ASTR 100
Intro to Astronomy and Cosmology
Lab Manual

(2nd Edition August 2020)

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Topic 1

Dark Matter – Dark Energy

Percentages in Universe:

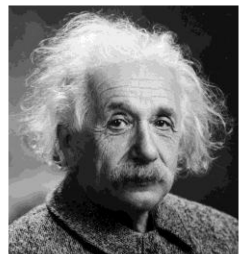
Dark Matter: ____________

Dark Energy: ____________

Normal Matter: __________

1

2



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Key Figures:

1. ___________________________

2. ___________________________

3. ___________________________

Fritz Zwicky:

Early 1930's studied/observed ____

____

____

Coma Cluster:

1: ____

2: ____

3: ____

Calculated ____

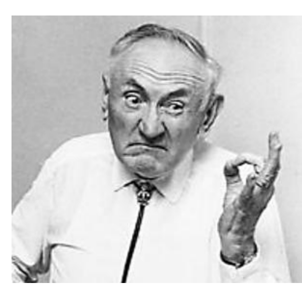
____

Determined ____

____

Concluded ____

____



Vera Rubin

1960's____

____

____

____

Observed that further objects (stars, etc) _______________________________

____

Overall, galaxies were spinning ____________________________________

Presented findings in early 1970's, _________________________________

Rubin's findings ____

Albert Einstein:

Gravitational lensing, ____

____

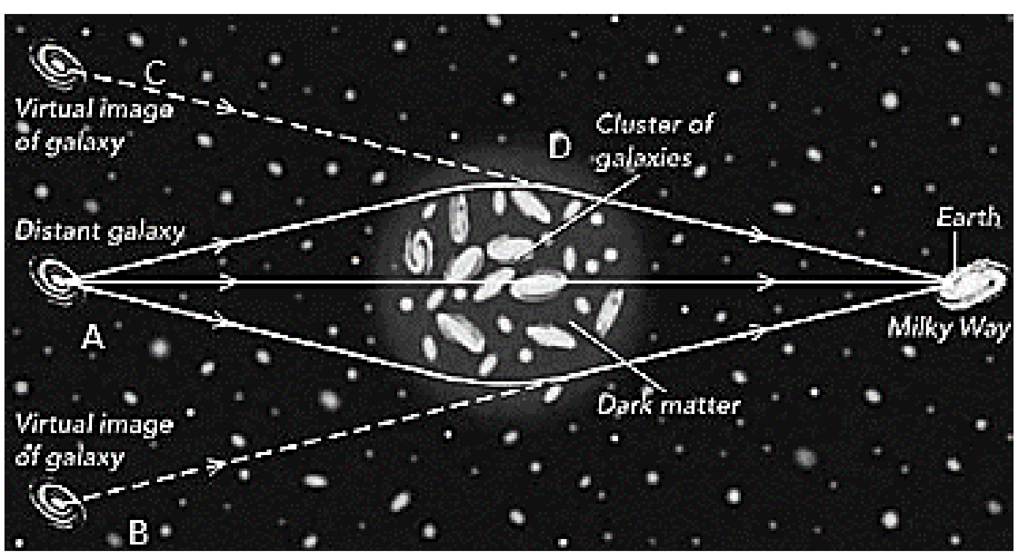
____

____

Lensing observed ____

____

____



Additional evidence:

Temperatures of intracluster medium (gas in cluster):

Temps in range of ______________________________ , determined by ________________

____

____

Temp is measure of ____

Wavelength, frequency related to ____

Higher the frequency, ____

____

Gases are in gravitational ____

____

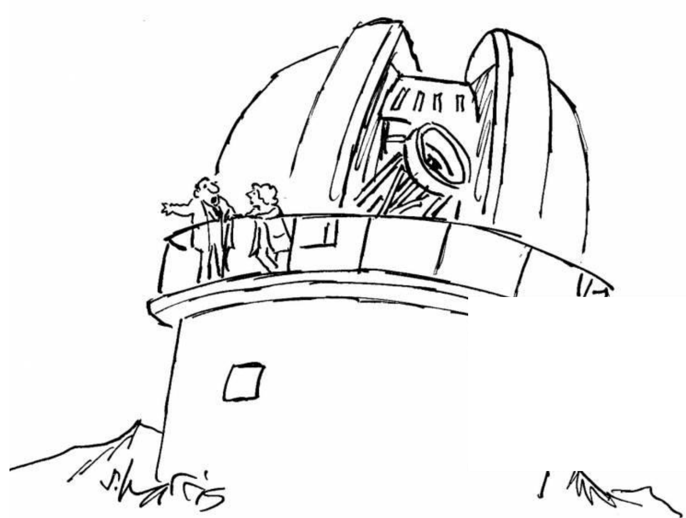
____

____

Mass calculations from these observations ____

____

____



"THE UNIVERSE IS EXPANDING FASTER THAN EVER, AND I DON'T EVEN FEEL A BREEZE."

So, what is dark matter, and what do we know about it?

8. Laws of motion (Kepler, Newton) ____

____

____

____

2. Does not emit ____

____

3. Does not interact ____

____

4. Does not interact with ____

____

5. No candidate within ____

____

6. By late 1990’s, thought to make up ____

7. Rubin’s calculations ____

____

____

8. Calculations also inferred size of ____

____

____

Possibilities:

MACHO's, WIMP's

MACHO's: ____

High _____________

Emit _______________ or ___________________________

Present ____

Possible candidates:

____

____

____

Pros:

____

Cons:

____

WIMP'S : ____

Neutrino: ____

____

____

"Exotic" particles:

____

____

____

____

____

Dark Energy: A Brief Synopsis

What Is Dark Energy?

By Adam Mann - Live Science Contributor August 21, 2019

Dark energy is an enigmatic phenomenon that acts in opposition to gravity and is responsible for accelerating the expansion of the universe. Though dark energy constitutes three-fourths of the mass-energy of the cosmos, its underlying nature continues to elude physicists. Dark energy has no real connections to dark matter, beyond sharing the word dark, which just means that scientists don't really know what these things are.

The realization that the universe is expanding can be traced back to the American astronomer Edwin Hubble, who noticed, in 1929, that the farther a galaxy is from the Earth, the faster it is moving away from us, according to the Hubble Space Telescope website. This doesn't mean that our planet is the center of the universe, but rather that everything in space is moving away from everything else at a constant rate.

Nearly 60 years after Hubble's revelation, scientists made another startling discovery. Researchers had long been trying to precisely measure cosmic distances by looking at the light of faraway stars. **In the late 1990s, after examining distant supernovas, two independent teams found that the stellar explosions' light is dimmer than expected. This indicates that the universe is not only expanding, but also accelerating in its expansion.**

That finding has given physicists cause to scratch their heads ever since then, also earning its discoverers the Nobel Prize in physics in 2011.

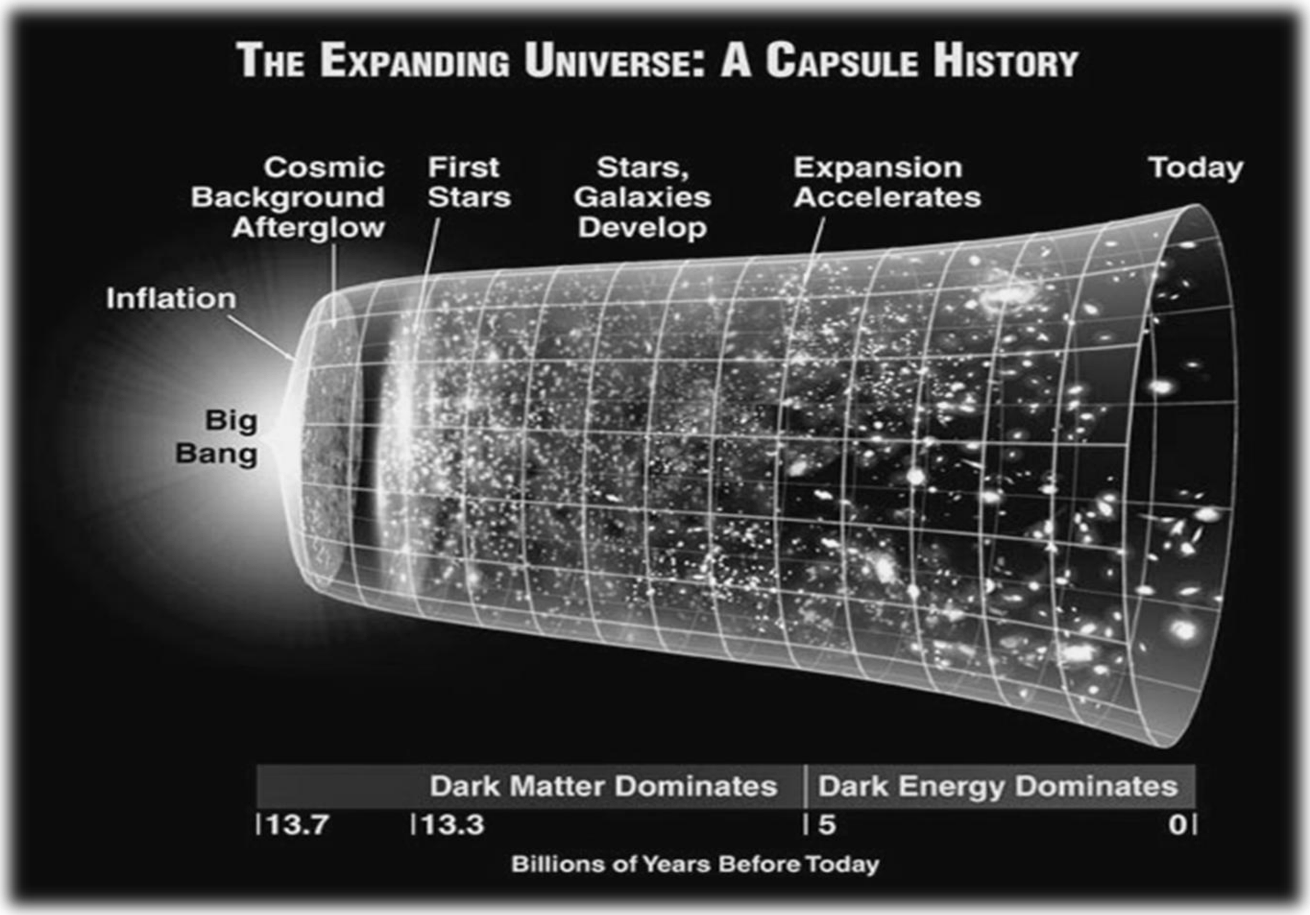
What does dark energy do?

Though researchers don't entirely understand dark energy, they have used their knowledge of the phenomenon to construct models of the universe that explain everything from the Big Bang to the modern-day large-scale structure of galaxies. Some of these models predict that dark energy will rip apart everything in existence billions of years from now.

The leading explanation of dark energy suggests that it is a type of pent-up energy inherent in the fabric of space-time. "This simple model works very well practically, and it is a straightforward addition to the cosmological model without having to modify the law of gravity," Baojiu Li, a mathematical physicist at Durham University in the United Kingdom, previously told Live Science. But the idea comes with one major problem: Physicists predict that the value of the vacuum's energy should be 120 orders of magnitude higher than what cosmologists observe in measurements, Li said.

An alternative idea posits that dark energy is an additional fundamental force, **joining the four already known (gravity, electromagnetism, and the strong and weak nuclear forces).** But this conjecture doesn't explain why humans don't notice this extra force in our day-to-day lives. So, theorists have also built creative models suggesting that this mysterious force is hidden in some way.

The measured value of dark energy is currently the subject of an intense debate between rival factions in physics. Some researchers have measured dark energy's power using the cosmic microwave background, a dim echo of the Big Bang, and produced one estimate.
But other astronomers, who measure dark energy's strength using the light of distant cosmic objects, have produced a different value, and nobody has yet been able to explain the discrepancy. Some experts have suggested that dark energy's power varies over time, though proponents of that idea have yet to convince a majority of their peers of this explanation.



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

____

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 1st 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

<u>Converting numbers in standard notation to scientific notation</u>

If the decimal point moves to the _______________, the exponent goes ____________

If the decimal point moves to the _______________, the exponent goes ____________

<u>Converting numbers in Scientific Notation to Standard Notation</u>

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:	**Example 2:**	**Example3:**
Convert 873.463 into correct scientific notation	Convert 0.00785 into correct scientific notation	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}

Lab Exercises: Remember: L R

Convert to Scientific Notation: 5,280 ft	Answer:
Convert to Standard Notation: 6.337×10^{2}	Answer:
Convert to Scientific Notation: 0.00276	Answer:
Convert to Standard Notation: 3.457×10^{-5}	Answer:
Convert to Standard Notation: 345.76×10^{1}	Answer:

Lab Exercise (Solutions)

Convert to Scientific Notation: 5,280 ft $5280. \times 10^0$ 5.28×10^3 ← exponent goes "up" decimal goes "left"	5.280×10^3
Convert to Standard Notation: 6.337 10^2 6.337×10^2 exponent goes "down" 633.7×10^0 decimal goes "right"	633.7
Convert to Scientific Notation: 0.00276 0.00276×10^0 decimal goes "right" 2.76×10^{-3} exponent goes "down"	2.76×10^{-3}
Convert to Standard Notation: 3.457×10^{-5} 3.457×10^{-5} exponent goes "up" 0.00003457×10^0 decimal goes "left" 0.00003457	0.00003457
Convert to Standard Notation: 345.76×10^1 345.76×10^1 exponent goes "down" 3457.6×10^0 decimal goes "right" 3457.6	3457.6

Convert to Standard Notation: 5.678×10^0	Answer:
Convert to Standard Notation: 4.592^0	Answer:
Convert to Scientific Notation: 3.453	Answer:
Convert to Scientific Notation: 12^2	Answer:
Convert to Scientific Notation: 5^{-2}	Answer:

Lab Exercise (Solutions)

Convert to Standard Notation: 5.678×10^0 5.678 (Recall, $10^0 = 1$)	5.678
Convert to Standard Notation: 4.592^0 1 (Recall, any non-zero number to the "zero" power = 1)	5.678
Convert to Scientific Notation: 3.453 3.453×10^0 (Recall, any standard notation number can be expressed as itself x 10^0)	5.678
Convert to Scientific Notation: 12^2 $12^2 = 12 \times 12 = 144$ $144 = 1.44 \times 10^2$	1.44×10^2
Convert to Scientific Notation: 5^{-2} $5^{-2} = \frac{1}{5^2} = \frac{1}{25} = 0.04$ 0.04×10^0 4.0×10^{-2}	4.0×10^{-2}

Operations in Scientific Notation

Multiplication Critical Rules:

Multiply ___________________

Retain ____________________

Add ______________________

RECALL:

Adding a negative number is the same as ____

Example 1:	Example 2:
$(4.75 \times 10^{\mathbf{3}}) \times (2.43 \times 10^{\mathbf{7}})$	$(3.72 \times 10^{\mathbf{7}}) \times 1.67 \times 10^{\mathbf{-2}})$

Division Critical Rules:

Divide ___________________

Retain ___________________

Subtract _________________

RECALL:

Subtracting a negative number is the same as ____

Example 1:	Example 2:
$(9.35 \times 10^{8}) \div (3.54 \times 10^{4})$	$(8.62 \times 10^{6}) \div (3.97 \times 10^{-3})$

Addition/Subtraction Critical Rules:

Exponents ____________ ___________

Add/Subtract ____________________

Retain __________________________

Retain __________________________

Example 1:	Example 2 :
$(6.72 \times 10^{3}) + (2.97 \times 10^{3})$	$(9.56 \times 10^{5}) - (8.47 \times 10^{4})$

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

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 1: $\sqrt[3]{9.46 \text{ x } 10^6}$
Example 3: $\sqrt{8.1 \text{ x } 10^5}$	Example 2: $\sqrt[3]{8.1 \text{ x } 10^5}$

$(3.93 \times 10^{7}) \times (5.37 \times 10^{6})$	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:

Lab Exercises (Solutions)

$(3.93 \times 10^{7}) \times (5.37 \times 10^{6})$ 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}

Lab Exercises (continued)

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

Lab Exercises (solutions)

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

LAB: ASTRONOMIC SCALES - SPEED, TIME, AND SPACE

Universal Constants:

____

____

Speed of light

Indicated by ____________

1. ______________________________________
2. ______________________________________
3. ______________________________________

Portland to Boston: _____________________

Round trip: ____________________________

Q 1 .How many round trips to Boston in 1 second travelling at "c"?

Solution:

answer: [ ]

Q 2. How many round trips to Boston in **0.5 seconds** travelling at "c"

(**0.5 sec**: the time it takes an object on the surface of the Earth to **FREEFALL** (drop) ________________*

Solution:

answer: [ ]

* One of Newton's formulas: $t = \sqrt{\frac{s}{.5a}}$

t = time (in seconds), **s = distance** (in feet), and

a = acceleration of gravity (a_g) (in feet per second per second, or ft/sec^2)

The acceleration of Earth's gravity is 32 ft/sec^2

Background info for Q 2 and Q 3:

Rough estimate of Earth's circumference:

Formula:

Rounding for rough estimate:

answer:

Q 3. How many times around the world in **1 Sec** travelling at "c" ?

