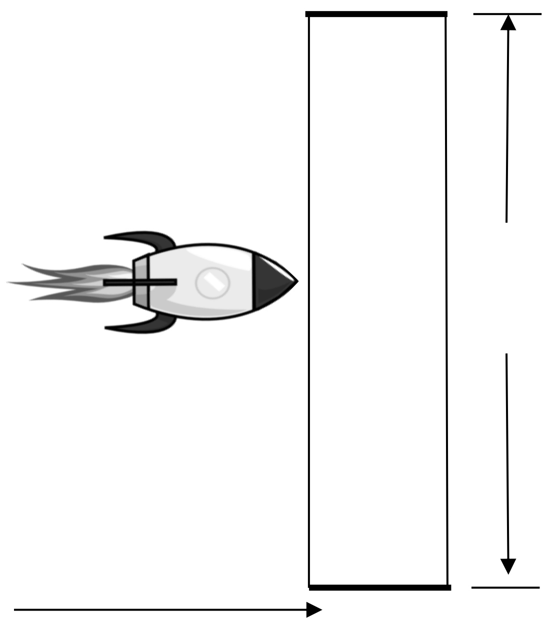




To understand why Relativity is necessary we have to look at the practical problems resulting from a Cosmic Speed Limit (The speed of light: “c”)

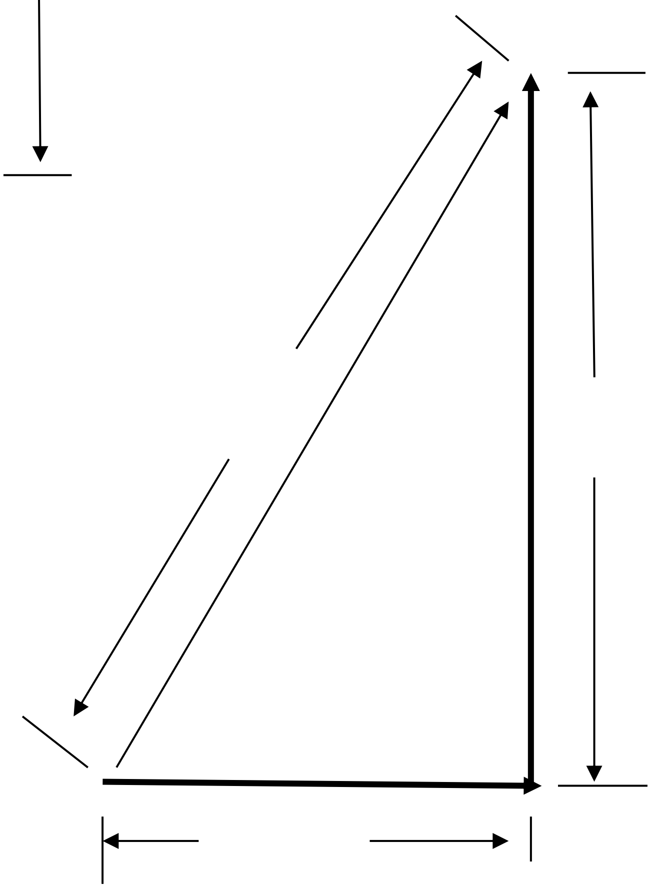
(C= 186,000 mi/sec, 300,000 km/sec, and/or 3.0×10^8 m/sec)

We’ll start with a ridiculous imaginary clock:



V = .5c
(1.5×10^8 m/sec)