Solution:

answer:

Q 4. How many times around the world in **0.5 Sec** travelling at "c" ?

Solution:

answer:

Background for Q 5 and Q 6

Distance from Earth to the Moon:

(Image drawn to scale)

Q 5. How long does it take light from the Moon to reach Earth?

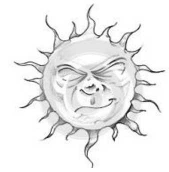
Solution:

answer:

Q 6. How long does it take to reach the Moon travelling at 100 MPH 24/7?

Solution:

answer:



Distance from Earth to the Sun: ____

(____)

Q 7 . How long does it take light from the Sun to reach the Earth?

Solution:

answer:

Q 8. Express the answer in **meaningful terms**:

Solution:

answer:

Q 9. How long would it take to reach the Sun travelling at average commercial jet speed (~ 500 MPH)
Express your answer in **meaningful terms**.
Solution:

answer:

Distance to nearest star: ___________________________ / ___________________________________

____

____

"Light Year" : ____

____

Q 10: How many miles is **1 LY**?

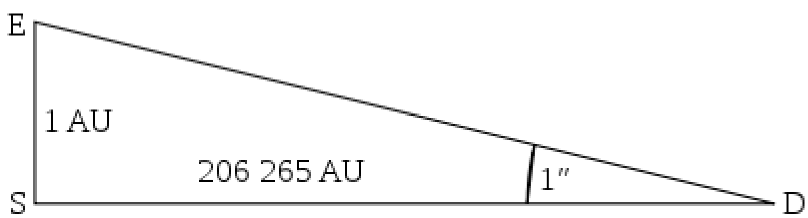
Solution:

answer:

Astronomical Unit (AU) Defined as: ____

= _________________________miles / ________________________km/_______________________m

1 Parsec = ________________________ (See also Appendix H-1)



In the diagram above *(not to scale)*, **S** represents the Sun, and **E** the Earth at one point in its orbit. Thus the distance **ES** is one astronomical unit (AU). The angle **SDE** is one arcsecond (1/3600 of a degree) so by definition **D** is a point in space at a distance of one parsec from the Sun.

One AU ≈ 1.5×10^{11}m

1 parsec ≈ (1.5×10^{11}m) x (2.063×10^{5} AU) = 3.0857×10^{16} m ≈ **3.26 LY.**

Scientific Notation and Metric Prefixes

Prefixes: Equivalent to ____________________________

Giga ________ or ____________________________________

Meg ________ or ____________________________________

Kilo ________ or ____________________________________

Centi ________ or ____________________________________

Milli ________ or ____________________________________

Micro ________ or ____________________________________

Nano ________ or ____________________________________

Measures of distance

Mile: ____

Kilometer: ____

Meter:____

____

"Standard Unit:" ____

____

____

Ex: Size of a proton: ____________________

Distance to Sun : _________________________

Corresponding range of orders of magnitude:

Measures of time (Standard Unit)

One _________________ ; ___________________ seconds = 1 hour

Converting prefixes to powers of ten:

Ex. 1

$$5.26 \underline{K}m = ?\ m$$

Ex. 2

$$6.6 \underline{M}pc = ?\ pc$$

Ex.3

$$3{,}345\ Km = ?\ m$$

Exercises

42.38 LY = _____ pc?	
4 pc = (approx) ______ AU?	
20 pc = _____ LY?	
4.5 Mpc = ? pc (scientific notation)	
380,000 Km = ? m (in scientific notation?	

Topic: Historical Figures

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.

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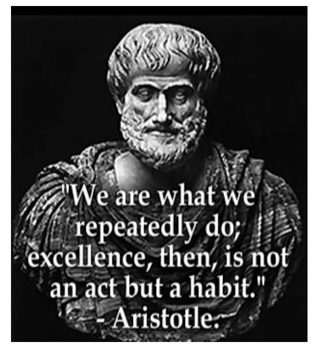

Aristotle 1.____

2.____

3. ____

4. ____

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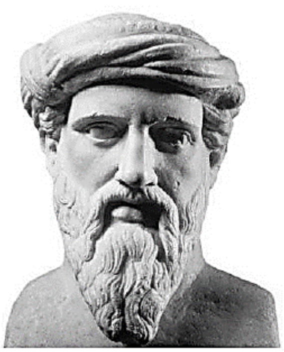
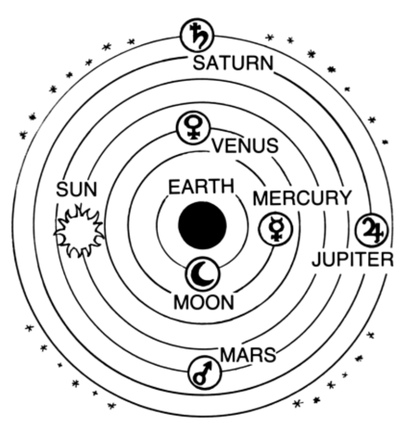
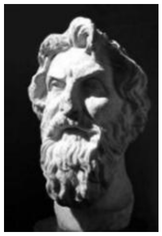


Pythagoras of Samos (569-475 BC) is regarded as the first pure mathematician to logically deduce geometric facts from basic principles. He is credited with proving many theorems such as the angles of a triangle summing to 180 deg, and the infamous "Pythagorean Theorem" for a right-angled triangle (which had been known experimentally in Egypt for over 1000 years). The Pythagorean school is considered as the (first documented) source of logic and deductive thought, and may be regarded as the birthplace of reason itself. As philosophers, they speculated about the structure and nature of the universe: matter, music, numbers, and geometry.



Aristarchus



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Ptolemy ____

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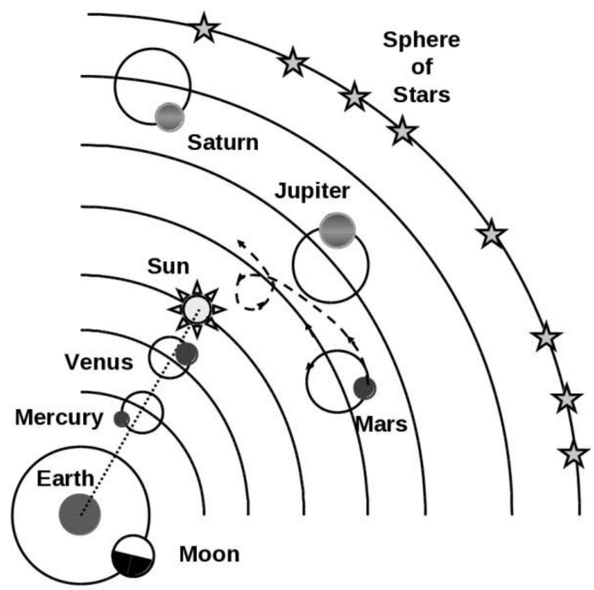
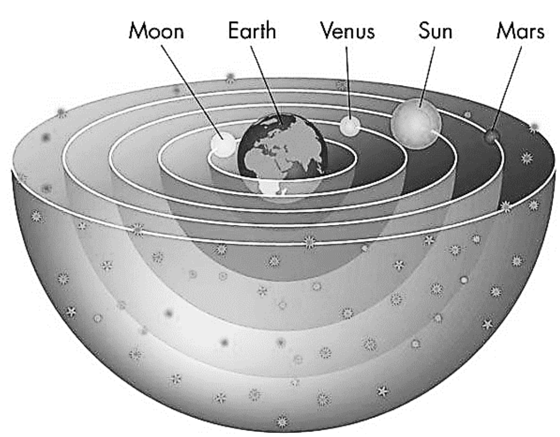
Epicycles

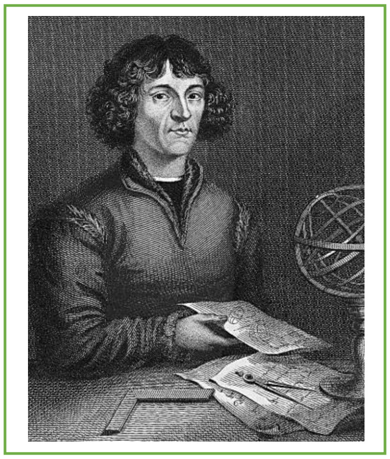


Deferents

Crystal Spheres



Copernicus

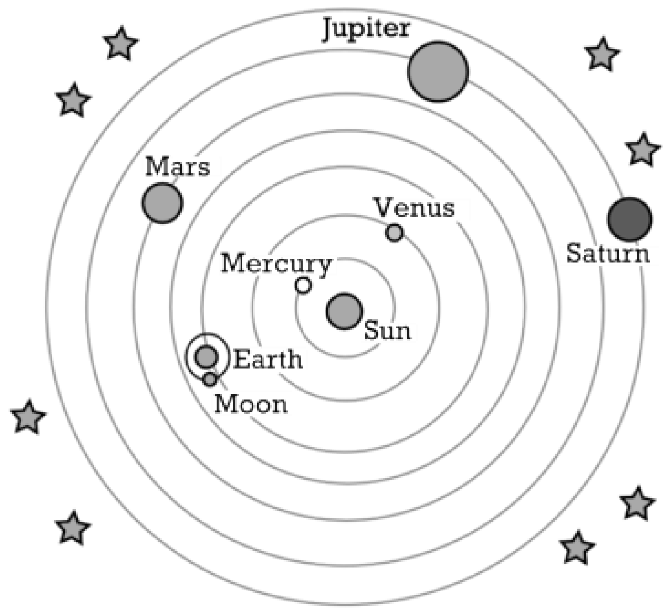


1. ____

2.____

3. ____

4. ____



Sun at the Center

Galileo

1. First to use the ____

2. Discovered the ____________________ of __________________________________

3. Discovered the ____________________ of __________________________________

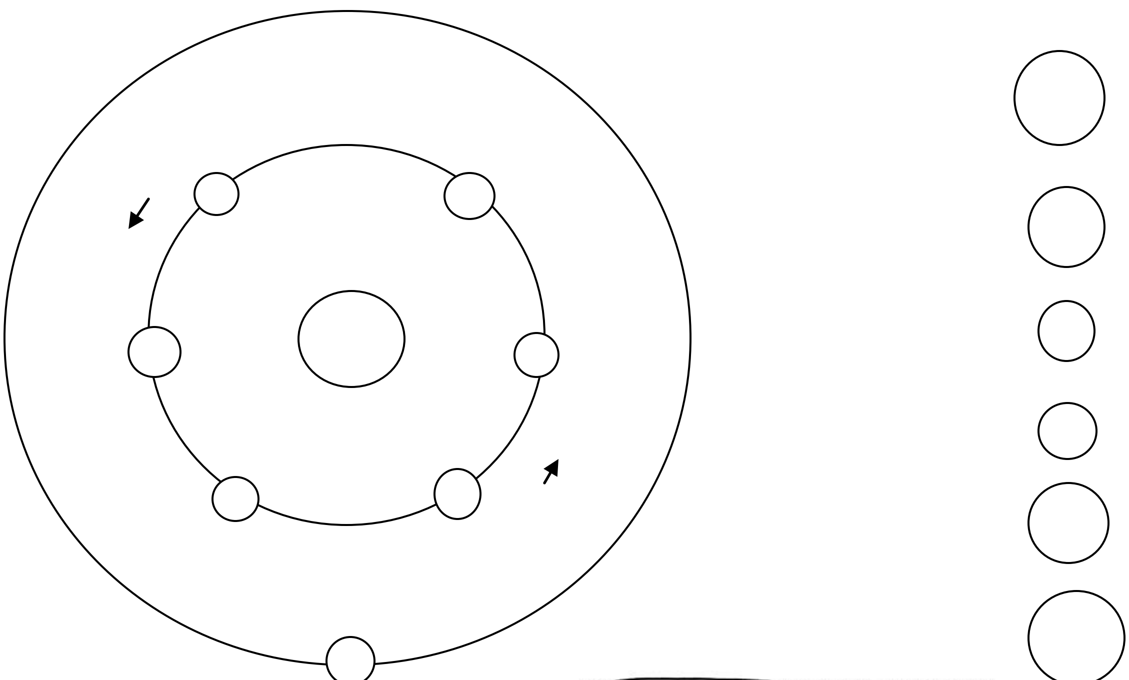
4. Discovered ____

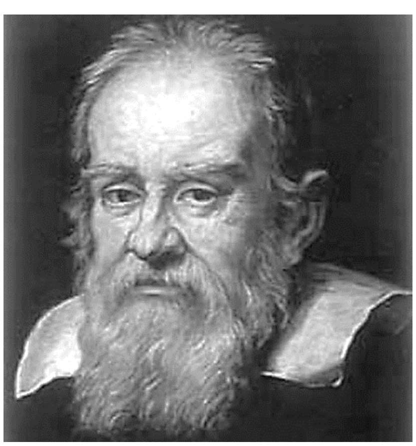
____

4. Prime author of the ________________________ _______________________

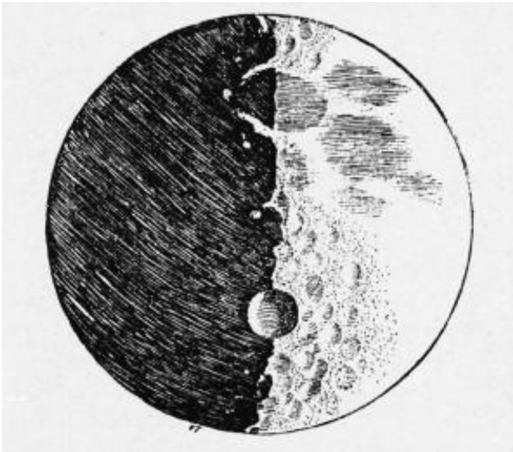
5. Was tried for ____

____



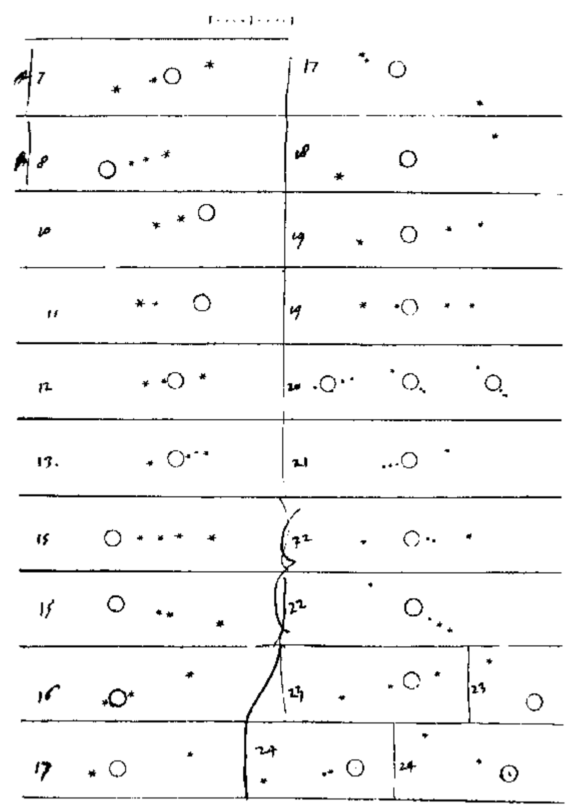


Galileo's Sketches:

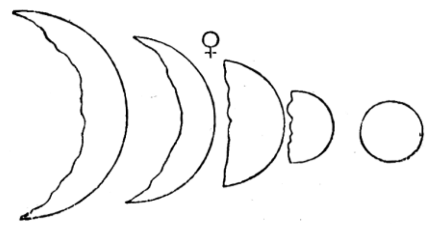


Galileo's first sketch of the Moon

Compare to actual photo

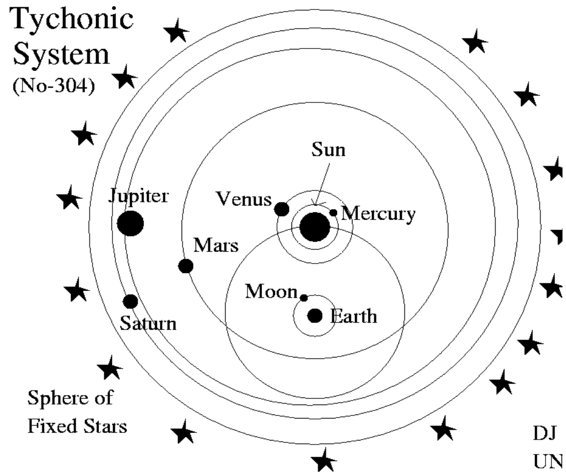


Galileo's sketches of Jupiter's moons. Note dates.



Galileo's sketches of the phases of Venus

Here is Galileo's sketch of the sun, note the spots on it. In his times, it was widely believed that the sun was a perfect sphere, but clearly it had spots. Further, by watching the spots over time it became clear that the sun was actually rotating. Both of these observations seemed to be at odds with interpretations of Aristotelian cosmology.



Tycho Brahe: ____________________________

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Paralax: ____

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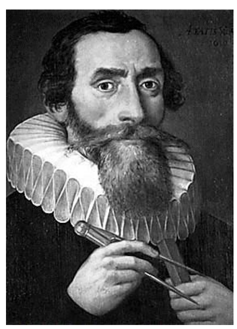
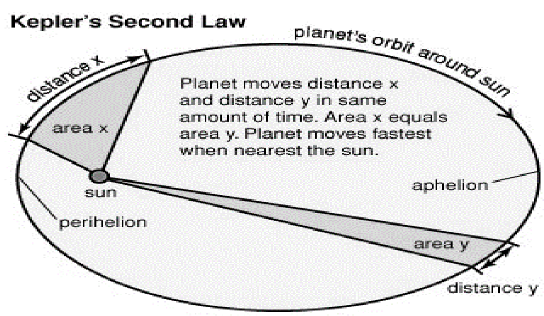
Johannes Kepler





Kepler's First Law____

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Kepler's Second Law ____

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Kepler's Third Law ____

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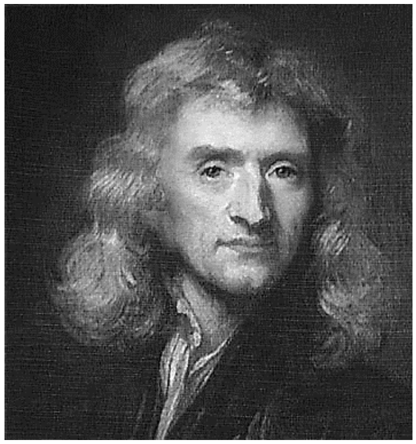
Sir Isaac Newton:



Newton's reflector telescope

1. Wrote ____

____

2. Discovered ____

____

____

3. Established the link ____

____

4. Sought to ____

____

5. Emphasized _____________________ , ______________________ results

6. Invented ____

7. Derived planetary motions ____

____

____

Lab Exercises: Calculating Orbits

Ex. 1

Using Kepler's Third law, determine the mean (average) distance (in AU's) of Jupiter from the Sun based on its orbital period (in Earth years)

Data:

Kepler's Third Law: $p^2 = a^3$

Period of Jupter's orbit: **11.862 Earth years**

Ex.2:

Using Kepler's Third Law, determine the period of Mars' orbit based on its mean distance from the Sun

Data: Mean distance from Sun = **1.5237 AU's**

`Newton's Version of Kepler's Third Law:

$$p^2 = \frac{4\pi^2}{Gm}\, a^3$$

or

$$p^2 = \frac{4\pi^2\, a^3}{Gm}$$

Where:

$\boldsymbol{p}$ = period in seconds

$\boldsymbol{a}$ = distance in meters

$\boldsymbol{G}$= Universal Gravitational Constant = 6.672 x 10^{-11} Nm2/Kg^2

$\boldsymbol{m}$ = mass of the primary in Kg

Ex. 1:

Using Newton's Version of Kepler's Third Law, determine the period (in days) of Jupiter's moon Ganymede

Data:

Ganymede's orbital radius: 1,070,000 Km (must be converted to meters. Use scientific notation!)

Mass of Jupiter (the primary in this case): 1.899 x 10^{27} Kg

Ex. 3:

Using Newton's Version of Kepler's Third Law, determine the mass of the Sun using Earth's orbital data

$$p^2 = \frac{4\pi^2 a^3}{Gm}$$

↓

$$Gmp^2 = 4\pi^2 a^3$$

↓

$$m = \frac{4\pi^2 a^3}{Gp^2}$$

(working formula)

Remember this formula. It is one of the methods used to calculate the mass of black holes

a = 149.6 x 10^6 Km (convert to meters)

p = 365 days (convert to seconds)

ASTR 100 Gravity Lab

This lab evaluates several key physics-based concepts essential to astronomy and cosmology, including:

1. Quantitative methodology, the Scientific Method (Galileo)

2. Application of fundamental laws of physics (Newton)

3. Sir Isaac Newton's breakthrough in explaining astronomical phenomena with a mathematical model based on physics principles vis-à-vis Kepler's explanation(s) which were derived from empirical observations.

Specifically, you will apply Newton's Version of Kepler's Third Law to calculate the period of the Moon's orbit.

Formulas used in this lab:

Velocity:	**Acceleration:**
$V = \frac{D}{T}$	$a = \frac{V_f - V_i}{T}$ (In this case $a = a_g$ = gravity)
Simplified ("Idealized") version of Newton's Law of Gravity: $F_g = \frac{GM}{r^2}$ $(F_g = a_g)$	**Mass of Primary (Earth in this case) using variant of simplified version of Newton's Law of Gravity:** $m = \frac{F_g r^2}{G}$
Kepler's Third Law: $p^2 = a^3$ **NOTE:** a = radius of orbit in AU, p = time of orbit Earth Years	**Newton's version of Kepler's Third Law:** $p^2 = \frac{4\pi^2 a^3}{GM}$ therefore, $p = \sqrt{\frac{4\pi^2 a^3}{GM}}$ **NOTE:** a = radius of orbit in meters p = time of orbit in seconds)

Preliminary Data/Instructions:

- Mean radius of Earth at equator: 6378 Km
- Mean radius of Moon's orbit: 384,000 Km
- Numeric value of Universal Gravitational Constant: 6.672×10^{-11}
- Remember, you cannot use kilometers, hours, days in Newton's formulas – you must use standard units: meters, seconds, kilograms!
- 1 hour = 3600 sec, 1 day = 24 hours
- **USE SCIENTIFIC NOTATION!**

Lab Procedure:

1. Using a laboratory freefall apparatus and a spark generator set at a 60 Hz pulse rate, measure and record the time(s) and distance(s) covered by a freefalling object.
2. Note that the space between each mark on the electrosensitive recording tape represents the passage of 1/60 sec.
3. Choose at random three (3) separate events (E_1, E_2, E_3) with a duration of 3/60 sec (.05 sec) and measure the distances covered in each. Measure the distances in centimeters (cm) and convert to meters by moving the decimal two places to the left.
4. Determine the elapsed time between events by counting the spaces between the beginning points of respective events; convert " *X*/60" to decimal equivalents.

Analysis 1:

1. Determine the average velocity of each event using the formula for velocity. Use measured distance(s) in meters for D, duration for T
2. Calculate the average acceleration of gravity by using the acceleration formula; use the average velocity of the earlier Event for V_i, the later Event for V_f, and elapsed time (not duration) for T.
3. Use procedure in Step 2 to compare E_2 with E_1, E_3 with E_2, and E_3 with E_1.
4. Average the results from Step 3. This is your measured/calculated average acceleration of gravity (a_g) at sea level.

Analysis 2:

1. Calculate the mass of Earth using the preliminary data and your measurement of a_g using the variant of simplified version of Newton's law of Gravity.
2. IMPORTANT: Use your measured/calculated a_g for the value of F_g

Analysis 3:

1. Calculate the period of the Lunar orbit (in seconds) using Newton's Version of Kepler's Third Law
2. Use values from Preliminary Data and your calculations from Analysis 2
3. Convert result to "days"
4. **USE SCIENTIFIC NOTATION!**

<table>
<tr><th colspan="3">ANALYSIS 1 WORKSHEET</th></tr>
<tr>
<td>Event 1 (E_1)

D = ______________ m

T = .05 sec (3 spaces)

D/T = _______________ m/sec

(V of E_1)</td>
<td>Event 2 (E_2)

D = ______________ m

T = .05 sec (3 spaces)

D/T = _______________ m/sec

(V of E_2)</td>
<td>Event 3 (E_3)

D = ______________ m

T = .05 sec (3 spaces)

D/T = _______________ m/sec

(V of E_3)</td>
</tr>
<tr>
<td>Elapsed time E_1 to E_2</td>
<td>Elapsed time E_2 to E_3</td>
<td>Elapsed time E_1 to E_3</td>
</tr>
<tr>
<td>Average acceleration E_1 to E_2

V_f = V of E_2 = _______________

V_i = V of E_1 = _______________

T = Elapsed time = ___________

$a = \frac{\quad - \quad}{\quad sec}$

$a_1 =$ ________________m/sec^2</td>
<td>Average acceleration E_2 to E_3

V_f = V of E_3 = _______________

V_i = V of E_2 = _______________

T = Elapsed time = ___________

$a = \frac{\quad - \quad}{\quad sec}$

$a_2 =$ ________________m/sec^2</td>
<td>Average acceleration E_1 to E_3

V_f = V of E_3 = _______________

V_i = V of E_1 = _______________

T = Elapsed time = ___________

$a = \frac{\quad - \quad}{\quad sec}$

$a_3 =$ ________________m/sec^2</td>
</tr>
<tr>
<td colspan="3">Calculate average acceleration (a_{avg}):

$a_1 + a_2 + a_3 =$

_____________ + ______________ + ________________ = _____________________________

Divided by 3 = _________________________________ m/sec^2 (a_{avg})</td>
</tr>
</table>

ANALYSIS 2 WORKSHEET

Required data:

1. Calculated a_{avg} : ____________________________

2. Radius of Earth (in meters) ____________________

3. Numerical value of G: ________________________

Calculations:

ANSWER:

ANALYSIS 3 WORKSHEET

Required Data:

1. Earth Mass as calculated in Analysis 2 ________________________________

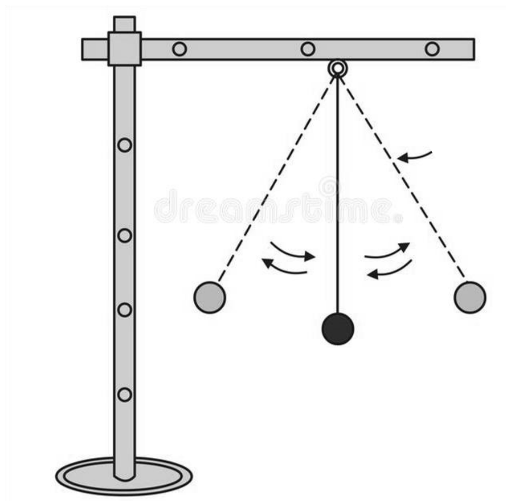
2. Numerical value of G ____

3. Radius of Lunar orbit in meters ______________________________________

ANSWER (IN DAYS):

Lab Addendum - Here's a gravity experiment you can do at home:

Using a string, a rock, a meter stick, and a wristwatch to determine the acceleration of Earth's gravity



Pendulum Formula:

$$\boldsymbol{g} = \boldsymbol{l}(2\pi \boldsymbol{f})^2$$

Where:

$\boldsymbol{g} =$ acceleration of gravity (m/sec2)

$\boldsymbol{f}$ = frequency (cycles/sec or Hertz / Hz)

$\boldsymbol{l} =$ length of pendulum (meters)

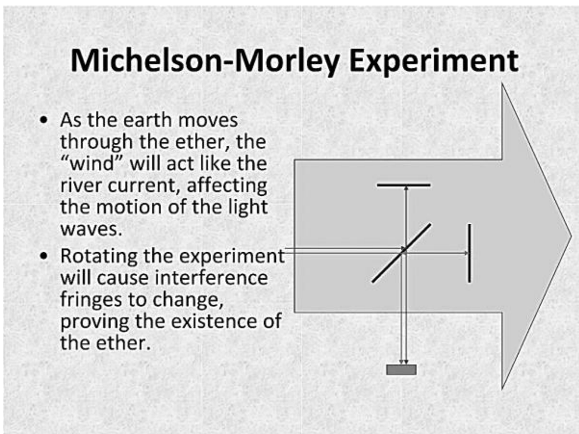
Michelson – Morley Experiment

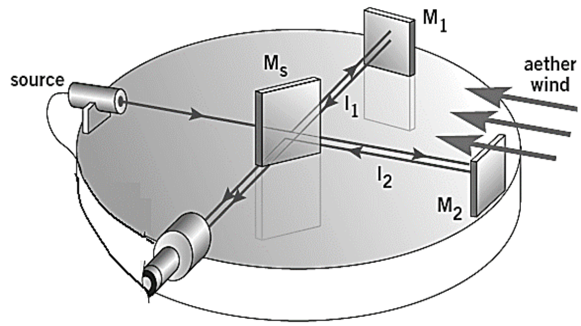
Albert Michelson

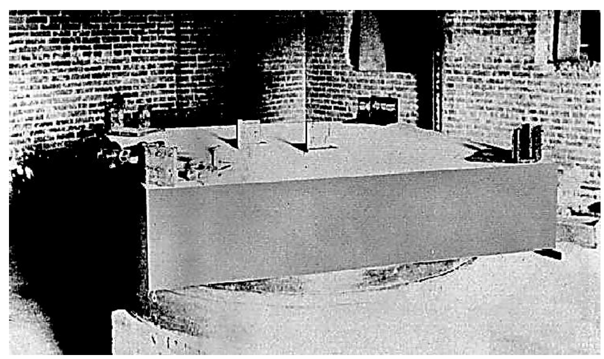
1. ________________________________
2. ________________________________

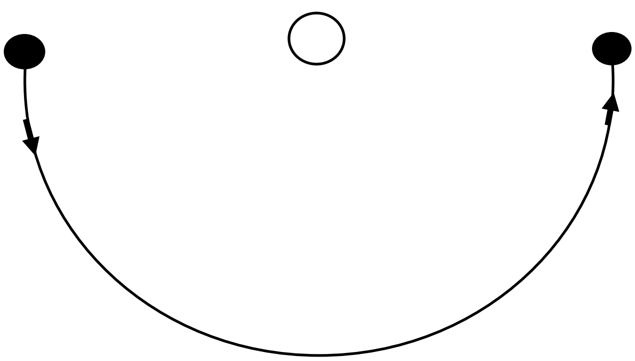
Luminiferous Ether (Aether) (the "Ether")

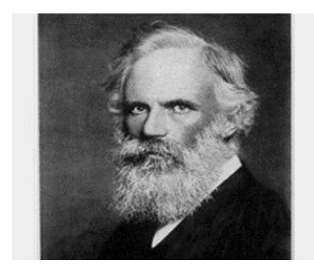
1. ____
2. ____



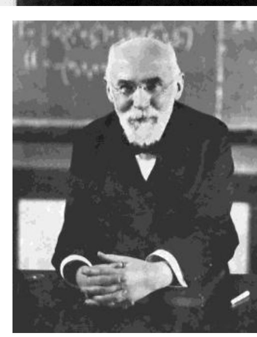








George Fitzgerald ______________________________



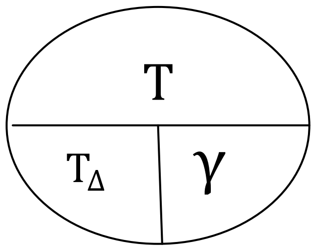
Hendrik Lorentz : ________________

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

Where

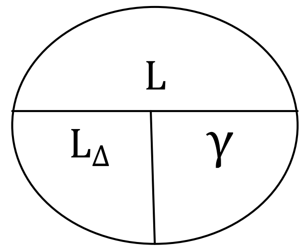
Time: $T_\Delta = \frac{T}{\sqrt{1-\frac{V^2}{c^2}}}$

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



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

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



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."

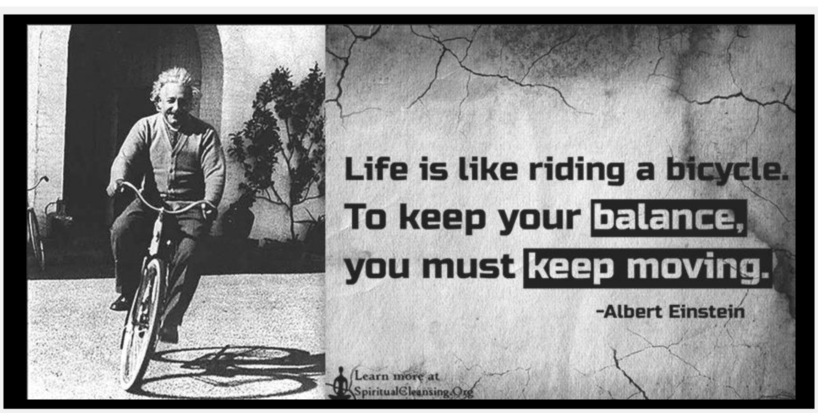
On virtue:

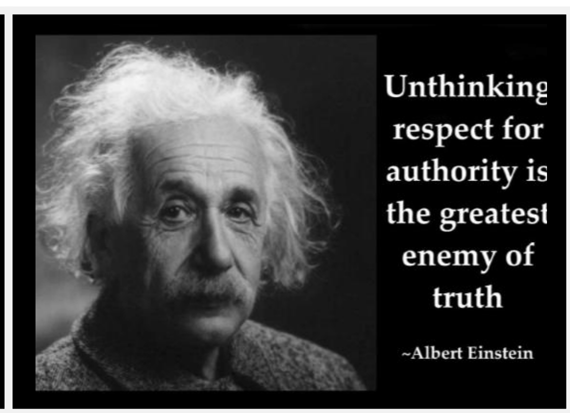
"As far as I'm concerned, I prefer silent vice to ostentatious virtue."