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

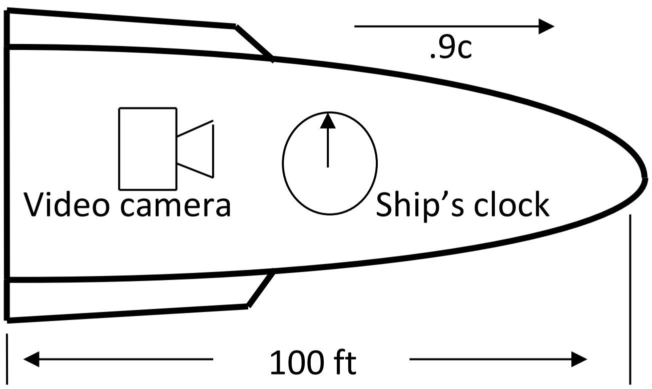
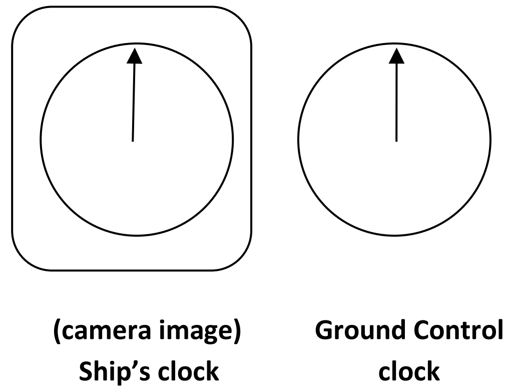


fig 2. **Ground Control observer's console**



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" (γ)

$$\gamma = \sqrt{1 - \frac{V^2}{c^2}}$$

Step 2: Solve for T_Δ

$$T_\Delta = \frac{T}{\gamma}$$

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

$$L = L_\Delta \times \gamma$$

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 .998c and a "life span" of **2.2 x 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)

(.998c) x (2.2 x 10^{-6}) = (2.994 x 10^{8} m/sec) (2.2 x 10^{-6} 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!

Solution:

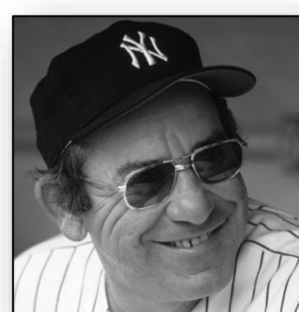
1. Calculate "Gamma" for .998c

2. Calculate T_{Δ}

3. Calculate L_{Δ} *from the perspective of the muon:*

Famous quotes by baseball legend and American philosopher Yogi Berra:

On Relativistic Time:
"This is the earliest I've ever been late!"
On Quantum Physics:
"When you come to a fork in the road, take it."
On the Abstract Mathematics:
"Baseball is ninety percent mental and the other half is physical."



The Twins Paradox

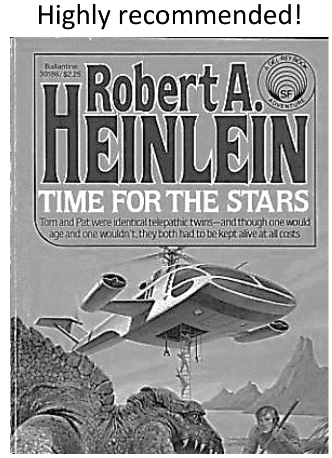
One of pair of identical twins is selected to be a crew member of a deep-space expedition to a star eleven light-years distant.

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

This one is a lot of fun, written in the 50's. It's all about the Twins Paradox. Highly recommended!



Gamma Chart For Relativistic Velocities

v	v^2	$1-v^2$	$\sqrt{(1-v^2)}$ ("γ")
.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	.00000002	.00014
.999999999c (.000000001 or one-billionth under "c")	.999999998	.000000002	.000045
.9999999999c (.0000000001 or one-ten billionth under "c")	.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 chart on previous page)

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

Further Practical Problems with Relativistic Velocity (Example 2)

Given: A space vessel traveling at .9c collides with an small object with a mass of grain of salt, approximately 5.86×10^{-8} Kg

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

(Comparison: 1 ton of TNT = 4.2×10^{9} Joules)

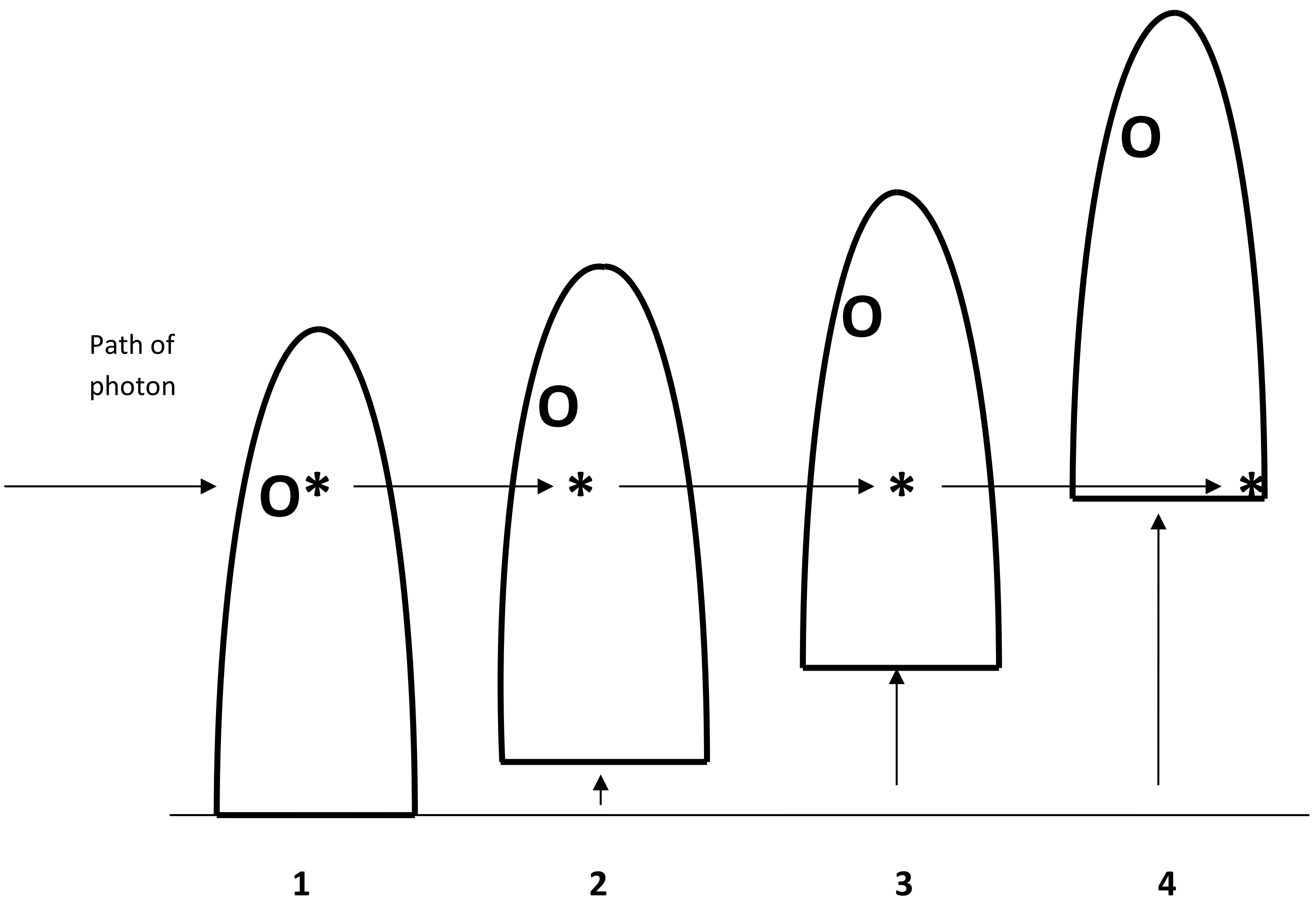
Further Practical Problems with Relativistic Velocity (Example 3)