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."

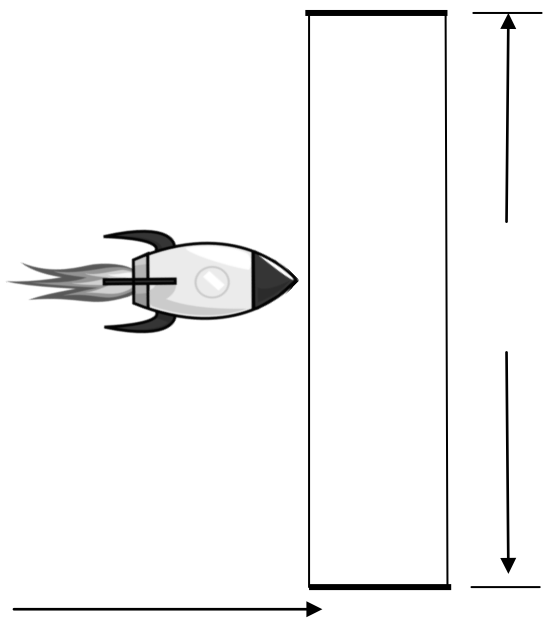




To understand why Relativity is necessary we have to look at the practical problems resulting from a Cosmic Speed Limit (The speed of light: “c”)

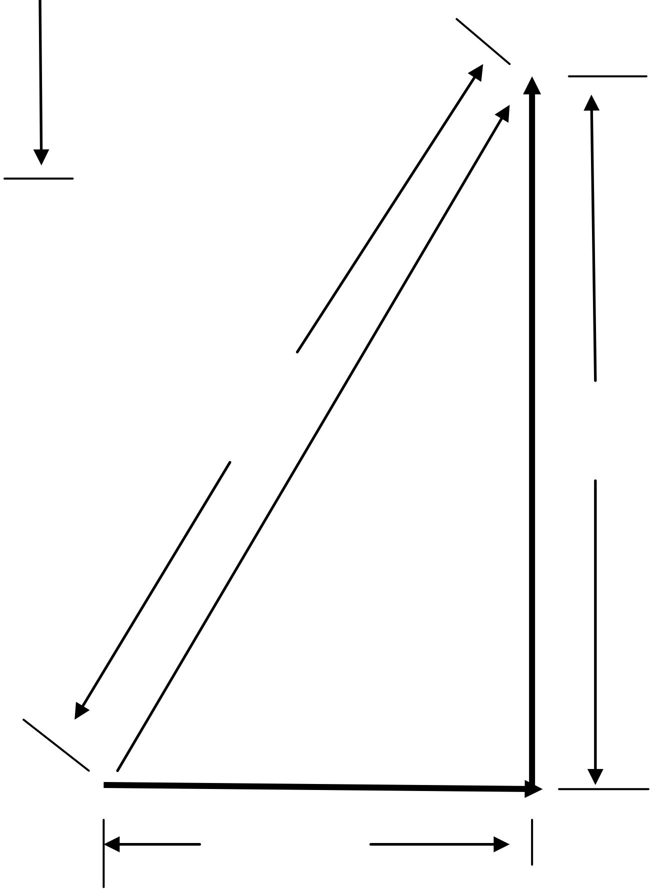
(C= 186,000 mi/sec, 300,000 km/sec, and/or 3.0 x 10^8 m/sec)

We’ll start with a ridiculous imaginary clock:



V = .5c
(1.5 x 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

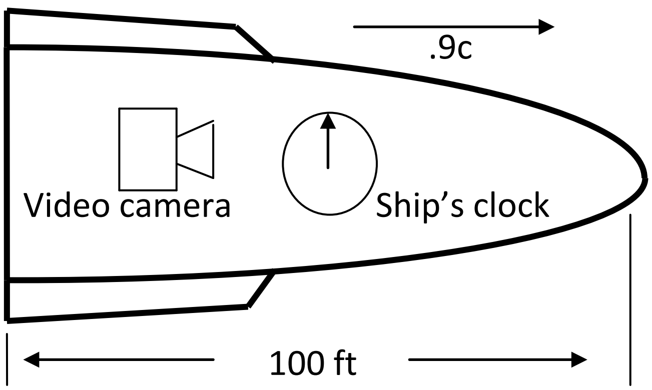
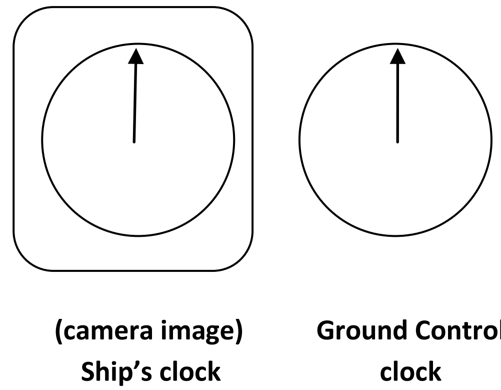


fig 2. **Ground Control observer's console**



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!

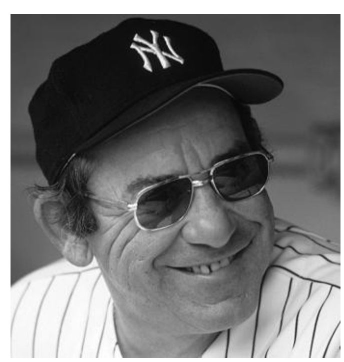
Solution:

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 Scientific Method:

"You can observe a lot just by watching."

The Twins Paradox

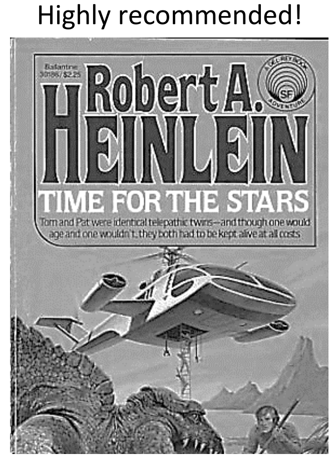
One of pair of identical twins is selected to be a crew member of a deep-space expedition to a star eleven light-years distant.

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	$1\text{-}v^2$	$\sqrt{(1\text{-}v^2)}$ ("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):

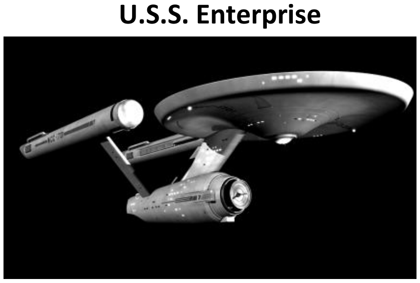
A crew of astronauts leaves Earth to explore deep space.
Given:

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.

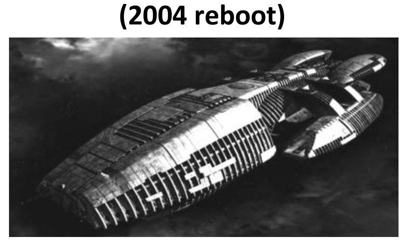
Point to ponder: Which famous Sci-Fi vessel most realistically depicts FTL (faster-than-light) travel?
You may have to root around Youtube for this one.
Hint: consider the passage of **time experienced on board a vessel** travelling **AT** the speed of light ("c")

U.S.S. Enterprise



Millennium Falcon

Battlestar Galactica (2004 reboot)



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 $5.86 \times 10^{\mathbf{-8}}$ Kg

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

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

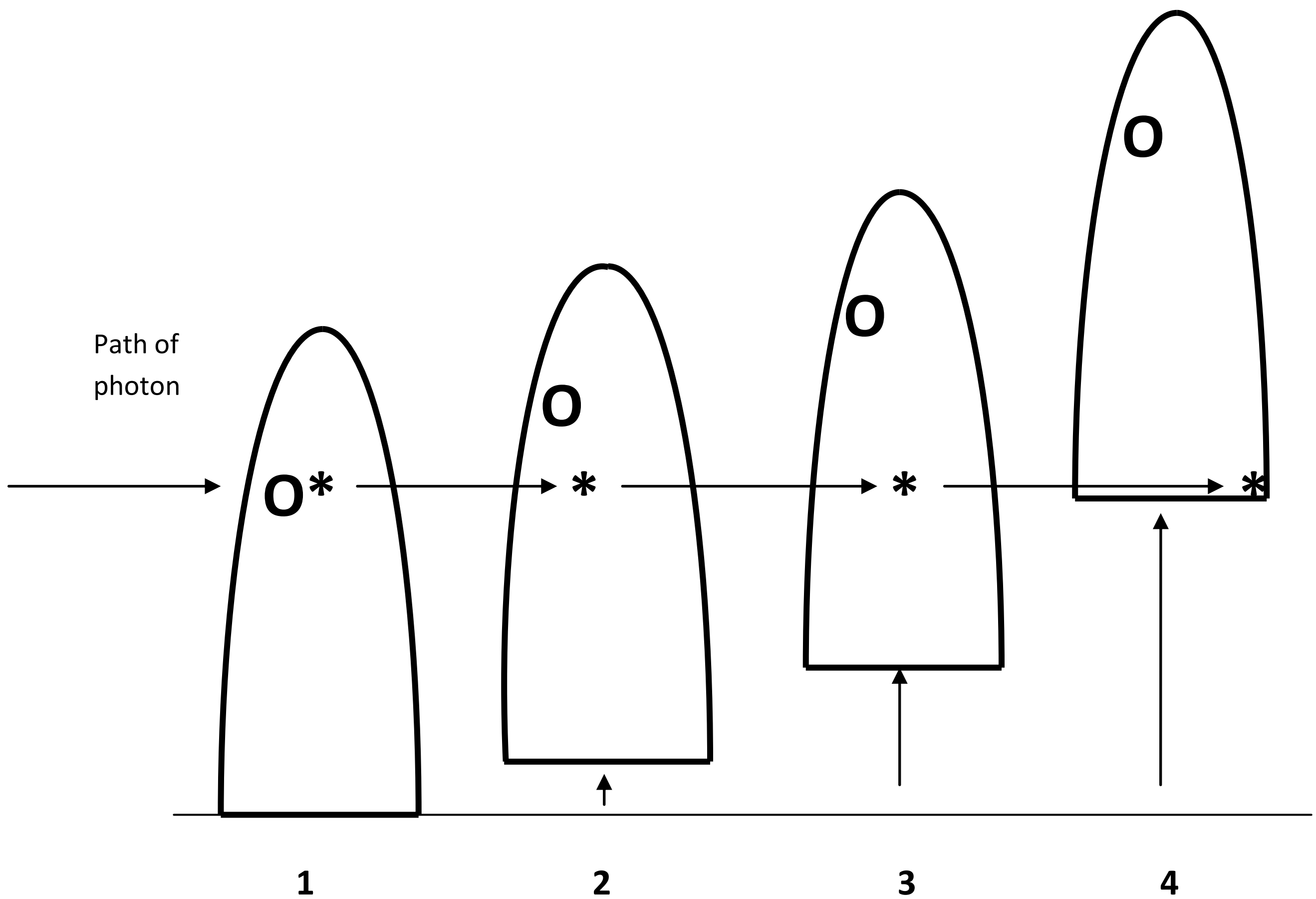
Further Practical Problems with Relativistic Velocity (Example 3)

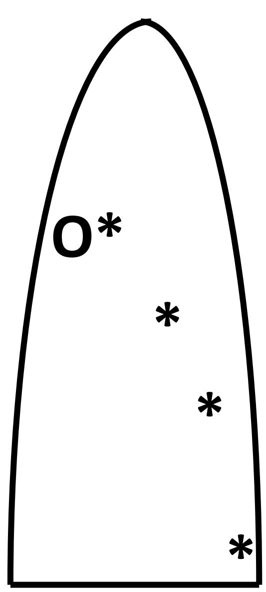
Given: A space vessel traveling at .9c collides with an small object with a mass of 2.5 grams (roughly the mass of a penny)

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)

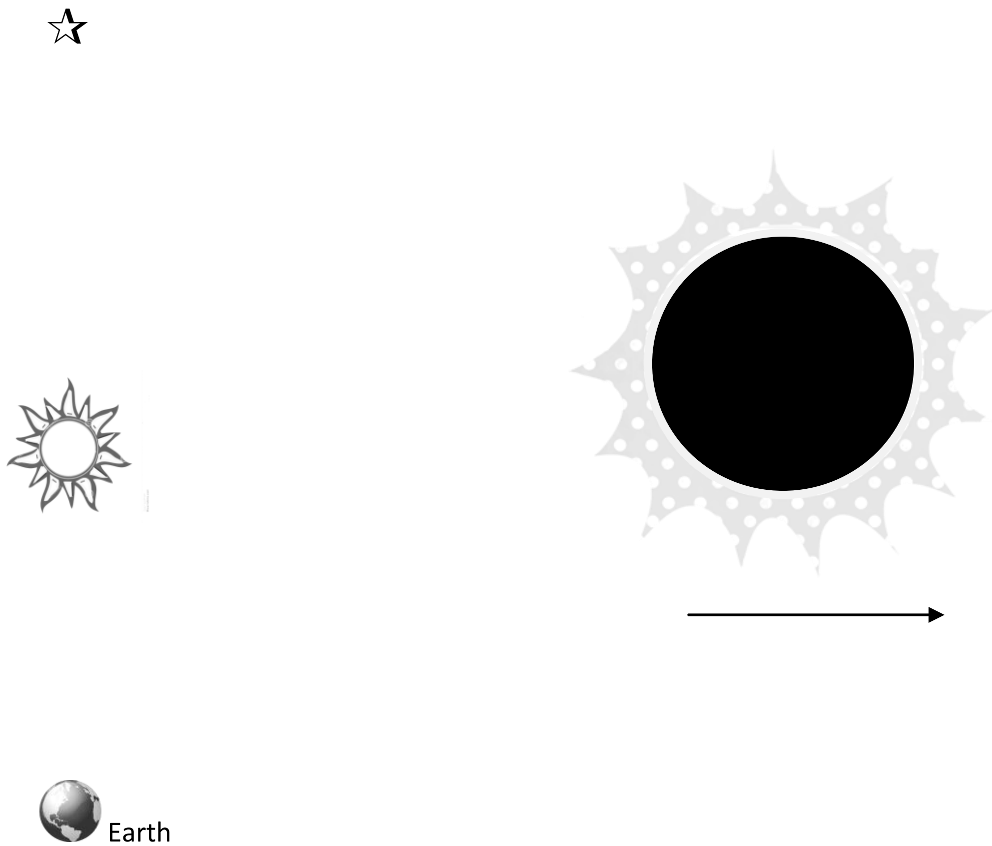
The effects of acceleration on the path of a photon





Path of photon relative to spacecraft

Proof of gravity affecting light during solar eclipse:



Topic: Star Formation

Text Reference:______________________________

Interstellar medium:

“Interstellar:” ____

Contains 10% ____

Overall Composition:

By Particles: ____

By Mass: ____

“Metals:” ____

Gas comprised of:

(1) ___________________________________

(2) ___________________________________

(3) ___________________________________

Chemical Makeup Includes:

(1)____________________________________

(2)____________________________________

(3) ___________________________________

(4) ___________________________________

(5) ___________________________________

(6) ___________________________________

(7) ___________________________________

Space dust:

Smaller Particles:

(1) ____

(2) ____

Larger Particles:

(1) ____

____

(2) ____

____

Nebulae:

(1) Definition: ____

____

(2) Often embedded in ______________________________________

____

(3) "Giant Molecular Clouds" ___________________________________

____

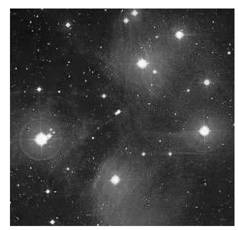
Types of Nebulae

(1) "Reflection Nebulae": ______________________________

____

____

Ex: Pleiades

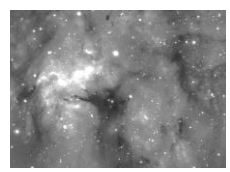


(2) "Emission Nebula": ______________________________

____

____

Ex. The Gamma Sygni Nebula



(3) "Dark Nebulae": ______________________________

____

____

Ex. The Horsehead Nebula

Interstellar Extinction: ______________________________

____

Interstellar reddening: ____

____

____

____

Supernova remnants ____

____

____

____

____

Process:

Gravitational collapse

(1) Bok Globules: ____

____

(2) "Dense Cores": ____

____

(3) Core temp: ____

____

____

(4) Jeans Instability: ____

____

____

Accretion: ____

____

Protostar: ____

____

Most heat ____

____

Radiation ____

____

If not spinning, ____

____

If spinning, ____

____

Pre- Main Sequence Stars

(1) Cannot be seen in visible light because ______________________________
____

(2) Radiation and outflowing gases_____________________________________
____
____

(3) Contracts ____
____
____

(4) Finally, at 10^7 K (100 million degrees Kelvin) :

(Temp result of ____)

(a) Hydrogen____
____

(b) Contraction ____
____

(c) Outer shell of gas and dust ____________________________________

Overall, the more massive the pre main sequence star, ________________
____
____

Example:

5 $M_\odot$ ____
____

1 $M_\odot$ ____
____

Pre main sequence Solar Mass breakout:

< .08 $M_{\odot}$**:**

____
____
____
____

> 7 $M_{\odot}$:

____
____
____

Upper Limits of $M_{\odot}$

:____
____
____
____

H II Regions:

Emission Nebula characterized by ______________________________

____

High mass:____

Surface temp: ____

____

Ultra Violet ____

____

As electrons ____

____
____
____

Oxygen ____

____

Star Formation according to mass:

.08 - .4 $M_\odot$

Class: ____

Red Dwarfs:

Lowest ____

Longest ____

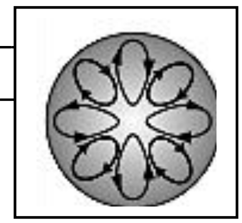
Most common _____________________________________

Limited to ______________________________________

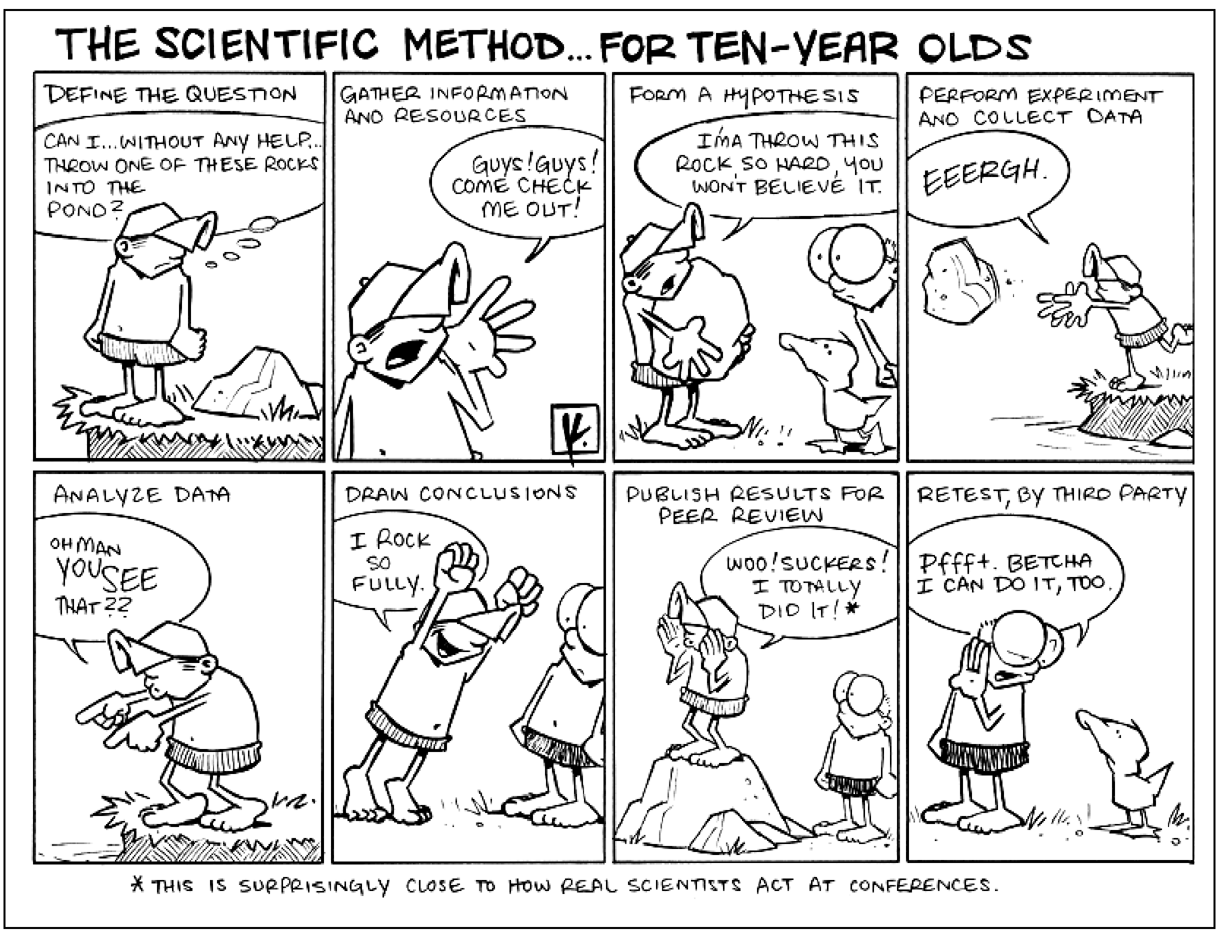
____

Helium transported ______________________________

____



Luminosity: ______________________________



> .4 M⊙

Does not ____

As fusion decreases,____

Hydrogen: ____

Compressed: ____

(“Hydrogen ______________ ________________ “)

More energy than during ____

____

Star then ____________________________

Surface Gases cool to ____

High mass _________________ ; ___________________________________

____

Helium Fusion

At beginning of star’s life, small ____________________________________

Almost ____

No fusion, ____

Two possible routes depending on mass:

(1) 0.4 – 2 M$_\odot$:

Helium Flash:

When star is young, ____

____

Atoms completely ____

"Degenerate" ____

____

____

Electron Degeneracy Pressure: ___________________________________

____

Pressure does not ____

____

At 100 x 10^8 k,, degenerate He ___________________________________

Expansion in ____

____

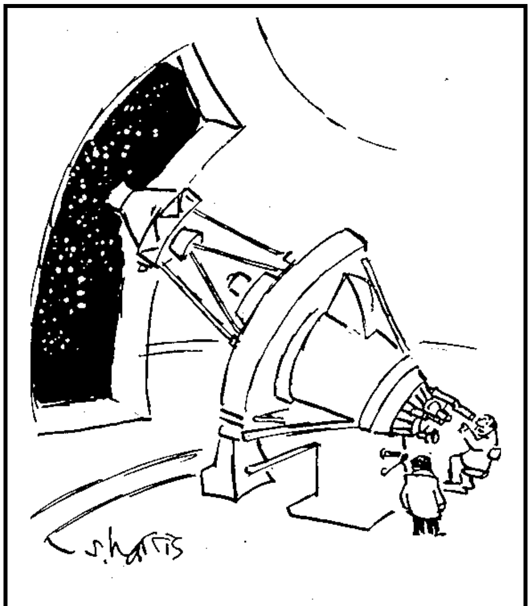
Expanding core ____

Flow of photons ____

Outer layers cool, ____

Star shrinks to ____

____



"Actually they all look alike to me."

More than 2 $M_\odot$:

No____

Mass is sufficient ____

No ____

Safety valve ____

Triple Alpha Process

(1) 3 He atoms ____

(2) (Helium nuclei: called ("__________________________________")

(3) 2 He ____

(4)(10^{-8} sec later) ____

(5) Carbon+ He ____

Variable Stars: the First "Standard Candles"

1. Mature core-helium fusion stars that ____
   ____
   ____

2. Strong direct relationship between ___________________ and __________________

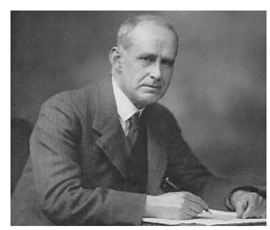
3. Period-luminosity relationship:____

   ____

4. Period/Luminosity relationship discovered by ___________________________________
____

5. Important _________________ ______________________ in ____________________
and _______________________ scales

Pulsation Process



Eddington valve ____

____

Also known as the "κ-mechanism ". Greek letter κ (kappa) denotes

____

____

Helium ____

Ionization of helium: ____

Single ionization: ____

Double ionization: ____

Sequence:

1. At dimmest part of cycle, outer layers ________________________________

____

2. As heat increases, ____

____

3. As star expands, ____

____

4. As star cools, ____

5. Expansion ____

____

____

____

Cepheids

Main Types of Cepheid variables

1. Type I (or classical) Cepheids

Very regular ____

Periods ____

Population _________ , heavy element ~_______ %

(“metal - _____________”)

Mass ____

Luminosity____

Yellow ____

Radii change by ____

Used to determine distances ___________________________________

____

Especially useful in establishing ________________________________

2. Type II Cepheids

Periods ____

Population _________ , heavy element ~_________ %

(“metal - ___________”)

Age : ____

Mass ____

Luminosity__________________________________

(Spectral class ____________)

Subgroups:

BL Hercules subclass: __________________________________

W Virginis subclass: ___________________________________

RV Tauri subclass: _____________________________________

Used to determine distances _________________________________

____

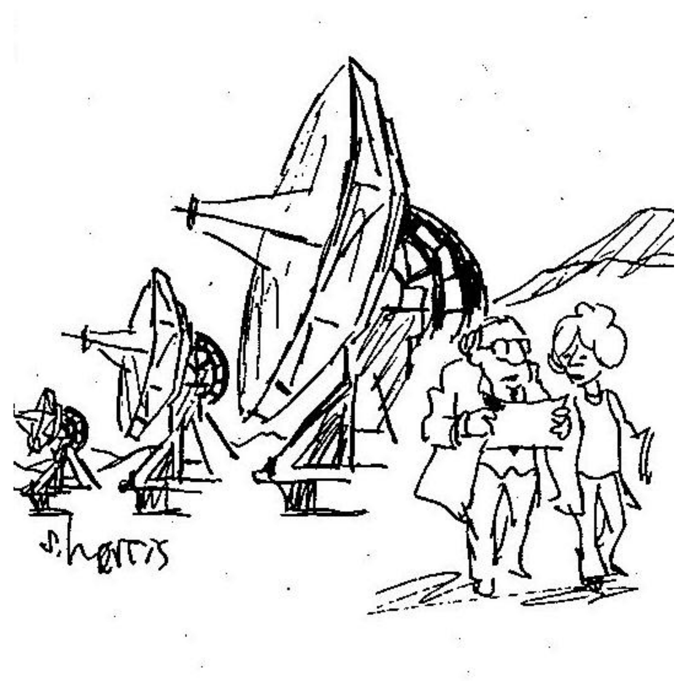
RR Lyrae Variables

Pulse in manner similar to ____

Population ____

Luminosity ____

Spectral class ____



“ We’ve discovered a massive dust and gas cloud which is either the beginning of a new star or just a hell of a lot of dust and gas.”

Background Info:

Standard Candle

Any astronomical object of known luminosity that can thus be used to obtain a distance. Cepheid variables, Main sequence stars, and type Ia supernovae have all be used as standard candles.

Population I stars

Relatively young stars, containing a larger fraction of metals, found mainly in the disk of the Galaxy.

Population II stars

Relatively old stars, containing a smaller fraction of metals, found mainly in the halo of the Galaxy and in Globular Clusters.

Absolute magnitude

A measure of the intrinsic brightness (hence absolute) of a star. Defined to be equal to the apparent magnitude of a star if viewed from the standard distance of 10 parsecs. The difference between the observed apparent magnitude and the intrinsic absolute magnitude (assuming this is known from some other means) provides the distance to the star, through a formula known as the distance modulus. The symbol used for Absolute magnitude is the upper case letter M.

Apparent magnitude

The brightness of a star as it *appears* to the eye or to the telescope, as measured in units of magnitude. The symbol used for apparent magnitude is the lower case letter m.

ASTR 100 Topic: Death of Stars

Death process determined by mass, categorized as follows:

$< 0.4M_\odot$ ____

$0.4M_\odot - 8M_\odot$ ____

$> 8M_\odot$ ____

Red Dwarfs

- Recall: fusion process ____

  ____

- Once hydrogen used up, ____

Larger Stars

- **Overview:** Fusion ____

  ____

  Recall:

- **$< 2M_\odot$:** ____

- **$> 2M_\odot$:** No ____

  ____

  \- In both cases, cores converted to ____

  ____

Low mass stars:

Background:

- Carbon, oxygen require _______________________ to fuse
- Core of low-mass star max's at _______________________
- Hence, no___________________________________ fusion

Sequence:

1. Photon production ____

2. Inner regions ________________________

3. Compression heats _____________________________________, and then -

4. Heats ____

Note: Size of core____

5. Temps reach fusion level ____

____

6. Star expands for 2nd and last time

- Star becomes ____

____

Ex 1: Sol will expand ____

Ex 2: $8M_\odot$ star will ____

As stars go into this giant phase, they lose mass due to reduced escape velocity at surface and stellar winds; all stars lose mass as a normal process, but in giant phase process is accelerated.

The sun, for example, will lose 10^{-5} $M_\odot$ per year, eventually losing half its mass.

Next Sequence:

1. Low mass star has less ____

2. Cools, therefore ____

3. Carbon – Oxygen core ____

4. Free electrons provide ____

5. Core temp drops to below ____

6. Slight rise in temp due to compression restarts ___________________________

____

7. Star expands, brief decrease ____

8. During fusion spikes, ____

9. Star goes through several of these "spikes," _____________________________

10. Outer surface cools enough to ____

11. Recombining process ____

12. Photons create ____
____

(Photons are ____)

13. Pressure decreases until ____

14. Ejected material ____

15. Finally, enough ejected material is visible as expanding cloud

(____), often greenish hue with dying star in middle

(green: ____)

Low mass stars can ultimately lose ____

Planetary nebula

- Roughly ____
- Planetary nebula approximately ___________________________________
- Goes into formation of ____

  ____
- Chemical makeup includes _______________________________________

  ____
- After 50 K years, ____

End Stage –

"White dwarf"

- Exposed core ____
-
- Supported by ____
-
- Approximately ____
- Thin outer layer of ____
- Extremely dense: ____

  (one million times ____

  ____)
- After several billion years, ______________________________________

  ____
- Carbon, oxygen ____

White Dwarfs in Binary Systems

"**Nova" vs. "Type 1a Supernova"**

Nova

1. "Normal" star in pair reaches limit of ___________________________________

____

2. Dumps ____

____

3. Gravitational pressure of added mass __________________________________

____

4. At 10 x 10^6 K, hydrogen fusion ______________________________________

____

5. Dwarf remains ____

____

Remember:

Newton's Law of Universal Gravitation:

$$F_g = \frac{GM}{r^2}$$

This simple arithmetic tells us that if star's material (mass) is compressed (degenerate), thereby decreasing the radius, then gravity increases proportionately to an enormous degree; hence, we can see how gravitational pressure can raise temp of hydrogen on surface to fusion level.

Type 1a Supernova

1. White dwarf is close to ______________________________

2. **Chandrasekhar Limit:**
   - Above limit, ______________________________

     ____

     ____

   - Limit is ______________________________

     ____

3. Giant dumps ______________________________

____

4. Dwarf undergoes ______________________________

5. Pressure reaches ______________________________

*** 6. **Entire** star ______________________________

____

7. Lots of radioactive ______________________________

____

8. Spectrum ______________________________

9. Reaches **absolute magnitude** ______________________________

____

10. Because this process has such ______________________________

and therefore a ______________________________,

the **Type 1a Supernova** is very **<u>precise</u>** ______________________________

Absolute magnitude:

- **Absolute magnitude** ____

  ____

  ____

- The magnitude scale is a bit counterintuitive: ______________________

  ____

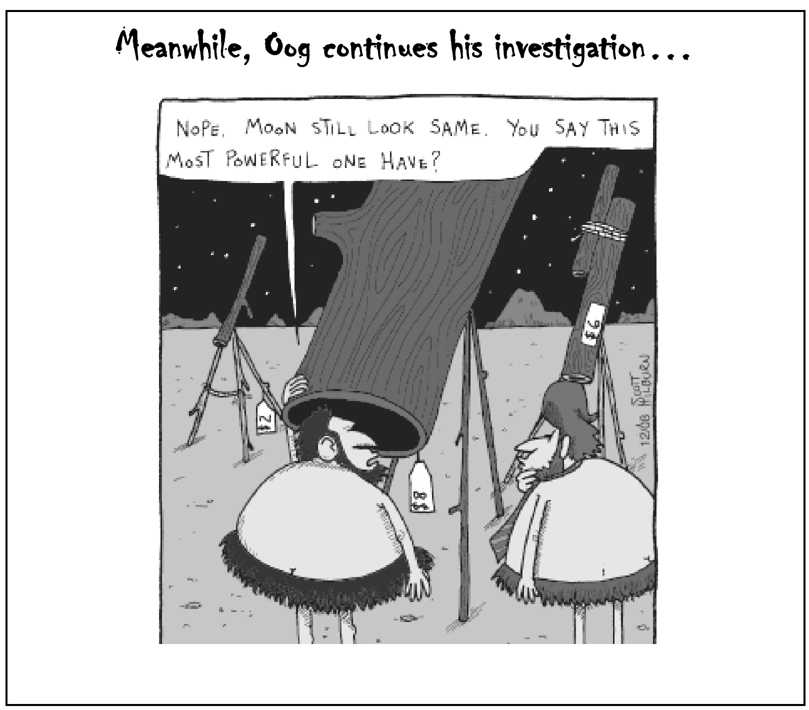
- The **apparent** magnitude of Sol as observed from Earth: _____________

- The full moon on a clear night has an apparent magnitude __________

- The human eye can see no further than magnitude_________________

- Binoculars can get us to magnitude ______________________________

- Sol has an **absolute magnitude** of only _____________ , which means that from a distance of 10 Parsecs, Sol would be barely visible.
  Yet a Type 1a supernova would be many times brighter than the full moon (____ times brighter), so you could read the newspaper at midnight (until the radiation killed you!)