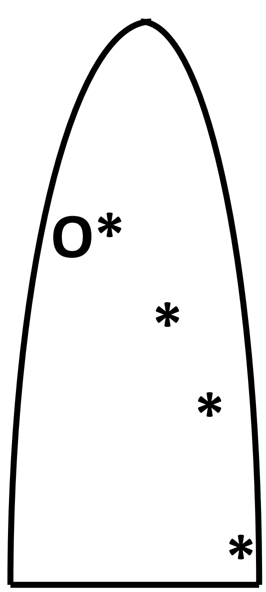
Given: A space vessel traveling at .9c collides with an small object with a mass of 2.5 grams (roughly the mass of a penny)

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

(Comparison: The energy released by atomic bomb detonated over Hiroshima was approximately 6.5×10^{13} J or 65, 000,000,000,000 or 65 thousand billion Joules)

The effects of acceleration on the path of a photon





Path of photon relative to spacecraft

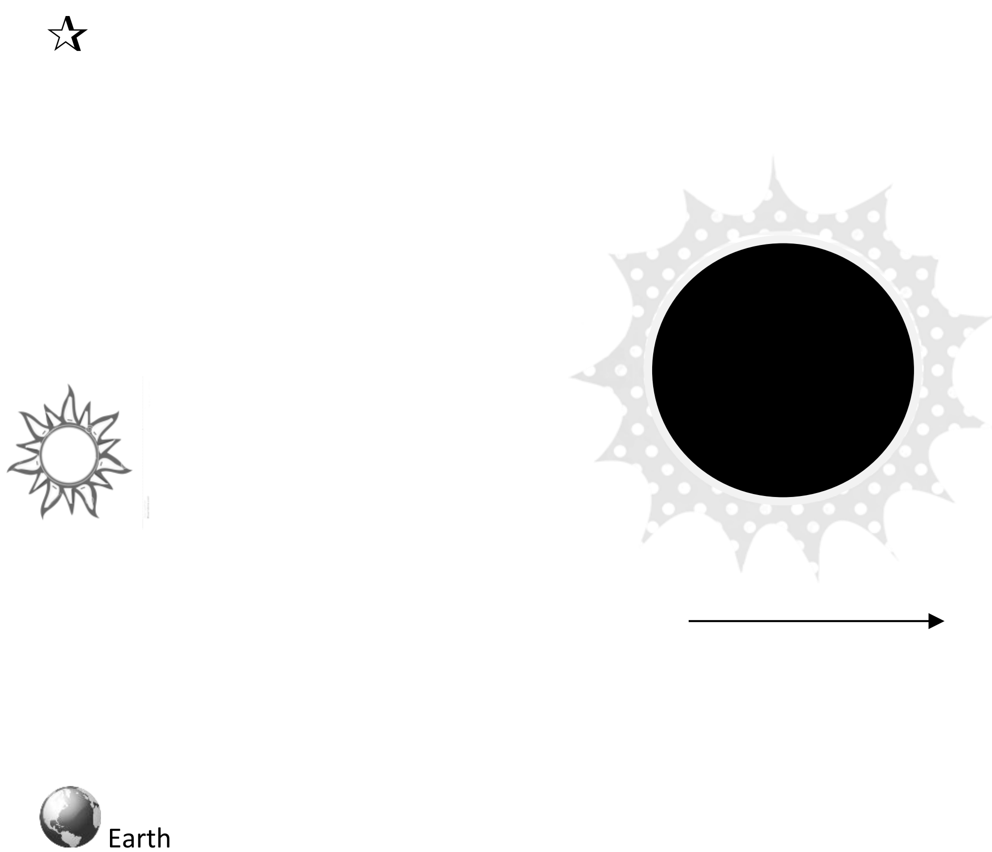
An Einstein “Thought Experiment”

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: ______________________________

____

Formula for Escape Velocity:

$$V_{esc} = \sqrt{\frac{2GM}{r}}$$

Data:
Radius of Earth: 6378 Km
Mass of Earth: 6.0×10^{24} Kg
Universal Gravitational Constant (G): 6.672×10^{-11}

Calculate Escape Velocity (V_{esc}) for Earth

****

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

Approx. actual size:

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:

$$E = \quad mc^2$$

Where:

E = "Binding Energy"

m = "mass defect"

C^2 = speed of light squared $(3.0 \times 10^8)^2$

Data:
Mass of a proton =1.67262 x 10^{-27} Kg
Mass of a neutron = 1.67493 x 10^{-27} Kg
Mass of an electron = 9.1094 x 10^{-31} 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

$^{4}_{2}\mathrm{H}$ compared to $^{235}_{92}\mathrm{U}$
Top#________________________
Botton# _____________________

2 protons ________________________ Kg

\+ 2 neutrons ________________________Kg

Predicted total = ________________________Kg

Actual total = 6.6463 x 10^{-27} Kg

Difference:________________________________Kg

(Missing mass or "____________________________")

$E = mc^2$

=____________________x ______________________

=____________________x ______________________

=_________________________Joules

Now compare the mass – energy conversion factor:

Original mass___________________________________

Resulting energy ________________________________

Note the exponential difference

Finally, **$E = mc^2$**

An alternate way to read the formula:

"There is an equivalence between mass and energy, with a conversion factor that is the square of the speed of light"

Question:

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

BOOM!

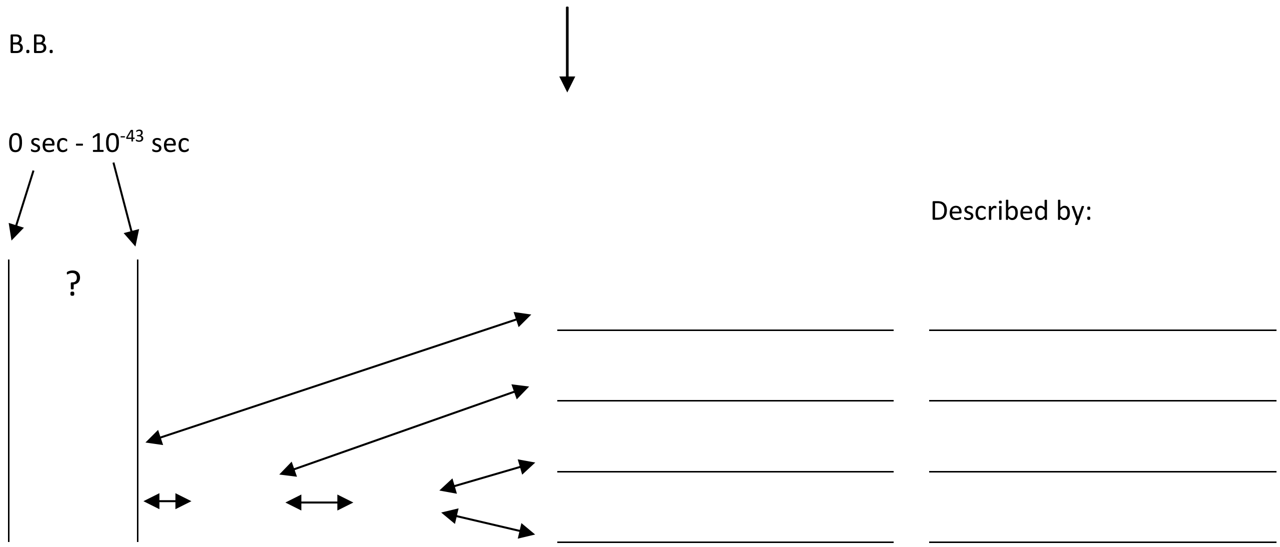
Epilogue: Where do we go from here?

The Four Fundamental Forces:

B.B.

0 sec - 10^{-43} sec

Described by:



Conflict: The existence of ______________________________

____

____

String Theory – possible solution?

All “matter” is

____

Original model called for the existence of

____

Problems developed because of mathematical

____

Anomalies resolved by ______________________________

Strength of String Theory:______________________________

Weakness of String Theory:______________________________

____