High Mass Stars

> 8M⊙

1. Gravitational pressure ____

2. Temp above 600 x 10^6 K: ______________________________________

3. 1.2 x 10^9 K: ____

4. 1.5 x 10^9 K: ____

5. 2.7 x 10^9 K: ____

(the "star killer")*

Higher temps and faster fusion process because less material available by proportion

Ex:

Carbon fusion – ____

Neon fusion - ____

Oxygen fusion - ____

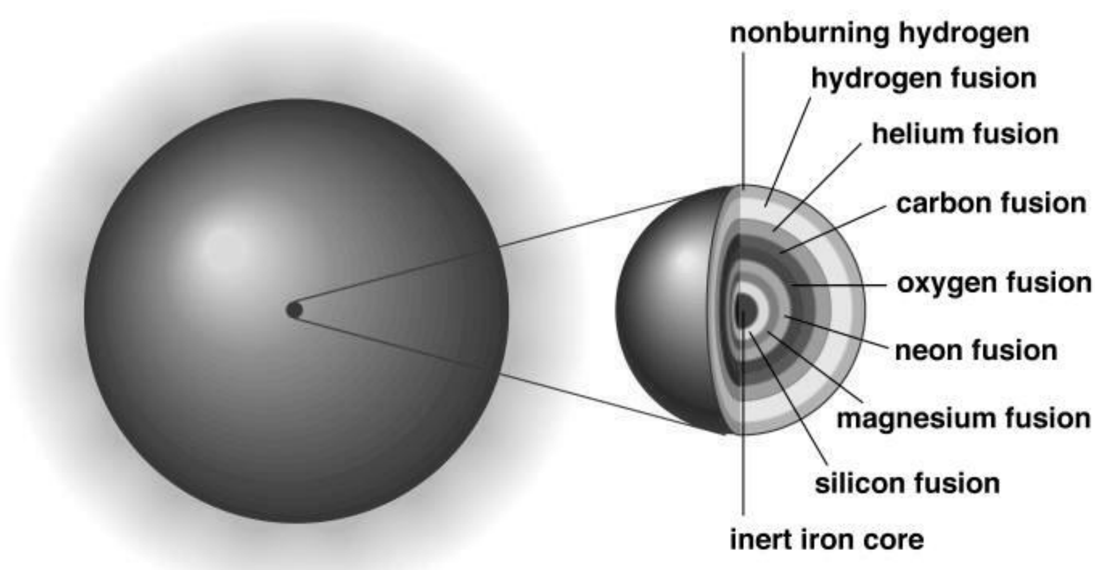
Silicon fusion - ____

*** Iron: The "Star Killer"**

- Iron in core does not __________, does not __________________
- Core is supported by _____________________________________
- As iron deposition continues,

  ____

  ____



Collapse of Iron Core:

1. Core is approx ____ in diameter
2. **0.1 sec** into collapse, ____
3. Gamma ray photons ____;
   Energy sufficient ____
   ____
4. **0.2 sec** into collapse, electrons combine with protons to create_________________
   ____
5. **0.25 sec** into collapse, density at core: _____________________________________
   ____

   "Nuclear density": this is dense as it gets under "normal" circumstances; stated another way, this is literally the density of neutrons themselves.

   By comparison, this is over ten trillion times as heavy as lead!
6. At the point of reaching nuclear density, __________________________________
   ____
7. This halt is so abrupt, ____
   ____
8. Unsupported layers of shell-fusing material _________________________________
   ____
9. Impacts core, ____
   ____
10. Several hours later, ____
    ____
    ____

TYPE II SUPERNOVA!

11. Layers compressed by ____:
    Fusion ____
    ____
12. Over lifetime, high mass star loses _______________________________________

Overview:

1. Generally, Type II Supernovas are _______________________________________
   ____
2. Type II shows ___________________________ in spectrum, Type 1a does not
3. Type 1a has gradual ____
4. Type 1a occurs approx once every _______________________ in Milky Way
5. Type II occurs once every _____________________________

Neutron Stars

1. "Stellar remnants" of ____
2. Essentially the "leftover" ____________________________________
   ____
3. Electron degeneracy pressure does not __________________________
   ____
4. Neutron degeneracy pressure is greater _________________________
   ____
5. Therefore, neutron stars can exceed ____________________________
   ____
6. Neutron Density: ____
   ____

High Mass Stars > 25M⊙

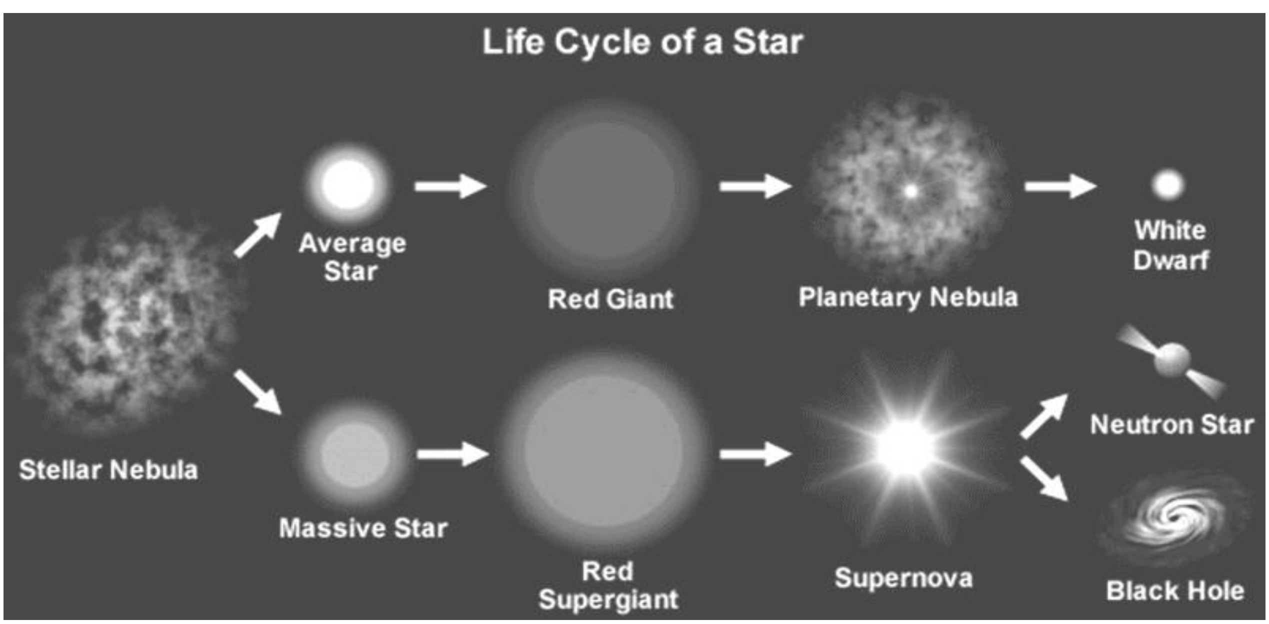
Stellar remnant ____

When neutron star exceed 3M⊙ ____

____

____

____



Black Holes Lab Exercise:

Escape Velocity

Formula for Escape Velocity:

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

Where:

V_{esc} = Escape velocity in meters/sec

$1M_{\odot}$ = 1.99 x 10^{30} Kg

r = radius in meters

C = speed of light = 3.0 x 10^{8} meters/sec

Calculate Escape Velocity (V_{esc}) for Earth

Given:

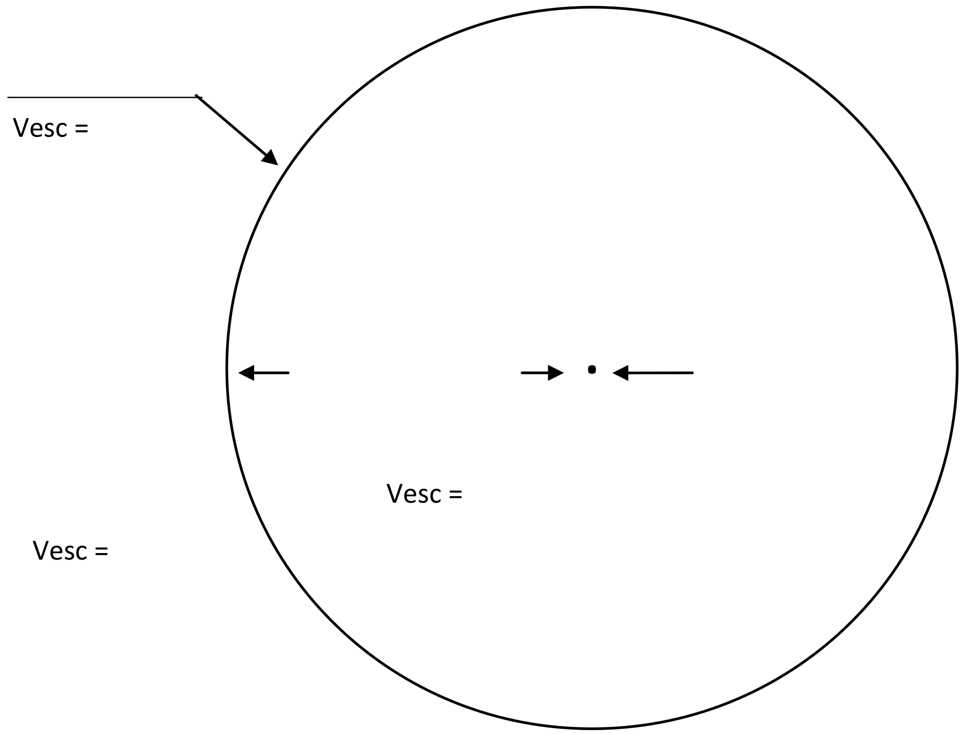
Radius of Earth: 6378 Km

Mass of Earth: 6.0 x 10^{24} Kg

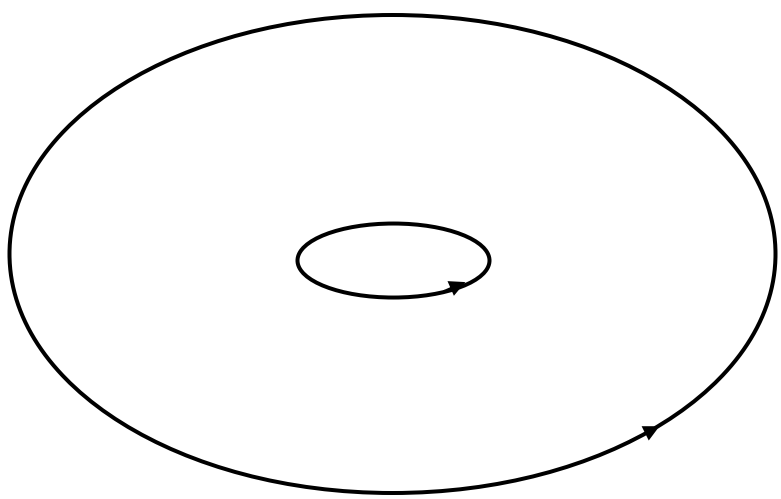
Universal Gravitational Constant (G): 6.672 x 10^{-11}

Now let's change the radius of the Earth to 7.8 mm (7.8×10^{-3} m)

Schwarzchild Black Hole



Kerr Black Hole



Basic Formulas for Black Holes

Given:

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

Where:
V= velocity in m/sec
G = Universal Gravitational Constant = 6.672 x 10^{-11} Nm2/Kg^2
M = mass in kilograms
r = radius in meters

If we stipulate "c" as Escape Velocity, then:

$$c = \sqrt{\frac{2GM}{r_{sch}}}$$

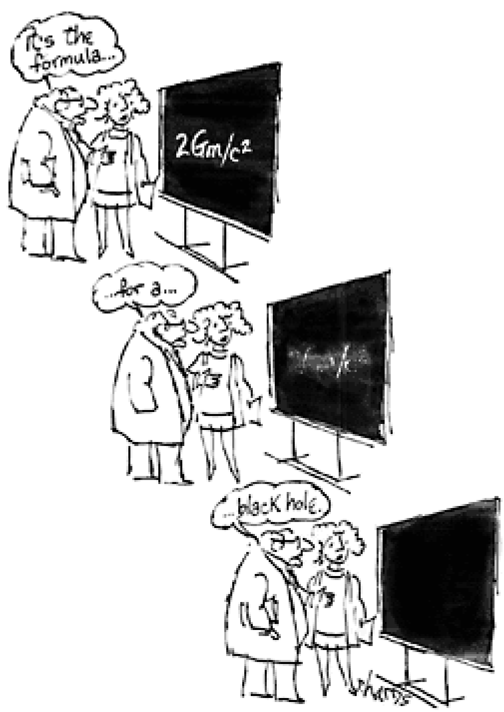
Where:
c = 3.0 x 108 m/sec
G = Universal Gravitational Constant = 6.672 x 10^{-11} Nm2/Kg^2
M = mass in kilograms
r_{sch} = Swarzchild Radius in meters

Therefore:

$$c^2 = (\sqrt{\frac{2GM}{r}})^2 = \frac{2GM}{r}, \text{ so } c^2 = \frac{2GM}{r} \text{ , and}$$

$$r_{sch} = \frac{2GM}{C^2}$$

r_{sch} = Swarzchild Radius



Lab Exercises

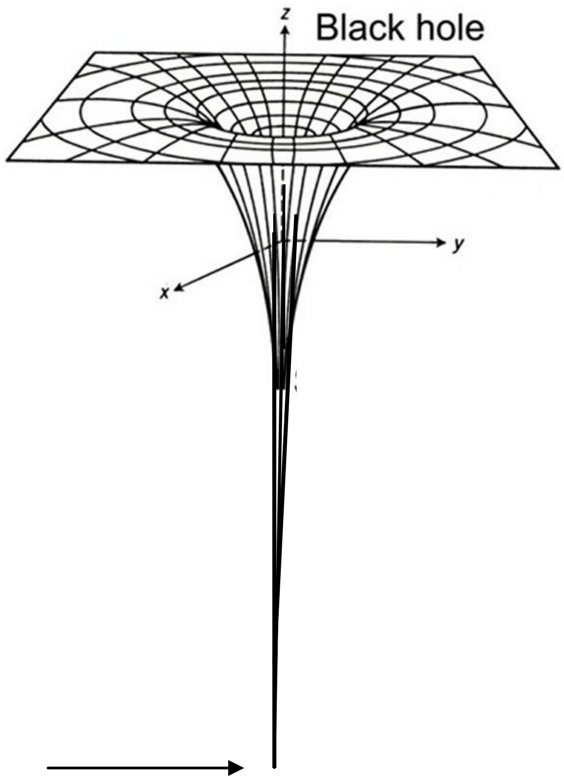
Ex. 1:

Determine the radius of a black hole with a mass of 6.5 $M_\odot$

Ex. 2: Determine the radius of a supermassive black hole with a mass of 5.7 x 10^6 $M_\odot$

Point To Ponder:

In what way is the interior of a black hole similar to Dr. Who's T.A.R.D.I.S.?



ASTR 100 Topic: PULSARS

1968

Jocelyn Bell: ____

Radio telescope ____

____

____

Cambridge team suspected ____

____

Designated ____

____

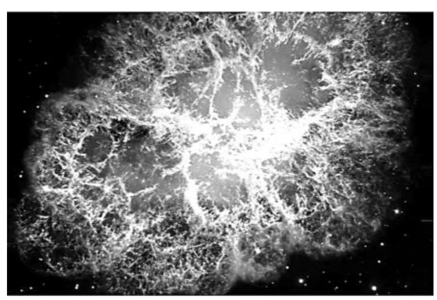
Then, several more ____

____

Now called ____

Expanding/contracting star ____

____



← Approx. 11 LY →

Discovery of pulsar in ____

Location of ____

____

____

Cannot be spinning white dwarf: ____

____

Period: ____

Discovery of PSR 1937 – 21:

Period: ____

Frequency: ____

Mechanism:

Rotation creates ____

Ex: Sol has ____

Think:

Angular ____

As star collapses, rotation ________________________________

So:

Main sequence star rotating @ ______________________________

Collapses to ____

at ____

Magnetic fields can increase to ______________________________

____

Lighthouse model:

Magnetic fields NOT ____

____

Therefore, ____

Magnetic field moves ____

____

Particles ____

Result: ____

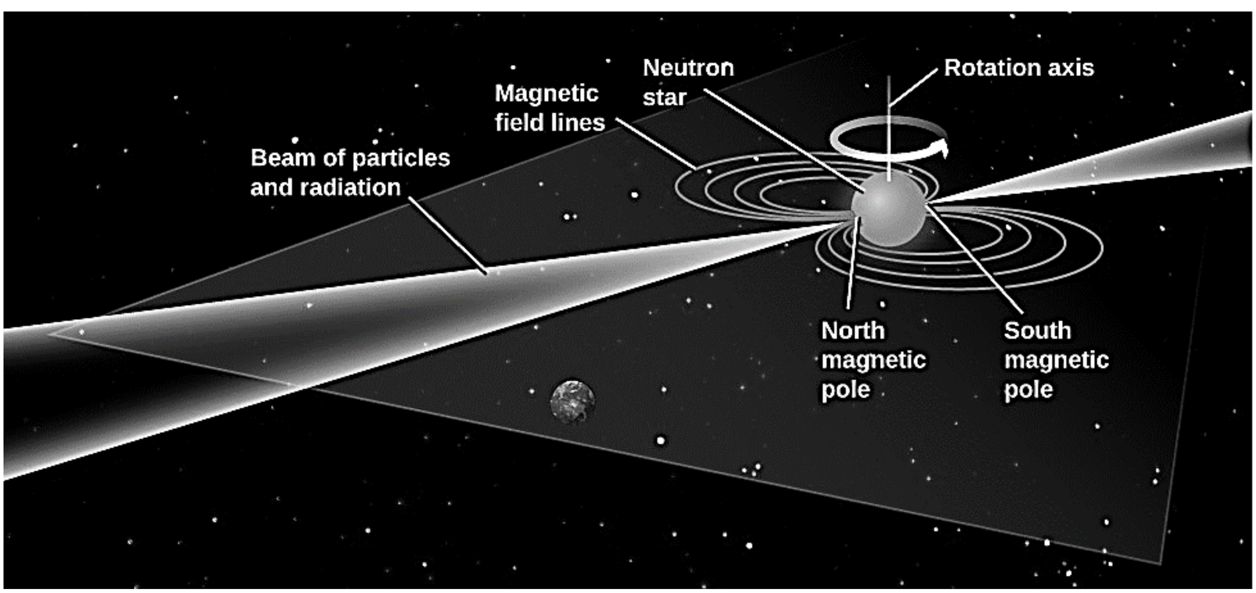
____

Can range from _________________________ to __________________________

X-Rays:

Highly ____

High _________________________, high ___________________________



Lab: Distance-Luminosity Modulus

Calculating Distance, Absolute Magnitude and Apparent Magnitude

Main Formulas:	Where:
$m - M = 5 \log d - 5$ **and** **$d = 10^{(m - M + 5)/5}$**	**m** = apparent magnitude **M** = absolute magnitude **d** = distance in parsecs (pc) **log d** = logarithm base 10 ($\log_{10}$) of distance

About logarithms: Logarithms are just exponents for a specific quantity in a given base

Ex. 1: $10^3 = 1000$, so $\log_{10} 1000 = 3$

Ex. 2: $10^6 = 1{,}000{,}000$, so $\log_{10} 1{,}000{,}000 = 6$

Calculator:

Ex. 1: hit [log], enter 1000, = 3

Ex. 2: hit [log], enter 1,000,000, = 6

Ex. 3: $10^x = y$, so $\log_{10} y = x$

Ex. 4:

Remember from earlier discussion:

$\sqrt{8.1 \, x \, 10^5}$

$= 2.864 \, x \, 10^{\frac{5}{2}}$

$= 2.864 \, x \, 10^{2.5}$ (reciprocal function of "log")

$= 2.864 \, x \, 316.228$

Calculator:

1. hit [2nd]
2. hit [log] (10^x)
3. enter 2.5
4. hit "=" (should read 316.228)

Lab Problems:

Ex. 1:

Determine the distance (d) to Betelgeuse given:

Absolute magnitude (M) = 5.14

Apparent magnitude (m) = .45

Formula for "d" : $d = 10^{(m - M + 5)/5}$

Ex. 2:

Calculate the Absolute Magnitude (M) of the Sun

Formula: $$\mathbf{m - M = 5\ logd - 5}$$ change to: $$\mathbf{M = m - (5\ logd) + 5}$$	d = 1 AU (change to pc) 1 pc ~ 2.06 x 10^5 AU 1 AU = $\frac{1}{2.06\ x\ 10^5}$ = 4.854 x 10^{-6} pc **1 AU ~ .000005 pc**

Ex.3:

Determine the Apparent Magnitude of the red dwarf Proxima Centauri from a distance of 1AU.
In other words, how bright would it be if we replaced the Sun with Proxima Centauri?
Absolute Magnitude (M) Proxima Centauri: **+ 15.53**

Ex. 4:

Astronomers discover a Type IA supernova in a galaxy cluster with an Apparent Magnitude of + 15.819. Determine the distance to the Galaxy cluster. **Express your final answer in Light Years.**

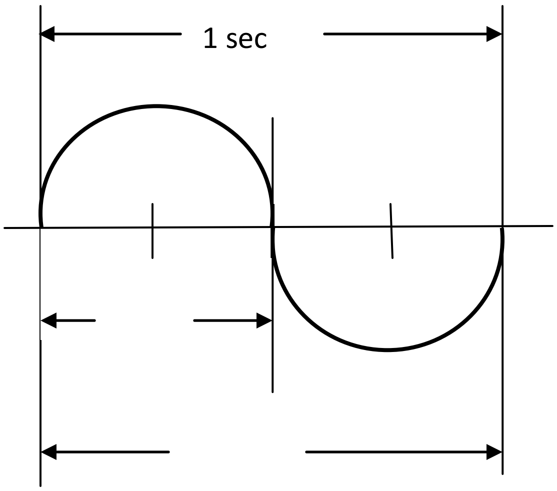
LAB: Doppler Effect, Relativistic Redshift, and Hubble Law

Key Terms and Concepts:

Given:

a. !00 Hz sound wave
b. 200 Hz sound wave

(Hz = Hertz = cycles per sec)



Basic Wave Formulas

velocity (v)) = frequency (f) x wavelength (λ)

$$v = f\lambda$$

$$\lambda = \frac{V}{f}$$

$$f = \frac{V}{\lambda}$$

IMPORTANT:
Frequency is
____________________ ___________________
to wavelength

Ex. 1:

Given:

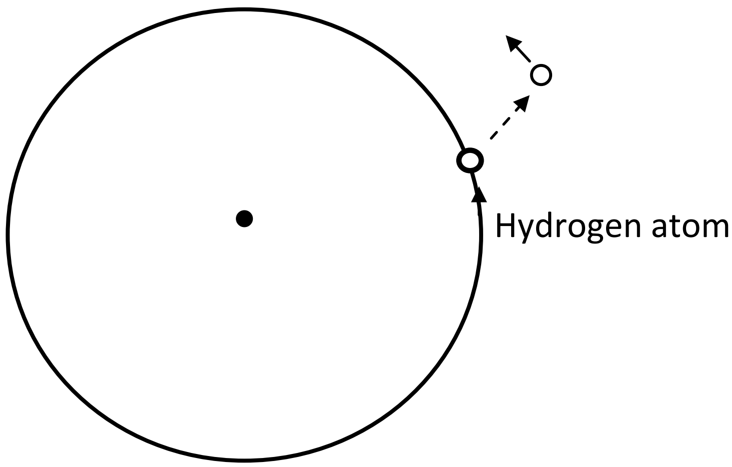
The speed of sound (Mach 1) at sea level is approx. 1100 ft/sec

Q: What is the wavelength of a 60 Hz (low b-flat) tone?

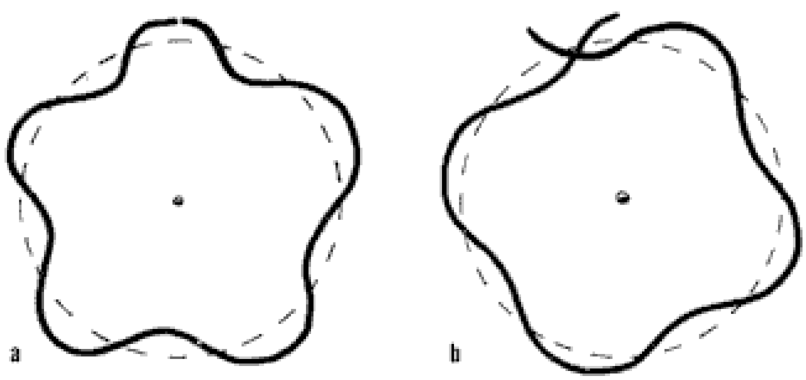
The Nature of Light Waves

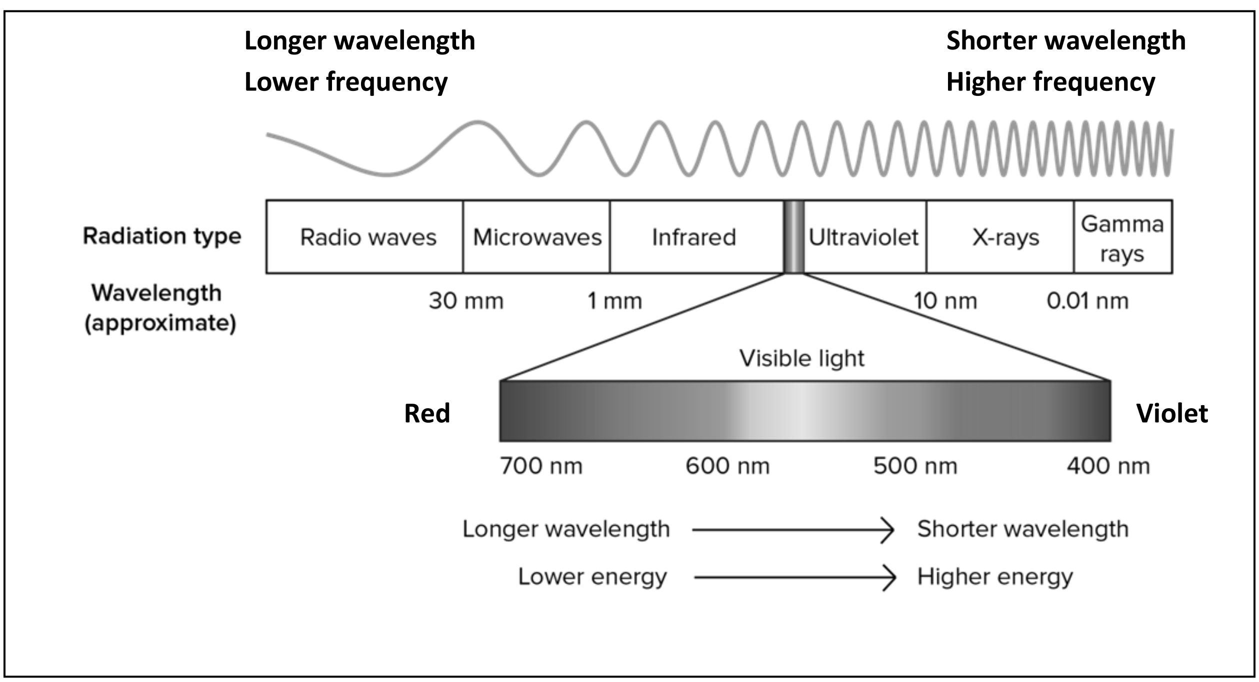
Structure of the atom and the nature of light

Recall:



De Broglie Wavelength





Ex. 1:

Given:

a. Radio waves travel at the speed of light (“c”)(3.0×10^8 m/sec)
b. WBLM-FM broadcasts with a carrier wave of 102.9 MHz

Determine the wavelength of WBLM’s carrier signal? Express as “nanometers” (nm)(10^{-9} m)

Ex. 2:

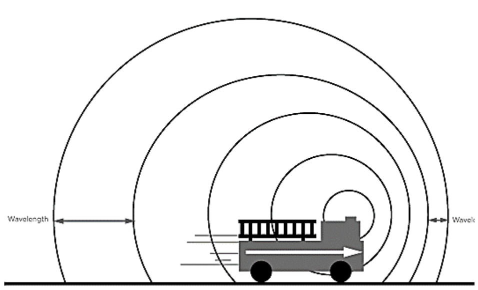
Hydrogen emits visible light at 410.2 nm (λ). What is the frequency?

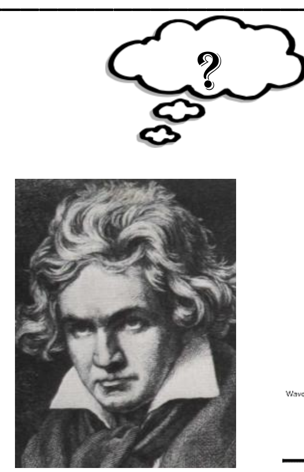
The Doppler Effect:

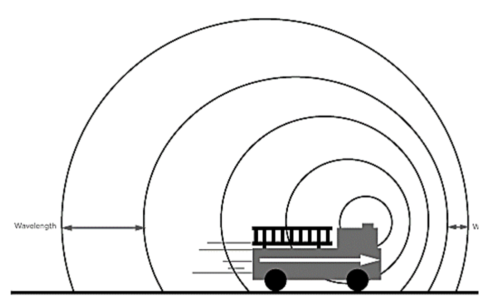
____

____

____







Wavelength compressed relative to observer

observer

Wavelength expanded relative to observer

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.

Edwin Hubble

Hubble law: $V = H_oD$

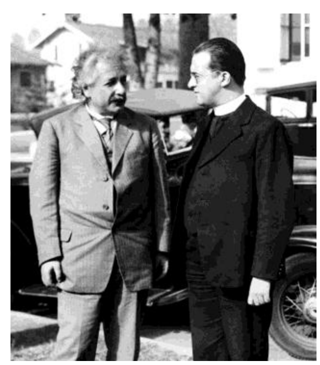
Where:

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



Einstein and LeMaitre

Using Hubble Law ***without*** taking into account relativistic effects

Example:

Scientists observe a galaxy 7 billion LY distant.

Using the Hubble law, determine its receding velocity and express answer as decimal of “c”

Relativistic Doppler Effect Formulas Used in Astronomy

Where
"V " is expressed as a fraction or decimal of "c" ((Ex.: "¾ c" or more commonly ".75c")
"c" is the speed of light
"λ_o" is the original wavelength
"λ" is the changed or shifted wavelength (as in "redshift" or "blueshift")
"$\Delta\lambda$" is the total amount of wavelength shift (λ - λ_o)
"Z" is the amount of redshift)

Formulas:

$$Z = \frac{\lambda - \lambda_o}{\lambda_o} = \frac{\Delta\lambda}{\lambda_o}$$

$$Z = \frac{V}{c} \quad , V = Zc$$

If Z < 0.1, then v is ________________ ______________________

Example:

Astronomers on Earth observing a distant galaxy measure a visible light wavelength of the element sodium at 401.8 nm ($\lambda = 401.8$ nm)
Normally sodium emits a line of visible light at 393.3 nm (λ_o = 363.3 nm)
Determine:

a. If the wavelength is redshifted or blueshifted
b. If the galaxy is approaching or receding from Earth
c. Velocity of the galaxy relative to Earth

More Formulas:

Z for relativistic velocities

$$Z = \frac{\lambda - \lambda_o}{\lambda_o} = \frac{\Delta\lambda}{\lambda_o}$$

$$Z = \sqrt{\frac{c+v}{c-V}} - 1$$

$$\frac{v}{c} = \frac{(z+1)^2 - 1}{(z+1)^2 + 1}$$

Redshift Z	Recessional Velocity v/c	Distance at which we see object Mpc	Distance at which we see object 10^9 LY	Present distance Mpc	Present distance 10^9 LY
0	0	0	0	0	0
.1	.095	384	1.23	403	1.32
.2	.18	721	20.35	790	2.58
.3	.257	1020	3.32	1160	3079
.4	.324	1280	4.17	1510	4.94
.5	.385	1510	4.93	1850	6.04
.75	.508	2070	6.48	2620	8.54
1.0	.6	2350	7.65	3290	10.7
1.5	.724	2840	9.26	4390	14.3
2.0	.8	3160	10.3	5250	17.1
3.0	.882	3520	11.5	6500	21.2
4.0	.923	3710	12.1	7370	24.0
5.0	.946	3830	12.5	8010	26.1
10	.984	4060	13.2	9790	31.9∞
∞	1.0	4210	13.7	14500	47.4

Ex. 1:

Astronomers on Earth observing a distant galaxy measure a visible light wavelength for the element hydrogen at 972.226 nm (λ).

Normally hydrogen emits this wavelength at 486.133 nm (λ_o)

Determine:

a. The recessional velocity from Earth
b. Its actual distance from Earth

Ex. 2:

Astronomers on Earth observing a distant galaxy measure a visible light wavelength of the element hydrogen at 690.36912 nm (λ).

Normally hydrogen emits this wavelength at 383.5384 nm (λ_o).

Determine the recessional velocity of the galaxy relative to Earth

Cosmic Microwave Background: Remnant of the Big Bang

By Elizabeth Howell August 24, 2018

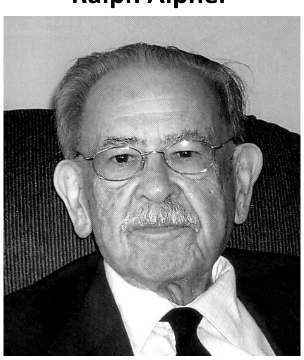
The cosmic microwave background (CMB) is thought to be leftover radiation from the Big Bang, or the time when the universe began. As the theory goes, when the universe was born it underwent a rapid inflation and expansion. The CMB represents the heat left over from the Big Bang.
You can't see the CMB with your naked eye, but it is everywhere in the universe. It is invisible to humans because it is so cold, just 2.725 degrees above absolute zero (minus 459.67 degrees Fahrenheit, or minus 273.15 degrees Celsius.) This means its radiation is most visible in the microwave part of the electromagnetic spectrum.

Origins and discovery

The universe began 13.8 billion years ago, and the CMB dates back to about 400,000 years after the Big Bang. That's because in the early stages of the universe, when it was just one-hundred-millionth the size it is today, its temperature was extreme: 273 million degrees *above* absolute zero, according to NASA.
Any atoms present at that time were quickly broken apart into small particles (protons and electrons). The radiation from the CMB in photons (particles representing quantums of light, or other radiation) was scattered off the electrons. "Thus, photons wandered through the early universe, just as optical light

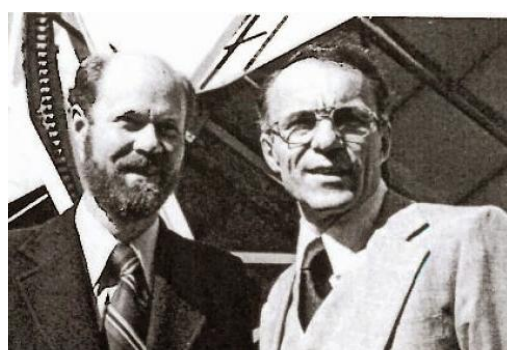
About 380,000 years after the Big Bang, the universe was cool enough that hydrogen could form. Because the CMB photons are barely affected by hitting hydrogen, the photons travel in straight lines. Cosmologists refer to a "surface of last scattering" when the CMB photons last hit matter; after that, the universe was too big. So when we map the CMB, we are looking back in time to 380,000 years after the Big Bang, just after the universe was opaque to radiation.

Ralph Alpher



George Gamow

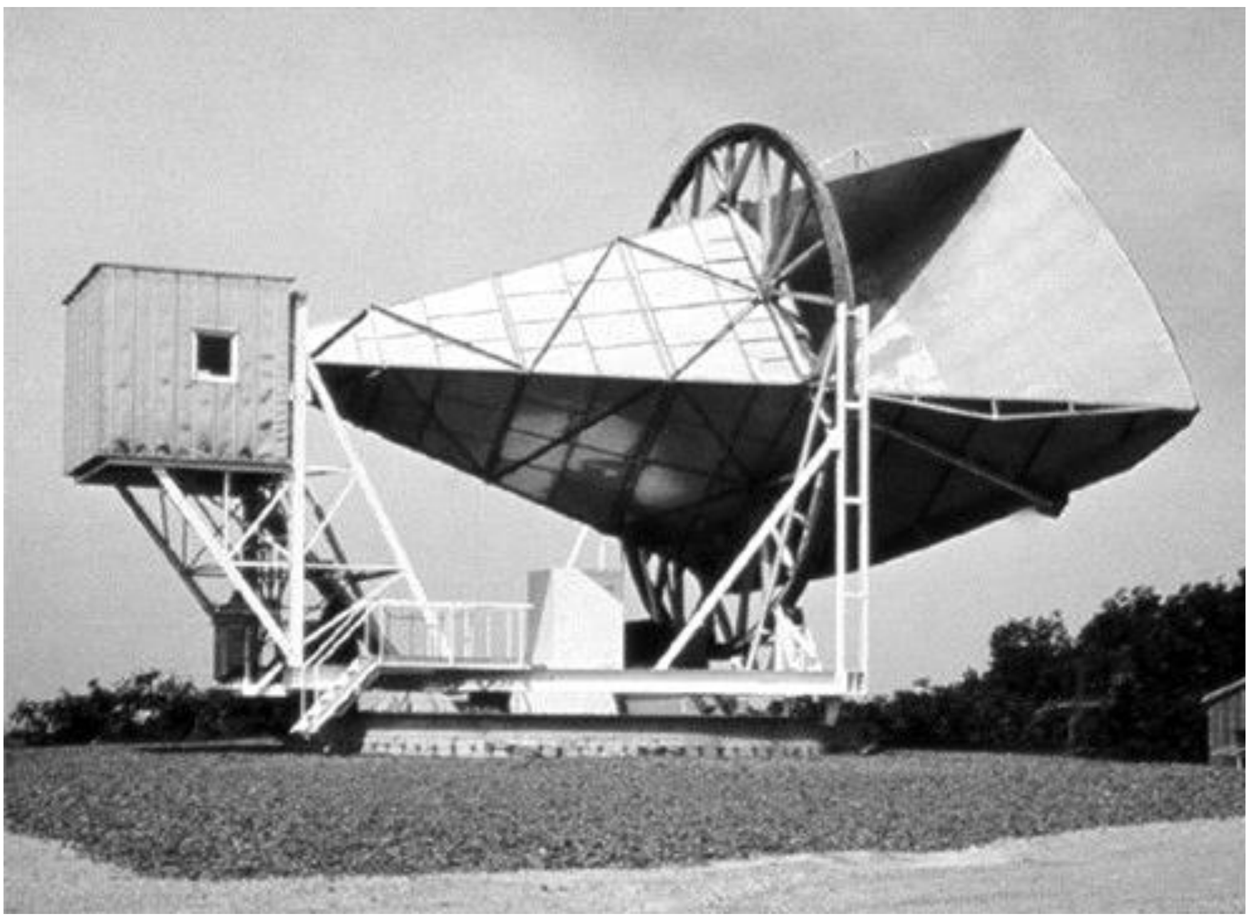
Robert Wilson and Arno Penzias



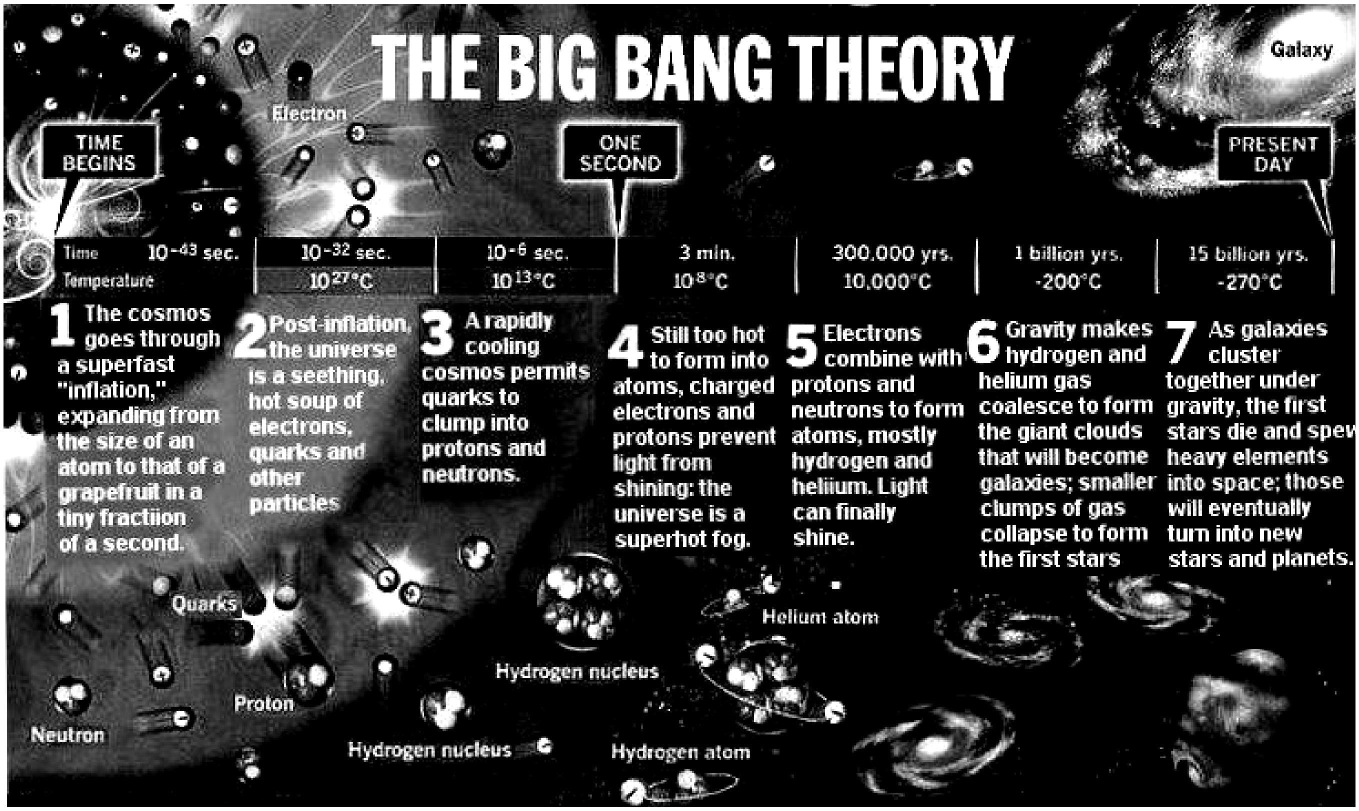
American cosmologist **Ralph Alpher** first predicted the CMB in 1948, when he was doing work with Robert Herman and **George Gamow**, according to NASA. The team was doing research related to Big Bang nucleosynthesis, or the production of elements in the universe besides the lightest isotope (type) of hydrogen. This type of hydrogen was created very early in the universe's history.

But the CMB was first found by accident. In 1965, two researchers with Bell Telephone Laboratories (**Arno Penzias** and **Robert Wilson**) were creating a radio receiver, and were puzzled by the noise it was picking up. They soon realized the noise came uniformly from all over the sky. At the same time, a team at Princeton University (led by **Robert Dicke**) was trying to find the CMB. Dicke's team got wind of the Bell experiment and realized the CMB had been found.

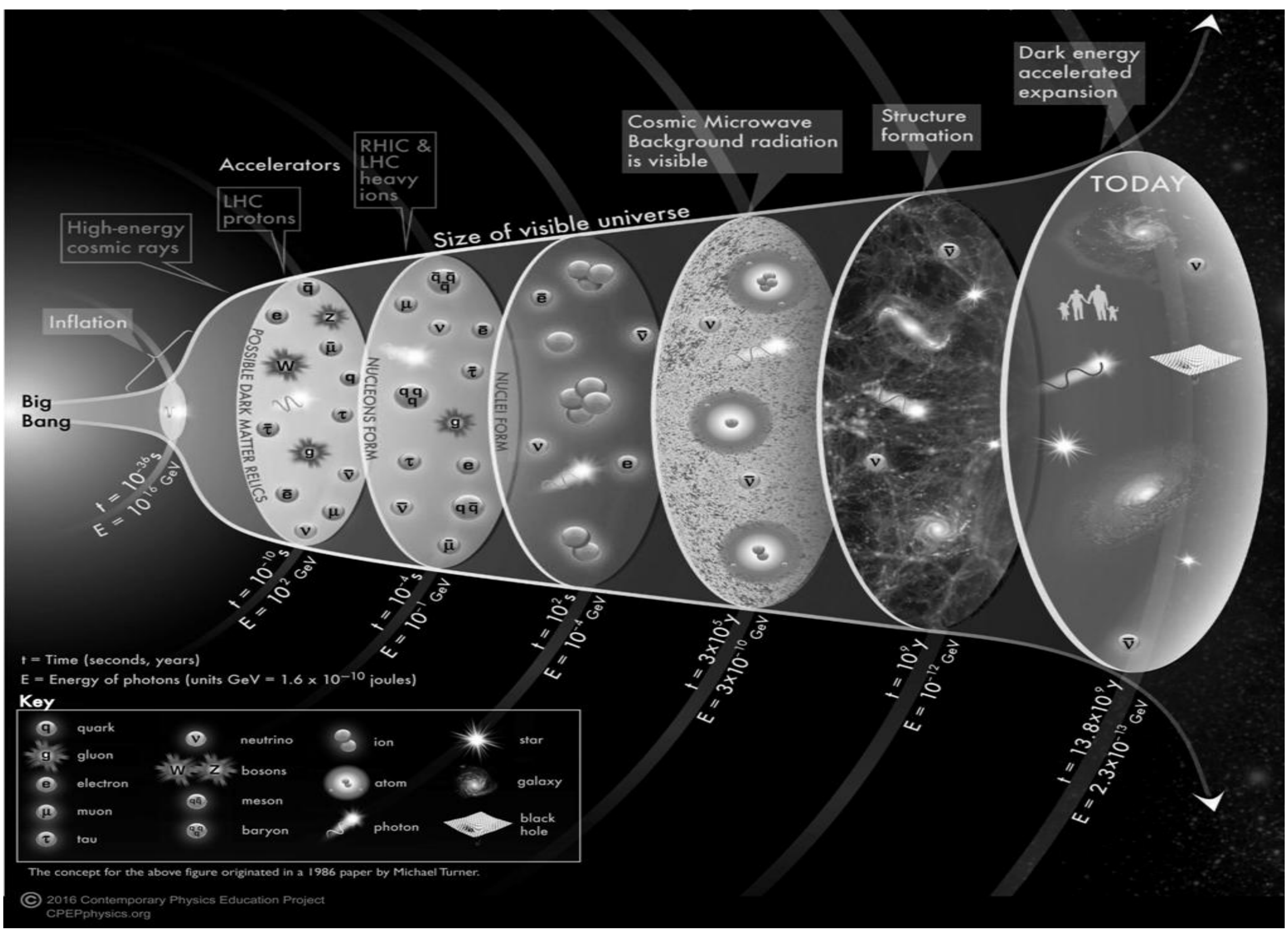
Both teams quickly published papers in the Astrophysical Journal in 1965, with Penzias and Wilson talking about what they saw, and Dicke's team explaining what it means in the context of the universe. (Later, Penzias and Wilson both received the 1978 Nobel Prize in physics).



The Bell Labs Antenna



Another representation:



Planck Era	0 - 10^{-43} sec	"Undiscovered Country:" Speculation: • Temp higher than 10^{32} K • 4 forces unified, "Superforce." • Random energy fluctuations, huge, beyond scope of current theory;
GUT Era	10^{-43} – 10^{-38} sec	Symmetry of four forces broken • 10^{32}K – 10^{27}K • Gravity "condenses" to separate force • No distinction between quarks and leptons • At 10^{29}K, Strong Force decouples • Decoupling of Strong Force releases enormous energy, causing "Inflation" (nucleus size expands to size of Solar System)
Electroweak Era	10^{-38} – 10^{-10} sec	• Intense radiation, spontaneously creating matter/antimatter, quickly annihilates and returns to photons • Three distinct forces : Gravity, Strong, Electroweak (Electromagnetism and Weak Force) • At 10^{15}K (10^{-10} sec) Electroweak decouples to Electromagnetism and Weak Force
Hadron Era (Overlaps Electroweak and Particle Era)	10^{-35} – 10^{-4} sec	• 10^{27}K -10^{13}K • Confinement of quarks • "Normal" particles formed, along with antiparticles • "Soup" of roughly equal parts particles, antiparticles, photons • At 10^{-6} sec (10^{13}K) particle/antiparticle annihilation (original ratio estimated 1,000,000,001:1,000,000,000) • Final ratio: 1 nucleon per 10^{9} photons
Particle Era	10^{-10} – 10^{-3} sec (.001 sec)	• At beginning of this era, photons are still converting into particle/antiparticles and back • End of era marked by cessation of this process
Lepton Era (Overlaps Particle Era and Era of Nucleosynthesis)	10^{-4} – 10 sec	• Lighter particles (electrons, positrons, neutrinos, photons) predominant

Era of Nucleosynthesis	.001 sec – 5 min	• At 10^9K and above, leftover "normal" particles begin to form, (protons + neutrons) then separate due to high temp (Fusion – fission and back) • Below 10^9K, fusion ceases
Radiation Era (Overlaps Era of Nucleosynthesis and Era of Nuclei)	10 sec – 1 million years	• Universe dominated by radiation • Major constituents photons and neutrinos
Era of Nuclei	5 min – 380,000 years	• Universe is hot plasma of hydrogen and helium nuclei, electrons • Nuclei fully ionized • Photons confined, similar to conditions inside Sun • Electrons free, capture and release photons • Universe is therefore "opaque" • At 3000K, electrons combine with nuclei, form stable H and He atoms, Universe becomes transparent
Era of Atoms	380, 000 – 1 billion years	• Universe consists of stable, neutral atoms, plasma (Fully ionized nuclei and electrons) and photons • Slight density variations exist • Dark matter exerts gravitational force • Protogalactic clouds form • Stars begin to form • First galaxies at end of this era, beginning Era of Galaxies ("Matter Dominated")

Epilogue: