ASTR 100
Intro to Astronomy
and Cosmology
Lab Manual

(2nd Edition Revised Aug 2024)

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Topic 1

Dark Matter – Dark Energy

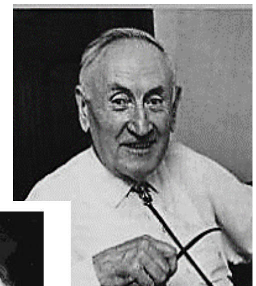
Percentages in Universe:

Dark Matter: ____________

Dark Energy: ____________

Normal Matter: __________

1



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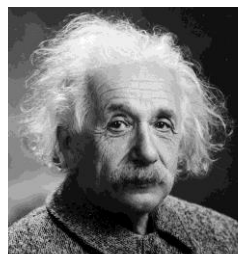

3

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, ____

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____

Lensing observed ____

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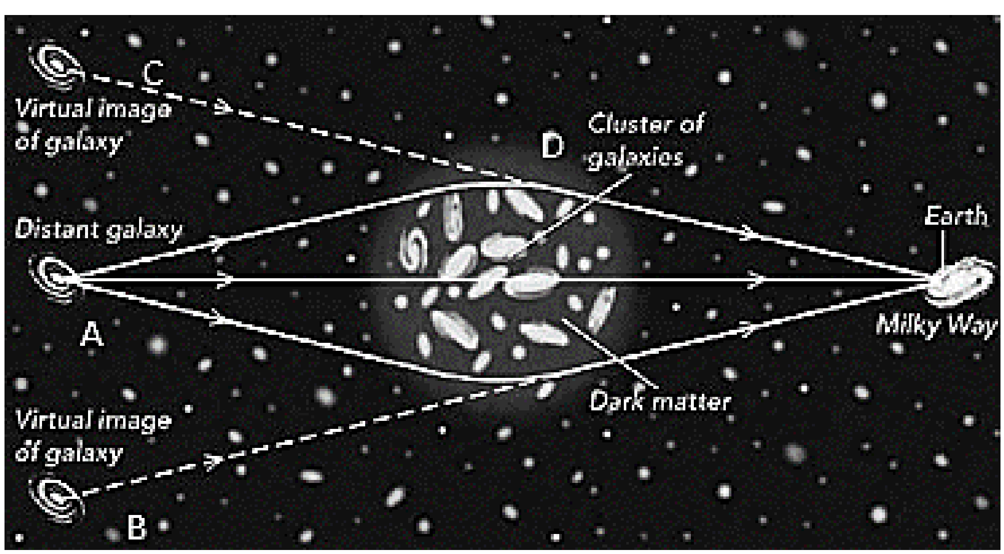


Additional evidence:

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 ____

____

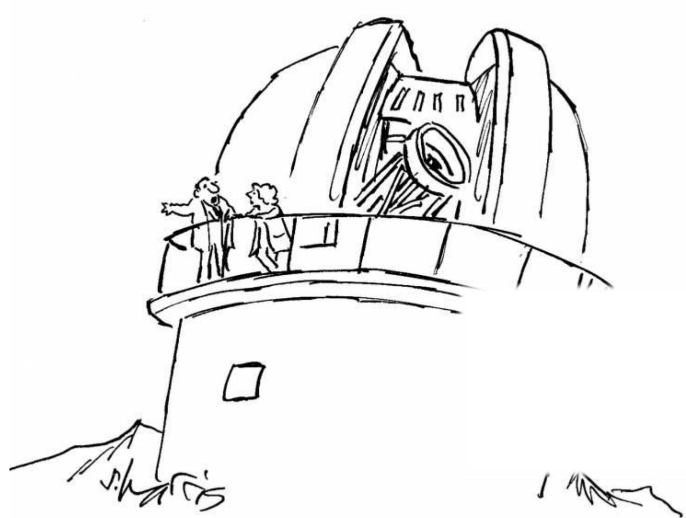
____

____

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:

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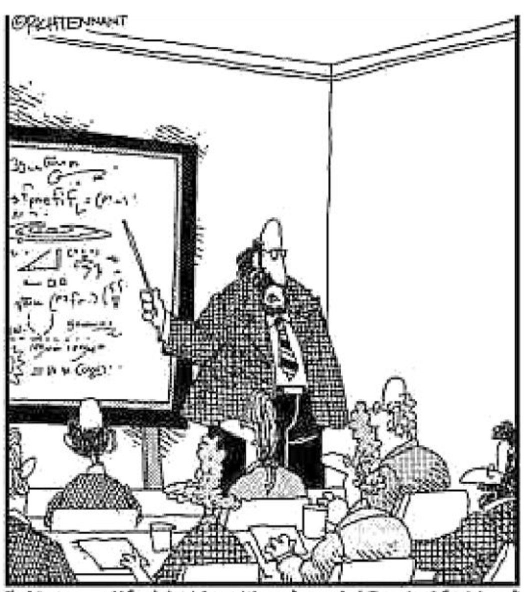


"Along with 'Antimatter,' and 'Dark Matter,' we've recently discovered the existence of 'Doesn't Matter,' which appears to have no effect on the universe whatsoever."

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.

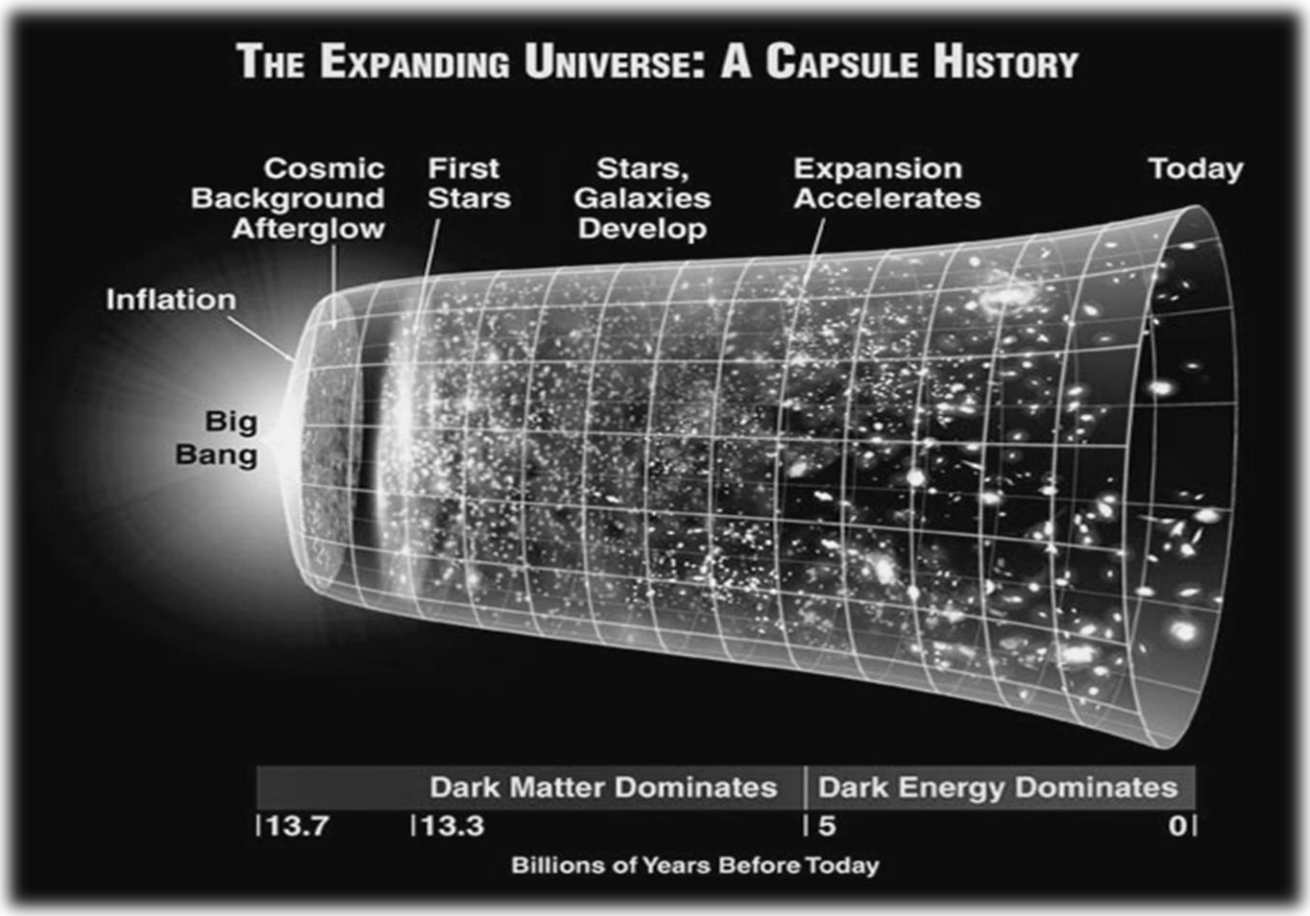
What does dark energy do?

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.



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NEWS RELEASE

HEIC0701: FOR IMMEDIATE RELEASE 19:30 (CET)/01:30 PM EST 7 January, 2007
http://www.spacetelescope.org/news/html/heic0701.html

News release:

First 3D map of the Universe's Dark Matter scaffolding

7-January-2007 **By analysing the COSMOS survey – the largest ever survey undertaken with Hubble – an international team of scientists has assembled one of the most important results in cosmology: a three-dimensional map that offers a first look at the web-like large-scale distribution of dark matter in the Universe. This historic achievement accurately confirms standard theories of structure formation.**

For astronomers, the challenge of mapping the Universe has been similar to mapping a city from night-time aerial snapshots showing only streetlights. These pick out a few interesting neighbourhoods, but most of the structure of the city remains obscured. Similarly, we see planets, stars and galaxies in the night sky; but these are constructed from ordinary matter, which accounts in total for only one sixth of the total mass in the Universe. The remainder is a mysterious component - dark matter - that neither emits nor reflects light.

An international team of astronomers led by Richard Massey of the California Institute of Technology (Caltech), USA, has made **a three-dimensional map that offers a first look at the web-like large-scale distribution of dark matter in the Universe in unprecedented detail. This new map is equivalent to seeing a city, its suburbs and surrounding country roads in daylight for the first time. Major arteries and intersections are revealed and the variety of different neighbourhoods becomes evident.**

The map was derived from largest survey of the Universe made by the Hubble Space Telescope, the Cosmic Evolution Survey (COSMOS), carried out by an international team of 70 astronomers led by Nick Scoville, also of Caltech. The COSMOS survey covers a sufficiently wide area of sky – nine times the area of the full Moon (1.6 square degrees) – for the large-scale filamentary structure of dark matter to be clearly evident. To add 3D distance information, the Hubble observations were combined with spectra from ESO's VLT (Very Large Telescope) and multicolour images from the Japanese Subaru and Canada-FranceHawaii telescopes.

The map provides the best evidence yet that normal matter, largely in the form of galaxies, accumulates along the densest concentrations of dark matter. The map reveals a loose network of filaments, intersecting in massive structures where clusters of galaxies are located.

The map, which stretches halfway back in time to the beginning of the Universe, also reveals how **dark matter has recently grown increasingly clumpy as it continues to collapse under gravity.**

This milestone takes astronomers from inference to direct observation of dark matter's influence in the Universe. Mapping dark matter's distribution in space and time is fundamental to understanding how galaxies grew and clustered over billions of years. Tracing the growth of clustering in the dark matter may also eventually shed light on dark energy, a force which repels matter rather than attracts it as gravity does, which may have influenced how dark matter clumps.

The map is consistent with conventional theories of how structure formed in the evolving Universe under the relentless pull of gravity, making the transition from a smooth distribution of matter into a sponge-like structure of long filaments.

The results of this research have appeared online today in the journal Nature and will be presented at the 209th meeting of the American Astronomical Society in Seattle, Washington, by Richard Massey for the dark matter and Nick Scoville for the galaxies.

"*It's reassuring how well our map confirms the standard theories for structure formation.*" Massey said. **He calls dark matter the scaffolding surrounding the assembly sites of stars and galaxies over billions of years.**

The dark matter map was constructed by measuring the shapes of half a million faraway galaxies. To reach us, their light has had to travel through the intervening dark matter, and the path of the light was slightly deflected. The observed, subtle distortion in the galaxies' shapes was used to reconstruct the distribution of intervening mass along Hubble's line of sight. The method is called weak gravitational lensing. This effect is analogous to deducing the rippling pattern in a glass shower door by measuring how light from behind it is distorted as it passes through the glass.

"*To achieve this result, we extended gravitational lensing techniques - previously used to map the dark matter distribution in clusters of galaxies - and applied these in the COSMOS field to reveal a 3D dark matter*" said co-investigator Jean-Paul Kneib of Observatoire MidiPyrénées.

“*Although this technique has been employed previously, the depth of the COSMOS image and its superior resolution enables a more precise and detailed map, covering a large enough area to see the extended filamentary structures,*” said co-investigator Richard Ellis of Caltech.

A separate COSMOS team led by Nick Scoville of Caltech presented images of the large scale galactic structures in the same area as the dark matter. Galaxies appear in visible light seen with Hubble and in ground-based Subaru telescope images obtained by Yoshiaku Taniguchi and colleagues. **The hot gas in the densest galaxy clusters was imaged in X-rays** by Günther Hasinger and colleagues using the European Space Agency’s XMM-Newton telescope.

“*This is the first serendipitous detection of galaxy clusters through lensing and X-ray observations*”, says Günther Hasinger, leader of the XMM-Newton observations. He continues: “*Only through the availability of the excellent multi-wavelength dataset, in particular the XMM-Newton Survey, was it possible* ***to confirm the excellent correspondence between the clusters discovered first in X-rays and then independently in the lensing mass maps.*****”**

Galaxy structures inside the dark matter “scaffolding” show clusters of galaxies in the process of assembly. These structures can be traced across more than 80 million light-years in the COSMOS survey – approximately five times the extent of the nearby Virgo galaxy cluster. In the densest early Universe structures, many galaxies already have old stellar populations, implying that these galaxies formed first and accumulated the greatest masses in a “bottomup” assembly process whereby smaller galaxies merge to make bigger galaxies – like tributaries converging to form a large river.

The COSMOS survey shows that galaxies with on-going star formation, even to the present epoch, dwell in less populated voids and dark matter filaments. “It is remarkable how the environment on the enormous cosmic scales seen in the dark matter structures can influence the properties of individual stars and galaxies - both the maturity of the stellar populations and the progressive “down-sizing” of star formation regions to smaller galaxies is clearly dependent on the dark matter environment.” said Scoville.

“*The comparison is of fundamental importance,*” said Massey. “*Almost all current scientific knowledge concerns only baryonic matter. Now that we have begun to map out where dark matter is, the next challenge is to determine what it is, and specifically its relationship to normal matter.*”

The COSMOS survey (Hubble Space Telescope Cosmic Evolution Survey) has proven an invaluable dry run for future dedicated weak lensing missions in space. In fact the new 3D dark matter map resembles the first maps of the large-scale distribution of galaxies created from the measured light of galaxies 15 years ago. These maps have subsequently become incredibly detailed, and could be an indicator of future improvements in mapping dark matter.

In making the COSMOS survey, Hubble photographed 575 slightly overlapping views of the Universe using the Advanced Camera for Surveys (ACS) onboard Hubble. It took nearly 1,000 hours of observations and is the largest project ever conducted with Hubble. Multicolour information of the galaxies in the COSMOS field have been obtained with the Subaru and CFHT telescopes in Hawaii. Thousands of galaxy spectra were obtained with the European Southern Observatory's VIMOS instrument on the Very Large Telescope and the Magellan telescope in Chile. The distribution of the main part of the normal matter was determined with the European Space Agency´s XMM-Newton telescope, that observed the COSMOS region for 400 hours.

****

Almost all the currently favored models of how large-scale structure formed in the universe tell a story similar to that for individual galaxies: tiny dark matter "seeds" in the hot cosmic soup after the Big Bang grew by gravity into larger and larger structures as cosmic time ticked on (Figure 3). The final models we construct will need to be able to explain the size, shape, age, number, and spatial distribution of galaxies, clusters, and filaments—not only today, but also far back in time. Therefore, astronomers are working hard to measure and then to model those features of large-scale structure as accurately as possible. So far, a mixture of 5% normal atoms, 27% cold dark matter, and 68% dark energy seems to be the best way to explain all the evidence currently available.

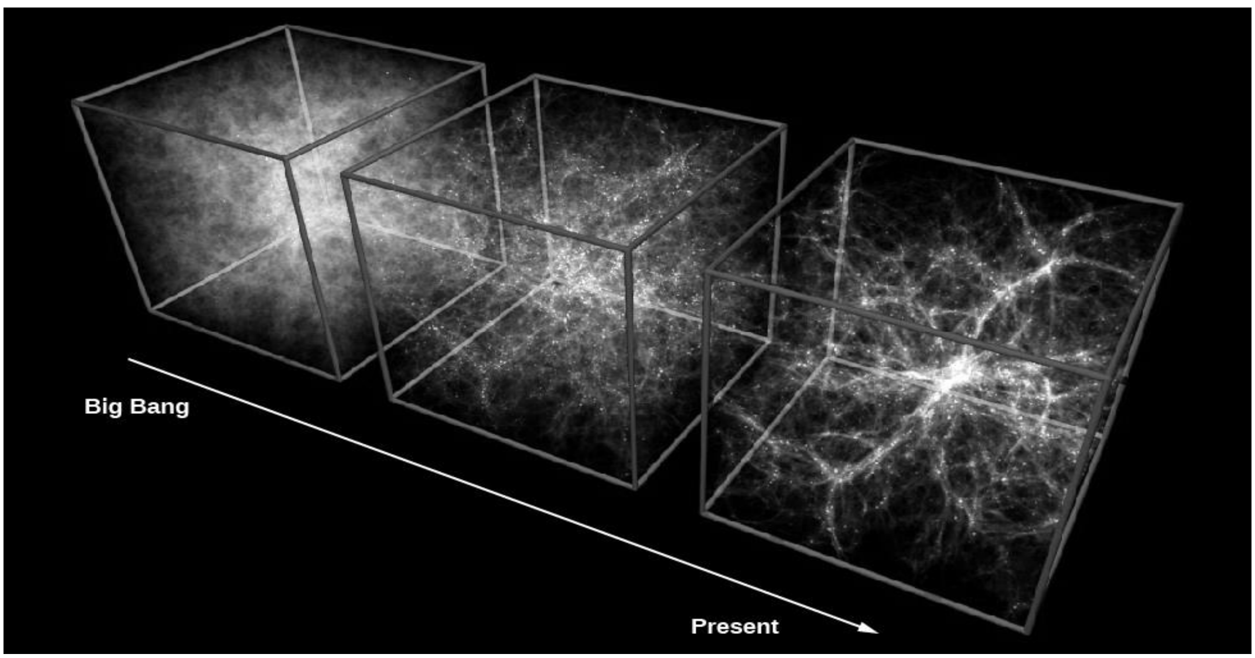


Figure 3: Growth of Large-Scale Structure as Calculated by Supercomputers. The boxes show how filaments and superclusters of galaxies grow over time, from a relatively smooth distribution of dark matter and gas, with few galaxies formed in the first 2 billion years after the Big Bang, to the very clumpy strings of galaxies with large voids today.

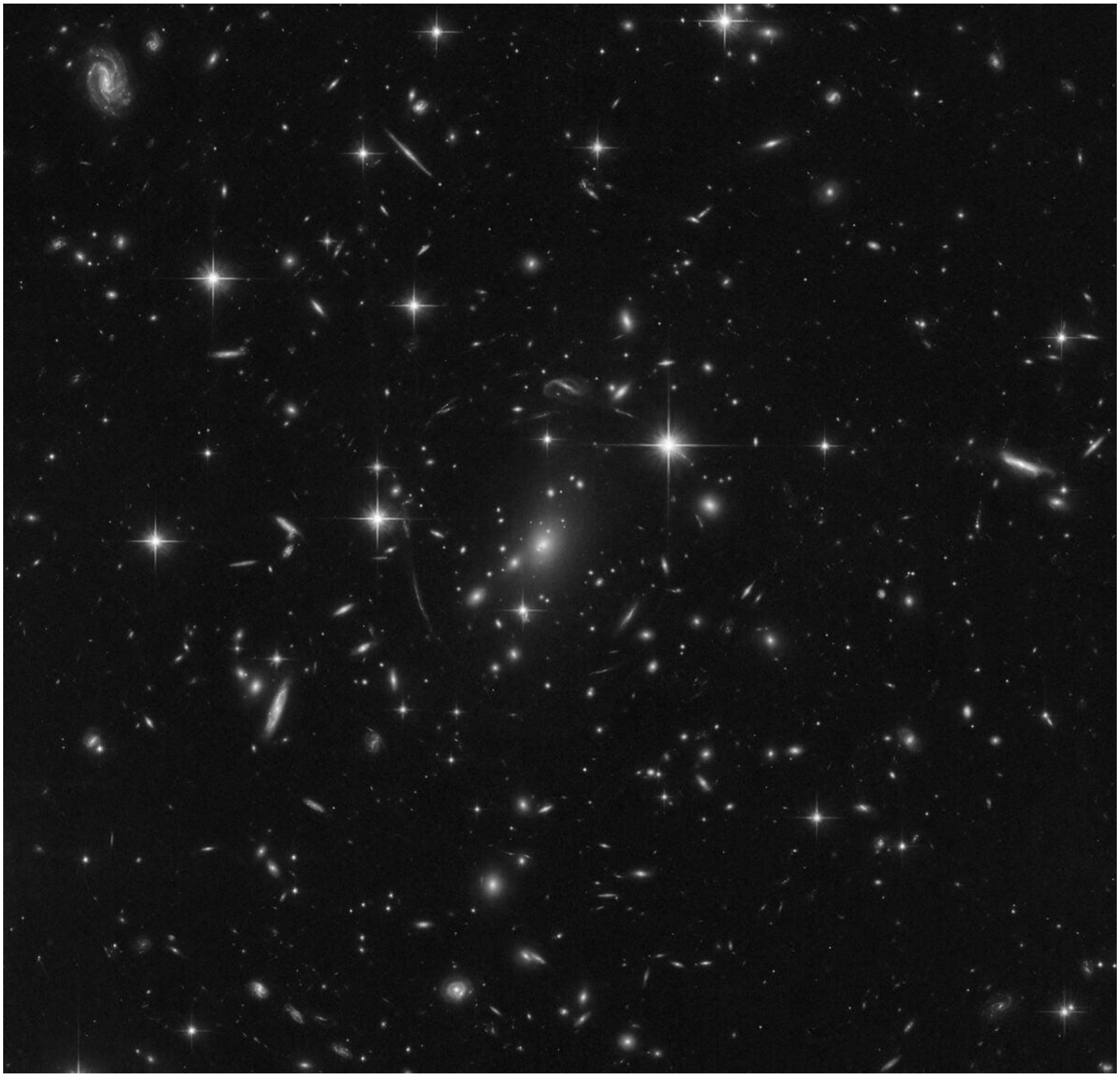
The box at left is labeled "Big Bang," the box at center is unlabeled and the box at right is labeled "Present". A white arrow points from left to right representing the direction of time.

ASTRONOMY MAGAZINE

What we do — and don't — know about dark energy

Here's how scientists are trying to understand the mysterious force that controls the ultimate fate of the universe.

By Lindsay R. House | Published: July 23, 2024



Massive galaxy clusters, such as in this Hubble Space Telescope image, can help astronomers test theories about dark matter and dark energy. Credit: ESA/Hubble & NASA, RELICS

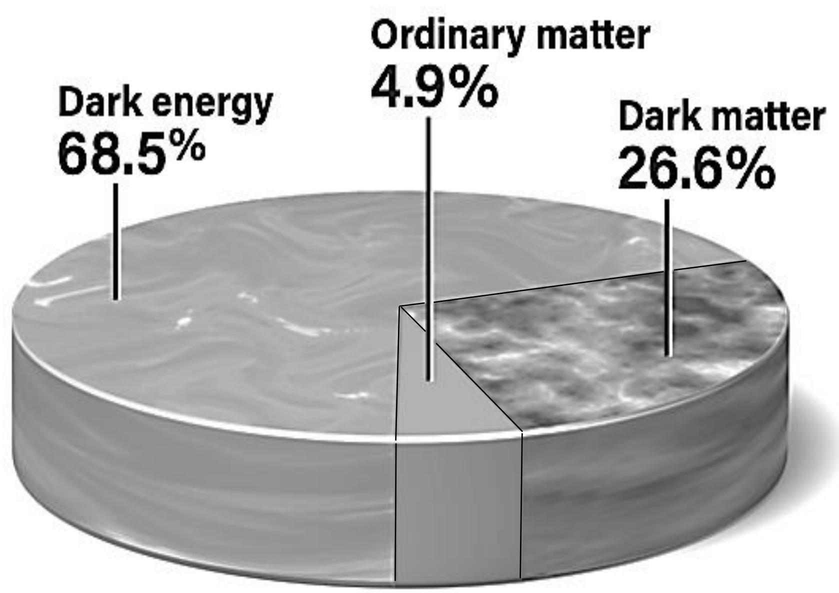
Our universe is shrouded in mystery, with about 70 percent of it consisting of dark energy. The exact nature of dark energy remains a puzzle that, once solved, could unlock profound insights into the formation of our solar system, the evolution of the Milky Way Galaxy, the origins of life, and even the fate of our universe.

Dark energy can be described as the effect of a negative pressure pushing space outward. We will get more technical, I promise, but let's start with an analogy to understand this fundamental concept. Imagine you have a balloon representing the entire universe, and you place stickers all over its surface to represent galaxies or clusters of galaxies. Imagine the first pump of air into the balloon — this equates to the Big Bang and initiates the beginning of time as we know it. As the balloon expands and time passes, the distance between any two stickers (or galaxies) increases. This is similar to how galaxies are moving farther apart from each other, showing evidence for an expanding universe.

Not only is the universe expanding, but it is *expanding at an accelerated rate,* meaning it is getting bigger faster and faster over time. In our balloon analogy, imagine blowing air into the balloon rapidly, making it expand faster and faster. This additional pressure represents dark energy pushing the balloon (or our universe) to grow at an accelerated rate.

Dark energy and dark matter

Before diving deeper into the depths of dark energy, you might be asking what the difference between dark energy and dark matter is, or how they might be similar. Dark energy and dark matter, the enigmatic duo, make up about 96 percent of the universe (roughly 70 percent dark energy and 26 percent dark matter). Meanwhile, baryonic, or normal, matter, such as stars, plants, cats, you, and me, only accounts for about 4 percent of the universe's contents.



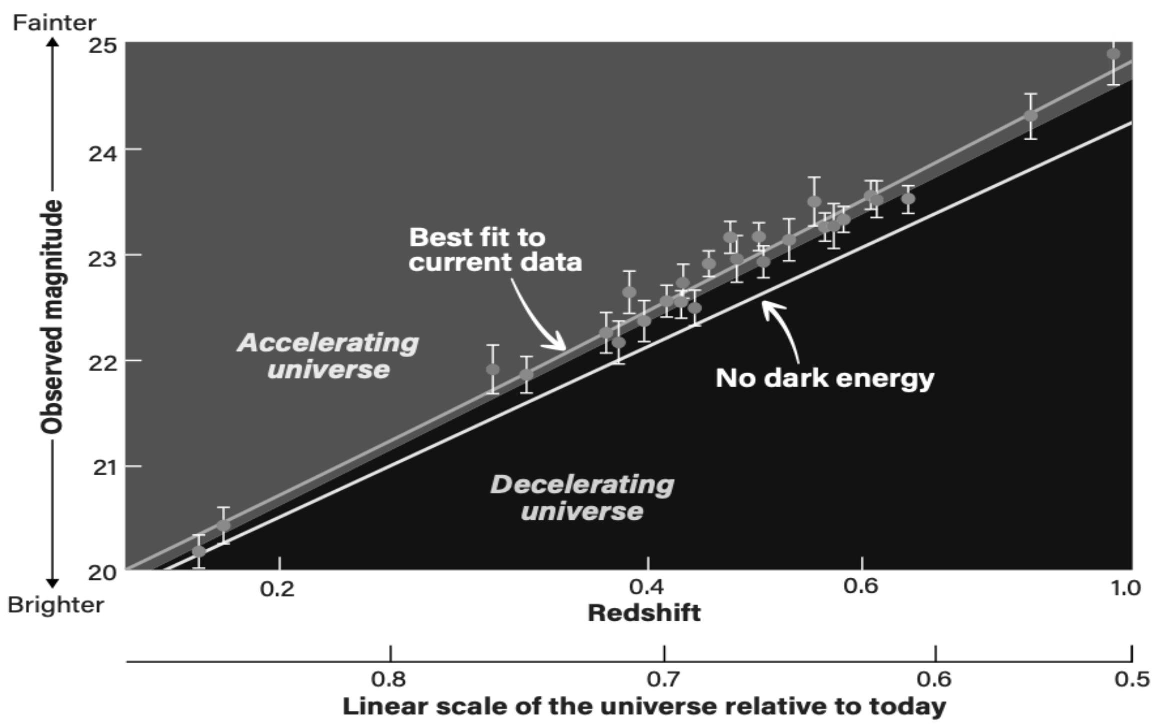
Ordinary matter such as that in people, planets, stars, and galaxies, comprises only some 5 percent of the universe. Dark matter accounts for roughly a quarter, while dark energy is the largest component of the cosmos. Credit: Astronomy: Roen Kelly, after NIST

While the terms are often confused, the effects of dark energy and dark matter are very different. Dark energy is a theoretical form of energy that counteracts gravitational attraction and drives or "pushes" the universe's accelerated expansion. On the other hand, dark matter exerts a gravitational influence that can be detected through its effects, which "pull" together stars and galaxies, affecting their motions.

While their effects differ, they both earn their mysterious first name, "dark," because we cannot directly observe them. Neither emits, absorbs, nor reflects light. Yet, we *can* observe how dark energy and dark matter interact with normal matter. This allows astronomers to achieve the seemingly impossible and study something we can't see.

Detecting the unseen

Dark energy's acceleration effects were first discovered by observing distant supernovae in the late 1990s. This was done with Type Ia supernovae, which act as "standard candles," meaning they have a predictable luminosity. So, the fainter one of these supernovae appears, the farther away it is. This makes them valuable for measuring distances across vast cosmic epochs. By observing their brightness and redshift (a proxy for distance, which is affected by the expansion of the universe), scientists can trace the history of cosmic expansion and infer the influence of dark energy.

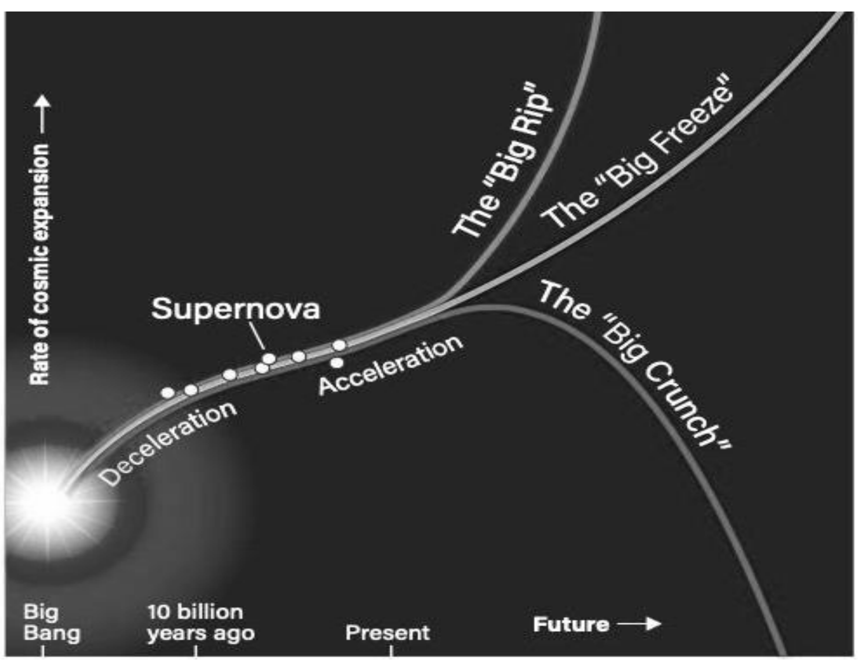


In 1998, astronomers revealed that observations of distant type Ia supernovae showed the universe is now expanding faster than in the past. Over the years, this discovery has held up, indicating that dark energy is a significant contributing factor in our cosmos. This graph shows the brightness of distant supernovae plotted against their redshift, a proxy for distance. The blue line shows the best fit to the current observations, which match predictions for an accelerating universe. The white line indicates how bright such supernovae would appear in a universe with no dark energy. It predicts that distant explosions should appear brighter than they actually do. Credit: *Astronomy*: Roen Kelly, after Carroll, Bradley W. and Ostlie, Dale A., An Introduction to Modern Astrophysics, 2nd Ed., Pearson Education, Inc., 2007.

It can also be studied by examining baryon acoustic oscillations (BAOs). BAOs are regular fluctuations in the density of visible matter caused by pressure waves in the early universe. Essentially, they cause galaxies to cluster more strongly at specific scales, which then change during different epochs as the universe expands. So, BAOs also provide a “standard ruler” for measuring distances over cosmic scales. Large surveys do this by creating maps of the universe, allowing astronomers to study the scale of BAOs to trace the expansion history of the universe and constrain dark energy parameters.

Another innovative approach to understanding dark energy involves analyzing the bending of light (gravitational lensing) from distant galaxies and clusters. By analyzing the distortions in the shapes and positions of galaxies caused by gravitational lensing, scientists can probe the distribution of dark matter and further infer the properties of dark energy by observing how its influence affects structures throughout the universe.

Our future is in dark energy’s hands



There are a few ways the universe might end, but exactly how depends on how the rate of cosmic expansion changes in the future. If gravity overpowers expansion, the cosmos will collapse in a Big Crunch. If the universe continues to expand indefinitely, as expected, we'll face a Big Freeze. But if dark energy pushes the expansion rate to near infinity, we'll have a Big Rip that tears everything, even atoms, apart. Credit: *Astronomy*: Roen Kelly.

Ongoing and future surveys like the Dark Energy Survey (DES), the Legacy Survey of Space and Time (LSST), the Euclid mission, the Baryon Oscillation Spectroscopic Survey (BOSS), and the Hobby-Eberly Telescope Dark Energy Experiment (HETDEX) aim to expand our understanding of dark energy by observing larger volumes of the universe and refining cosmological measurements.

These multi-million-dollar, decade-long experiments might expose the answer to how dark energy has shaped our universe or how it may yet destroy the universe (or potentially reveal another!).

There are three theories about how dark energy could impact the fate of the universe. The first theory is heat death or the so-called Big Freeze. In this scenario, dark energy keeps pushing galaxies farther apart, causing the universe to become emptier and darker. Eventually, everything — including us if we're still around — will reach a uniform temperature. To imagine a case like the Big Freeze, picture placing our balloon in the freezer. Eventually, with enough time, the balloon will reach the same temperature as the freezer, relinquishing all the properties we previously associated with how a balloon functions at room temperature. The same applies to our universe.

The second is a fascinating conjecture known as the Big Rip scenario. According to this hypothesis, the pervasive influence of dark energy will propel the universe's expansion at an increasingly rapid pace. Ultimately, cosmologists theorize that this relentless acceleration will reach a point where it exerts a force so potent that it rends apart celestial entities. Equivalently, this is an example I'm sure all of us have experienced when blowing up a balloon. When you push too much air into the balloon too quickly, the balloon pops and is strewn around the room, leaving behind balloon fragments and stickers — or, in the cosmic case, galaxies and planets — that were blown apart.

The third scenario is called the Big Crunch, which is the opposite of expansion. It suggests that the effects of dark energy could change from causing the universe to expand to causing it to collapse. This would lead to everything collapsing in on itself and possibly resetting us back to the way things looked at the beginning of time. This would be like letting all the air out of our balloon and watching the chaotic universe fly around the room until it peacefully rests on the ground, waiting to be blown up again.

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

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

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

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)

$(3.93 \times 10^7) \times (5.37 \times 10^6)$ $3.93 \mid \times 10^7$ $5.37 \mid \times 10^6$ 21.104×10^{13} $= 2.1104 \times 10^{14}$	2.1104×10^{14}
$(3.92 \times 10^3) \times (3.48 \times 10^{-5})$ $3.92 \mid \times 10^3$ $3.48 \mid \times 10^{-5}$ 13.642×10^{-2} $= 1.364 \times 10^{-1}$	1.364×10^{-1}
$(8.14 \times 10^7) \div (4.05 \times 10^9)$ $\frac{8.14 \mid \times 10^7}{4.05 \mid \times 10^9}$ $= 2.0098 \times 10^{-2}$	2.0098×10^{-2}
$(8.16 \times 10^{-5}) \div (4.89 \times 10^6)$ $\frac{8.16 \mid \times 10^{-5}}{4.89 \mid \times 10^6}$ $= 1.669 \times 10^{-11}$	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) = 4.858×10^3	4.858×10^3
(2.64×10^7) - (1.37×10^7) 2.64×10^7 -1.37×10^7 1.27×10^7	1.27×10^7
$(3.93 \times 10^7)^2$ = 15.445×10^{14} = 1.5445×10^{15}	1.5445×10^{15}
$(5.37 \times 10^6)^3$ = 154.854×10^{18} = 1.54854×10^{20}	1.5445×10^{15}
$\sqrt{8.26 \times 10^8}$ 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) = 3.699×10^5	3.699×10^5

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:

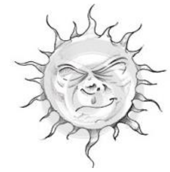
answer:

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**?

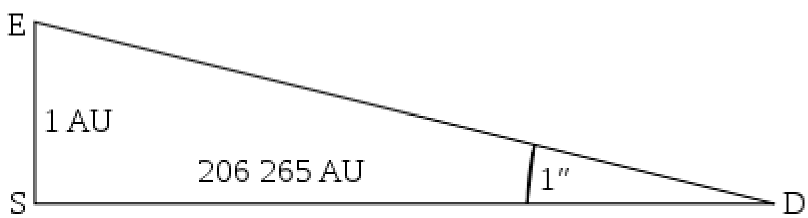
Solution:

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 <u>K</u>m = ? m

↓

Ex. 2

6.6 <u>M</u>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.

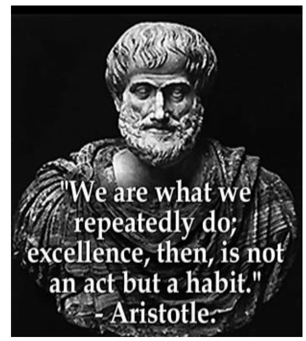
****

Aristotle 1.____

2.____

3. ____

4. ____



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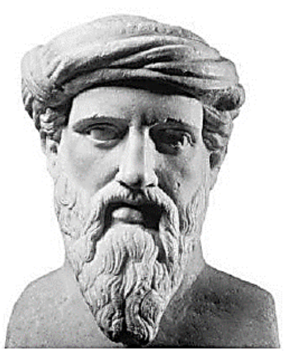
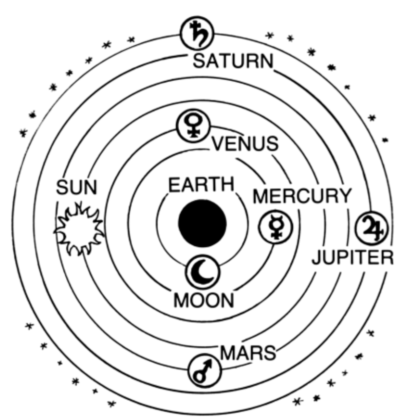
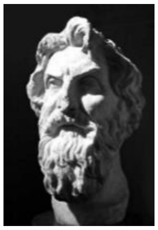


Pythagoras of Samos (569-475 BC) is regarded as the first pure mathematician to logically deduce geometric facts from basic principles. He is credited with proving many theorems such as the angles of a triangle summing to 180 deg, and the infamous "Pythagorean Theorem" for a right-angled triangle (which 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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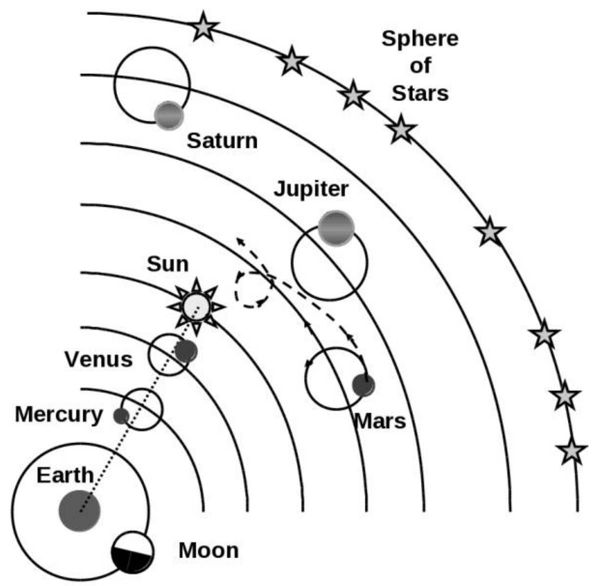
____

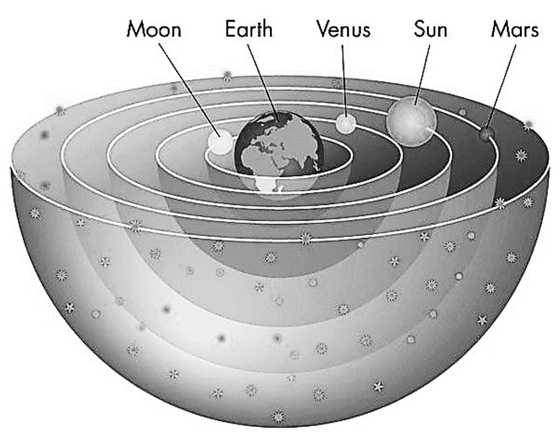
____

____



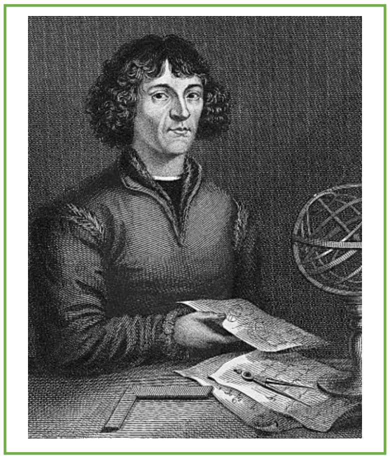
Epicycles

Deferents



Crystal Spheres

Copernicus

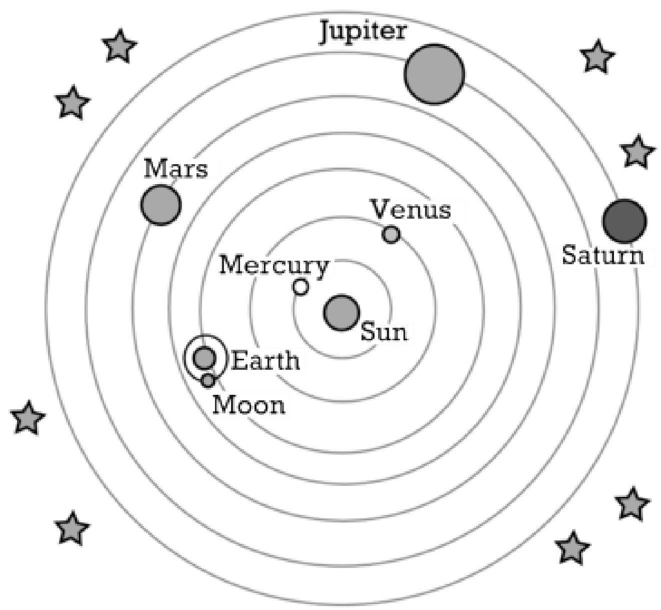


1. ____

2.____

3. ____

4. ____



Sun at the Center

Galileo

1. First to use the ____

2. Discovered the _________________ of _____________________________

3. Discovered the _________________ of _____________________________

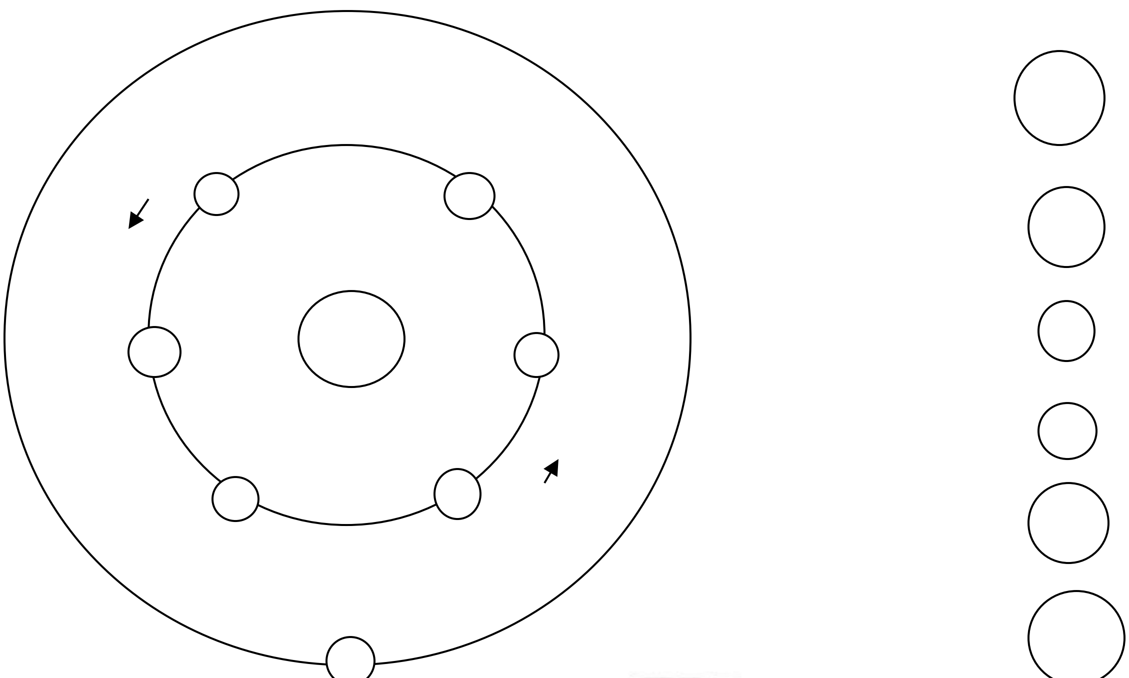
4. Discovered ____

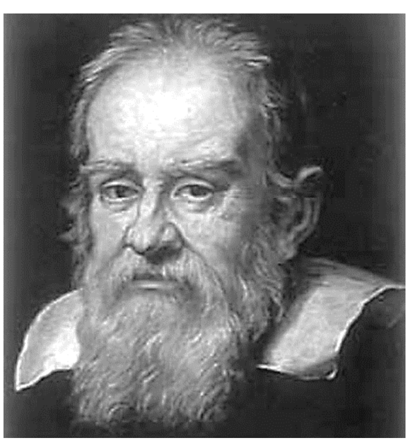
____

4. Prime author of the _____________________   ____________________

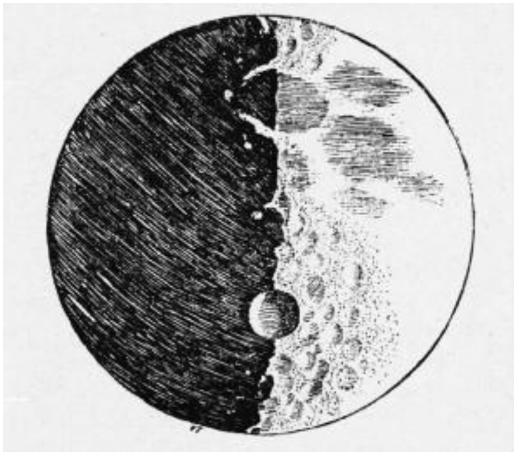
5. Was tried for ____

____

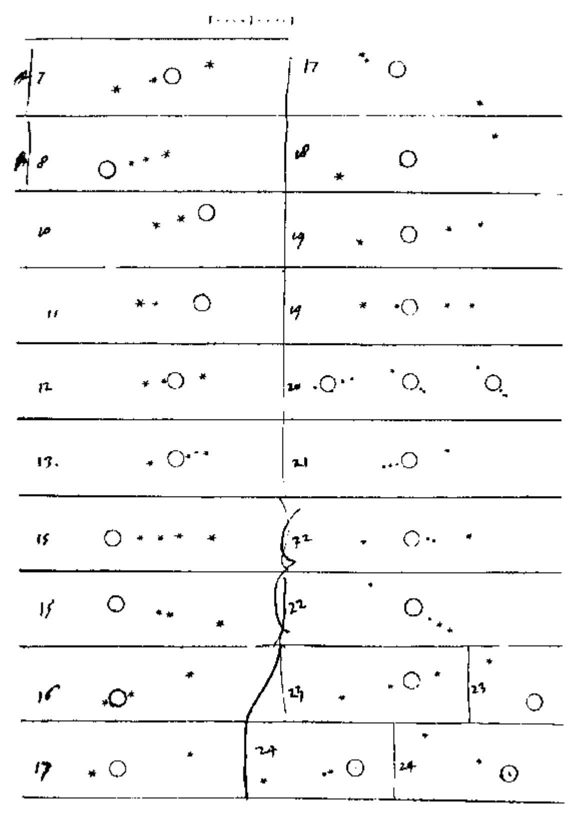




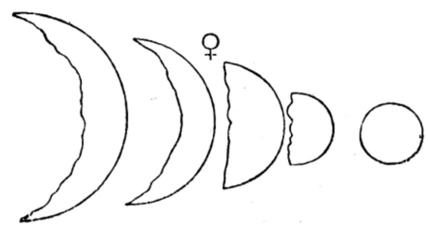
Galileo's Sketches:



Galileo's first sketch of the Moon

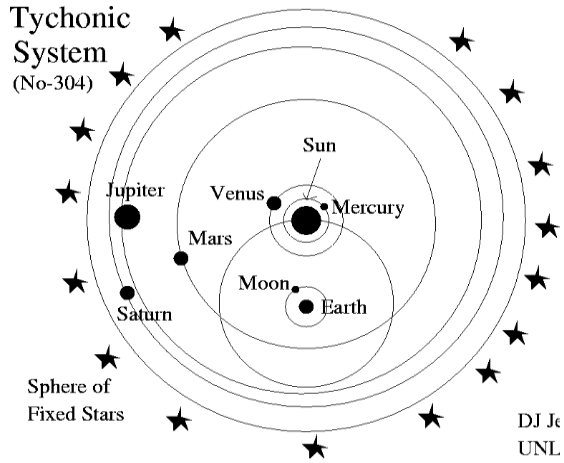


Galileo's sketches of Jupiter's moons. Note dates.



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: ___________________________

____

____

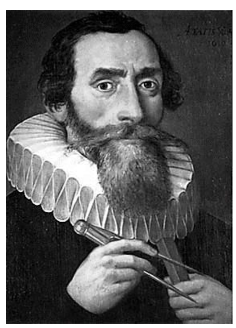
Paralax: ____

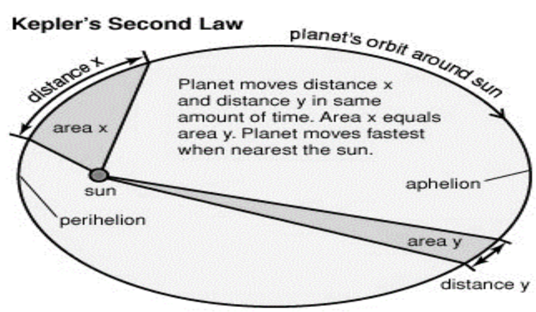
____

____

____

Johannes Kepler





Kepler's First Law____

____

____

Kepler's Second Law ____

____

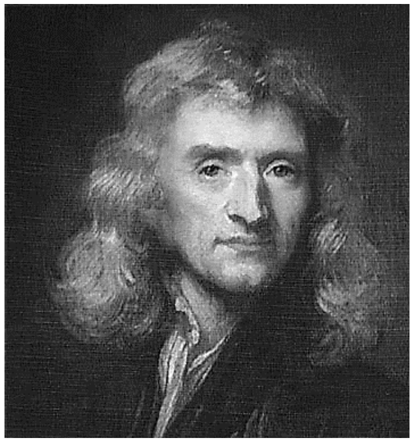
____

Kepler's Third Law ____

____

____

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: $\boldsymbol{p^2} = \boldsymbol{a^3}$

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 ________________________________

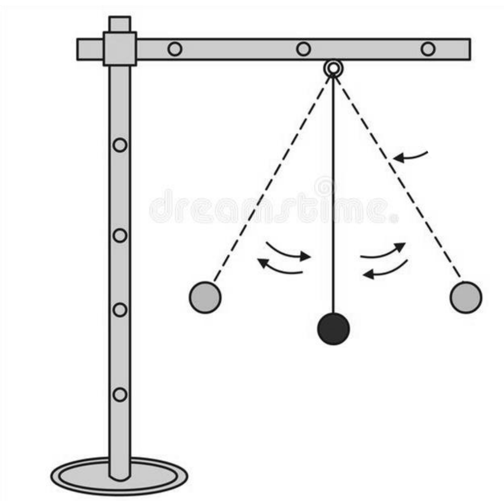
2. Numerical value of G ____

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:

$$g = l(2\pi f)^2$$

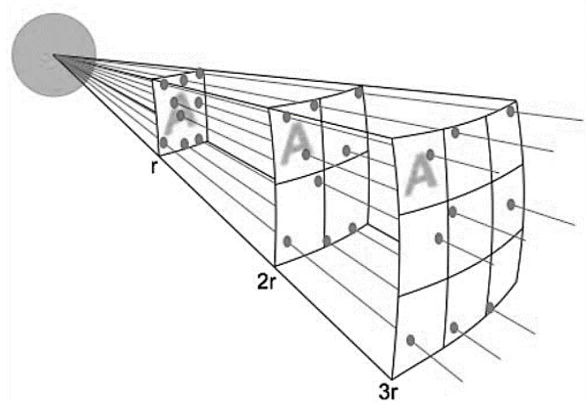
Where:

$g =$ acceleration of gravity (m/sec2)

$f =$ frequency (cycles/sec or Hertz / Hz)

$l =$ length of pendulum (meters)

The Inverse Square Law



Simply stated:

$$\boldsymbol{Intensity = \frac{1}{d^2}}$$

This rule applies to sound waves, gravity, and electromagnetic radiation (including visible light)

For example, if you double the distance (***2 x d***) from a light/wave/gravity source, then you get ***one quarter* of the intensity, not one-half.**

($\frac{1}{2^2} = \frac{1}{4}$ **= .25**)

Conversely, if you halve the distance (***.5 x d***) from a light source, then you get **four times the intensity, not twice.**

($\frac{1}{.5^2} = \frac{1}{.25}$ **= 4**)

Simple though it may seem, this formula and the idea it conveys is often daunting to many students, so let's try it another way:

Examples:

An object twice Earth's distance from the Sun receives _______________ the sunlight.

An object one-half Earth's distance from the Sun is subject to ______________ the Sun's gravity

An object four times Earth's distance from the Sun receives _______________ the sunlight.

An object one-fourth Earth's distance from the Sun is subject to ______________ the Sun's gravity

An object three times Earth's distance from the Sun receives _______________ the sunlight.

An object one-third Earth's distance from the Sun is subject to ______________ the Sun's gravity

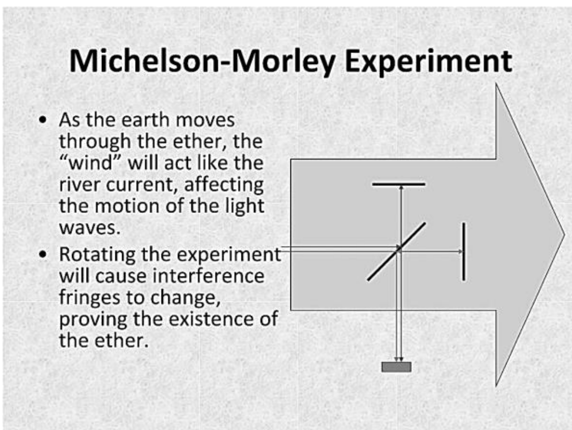
Michelson – Morley Experiment

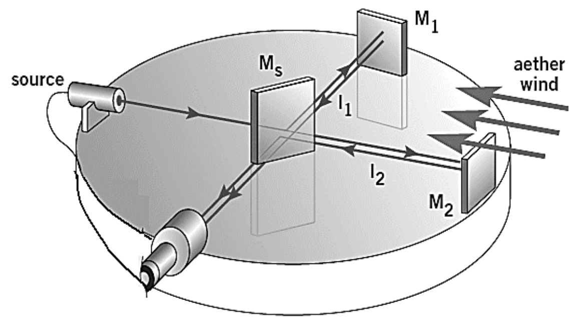
Albert Michelson

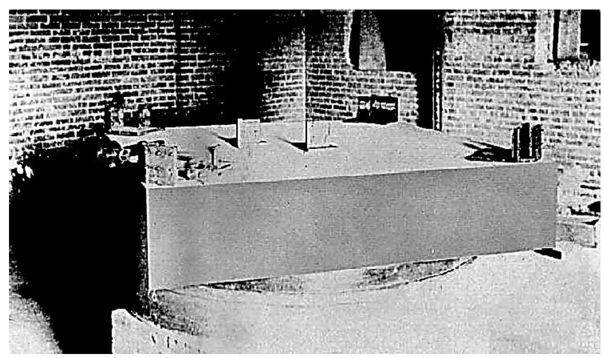
1. ________________________________
2. ________________________________

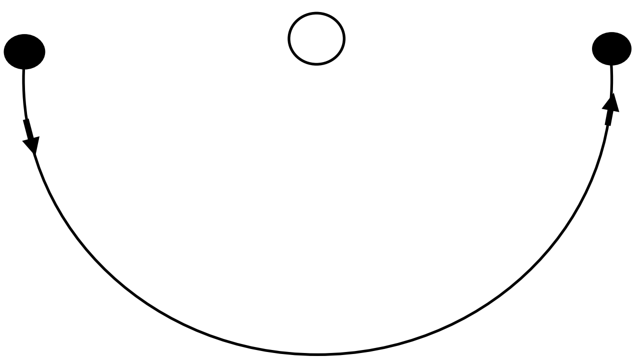
Luminiferous Ether (Aether) (the "Ether")

1. ____
2. ____

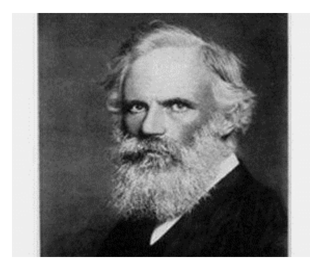




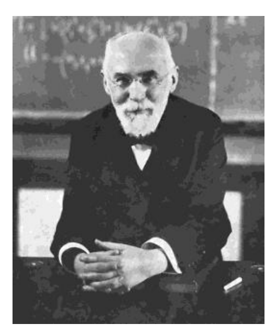




George Fitzgerald ______________________________



Hendrik Lorentz : ________________



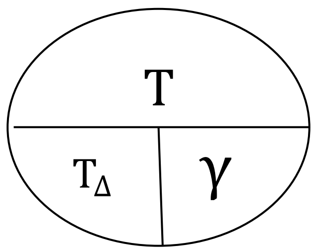
Lorentz Factor: $\sqrt{1-\frac{V^2}{c^2}}$ or γ ("Gamma")

Where

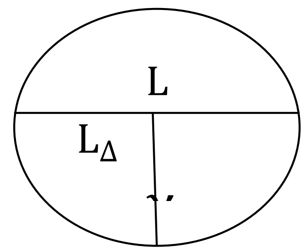
Time: $T_\Delta = \frac{T}{\sqrt{1-\frac{V^2}{c^2}}}$

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

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



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:

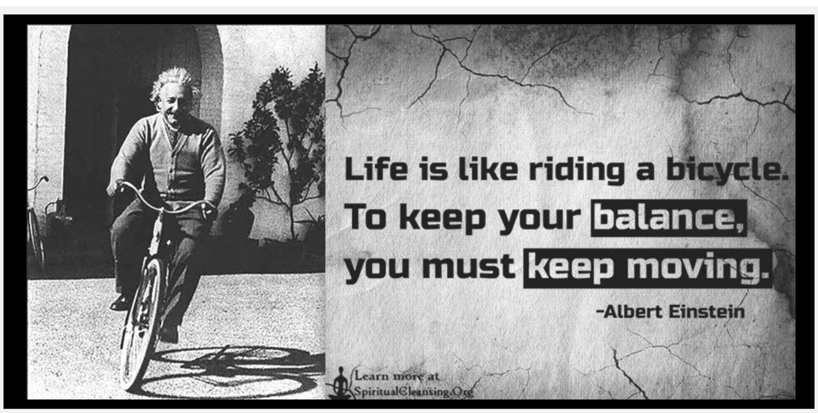
"As far as I'm concerned, I prefer silent vice to ostentatious virtue."

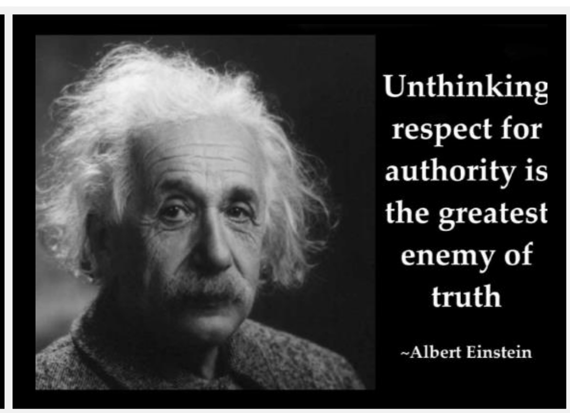
On traffic safety:

"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."

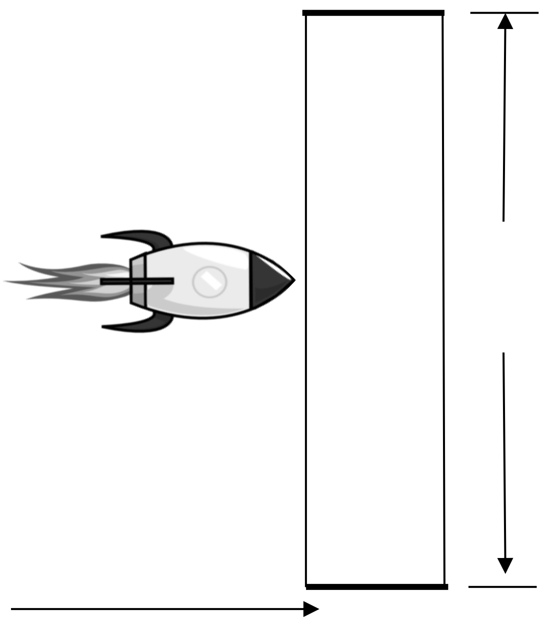




To understand why Relativity is necessary we have to look at the practical problems resulting from a Cosmic Speed Limit (The speed of light: "c")

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

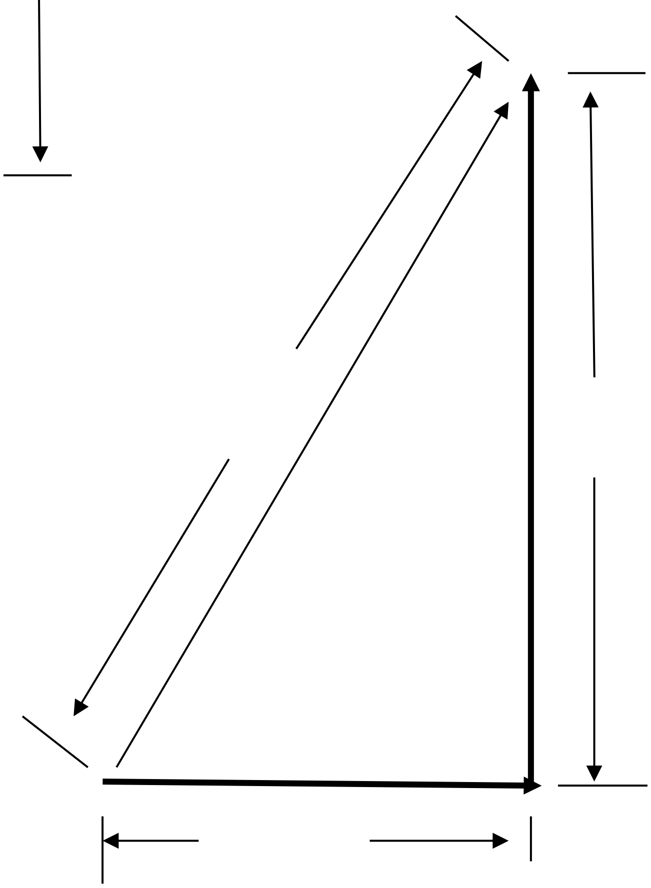
We'll start with a ridiculous imaginary clock:



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

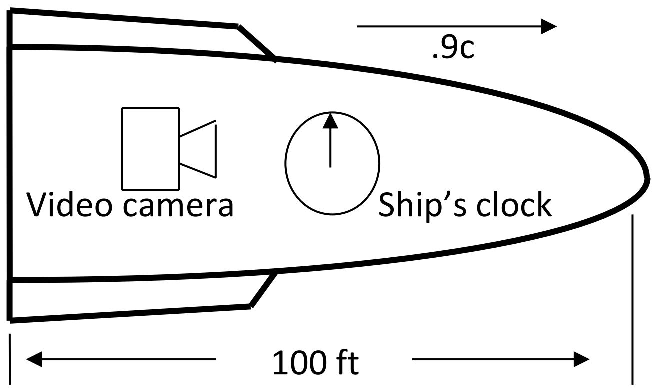
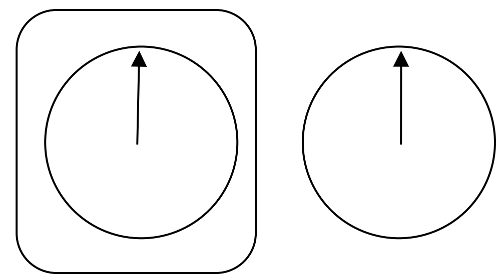


fig 2. **Ground Control observer's console**



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!

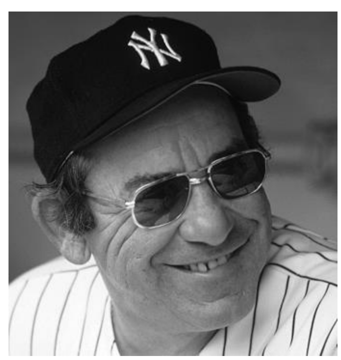
Solution:

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

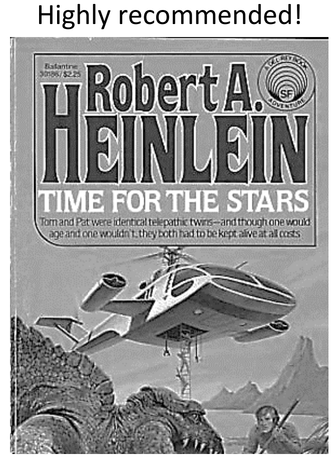
One of pair of identical twins is selected to be a crew member of a deep-space expedition to a star eleven light-years distant.

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

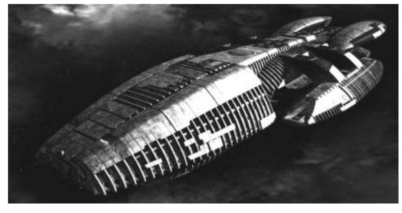
Determine how much time will have elapsed on Earth when they return.

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 **<u>AT</u>** 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 5.86×10^{-8} Kg

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

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

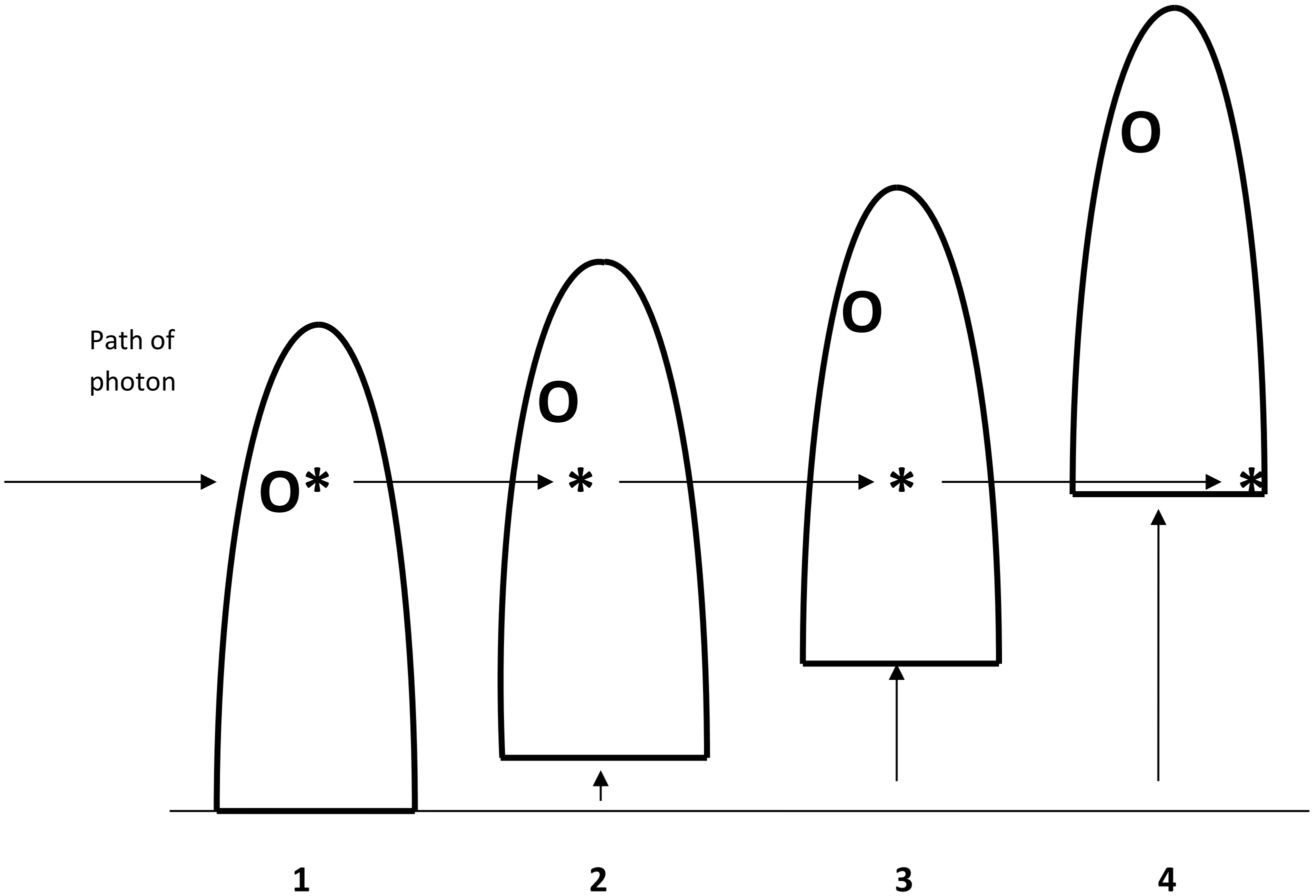
Further Practical Problems with Relativistic Velocity (Example 3)

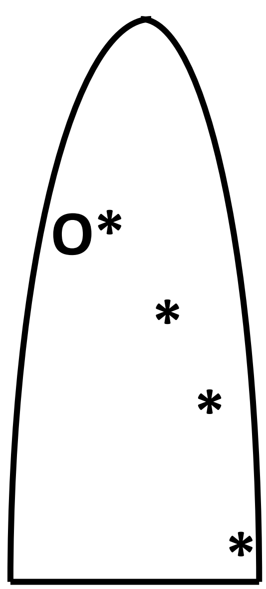
Given: A space vessel traveling at .9c collides with an small object with a mass of 2.5 grams (roughly the mass of a penny)

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

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

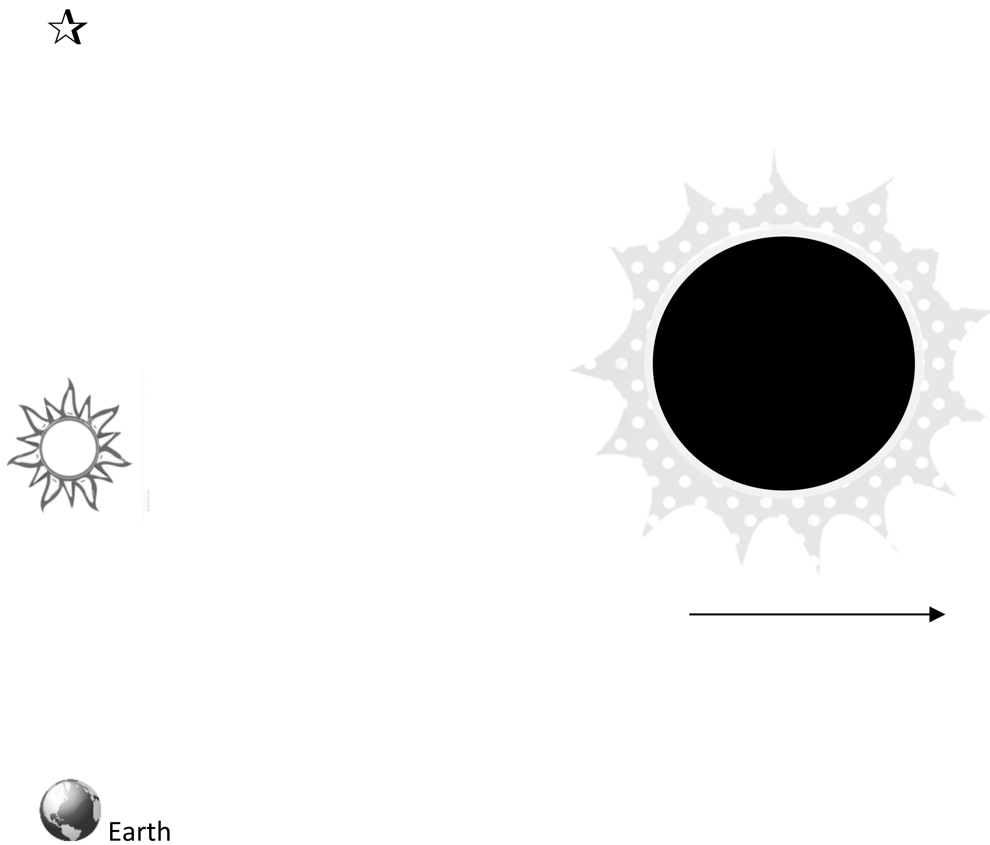
The effects of acceleration on the path of a photon





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": ______________________________

____

____

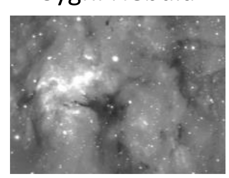
Ex: Pleiades

(2) "Emission Nebula": _________________________________

____

____

Ex. The Gamma Sygni Nebula

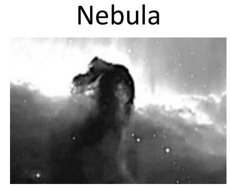


(3) "Dark Nebulae": ___________________________________

____

____

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 (10 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 ____

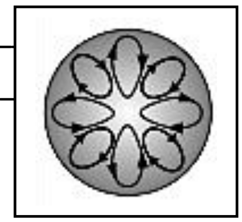
Most common ____________________________________

Limited to ______________________________________

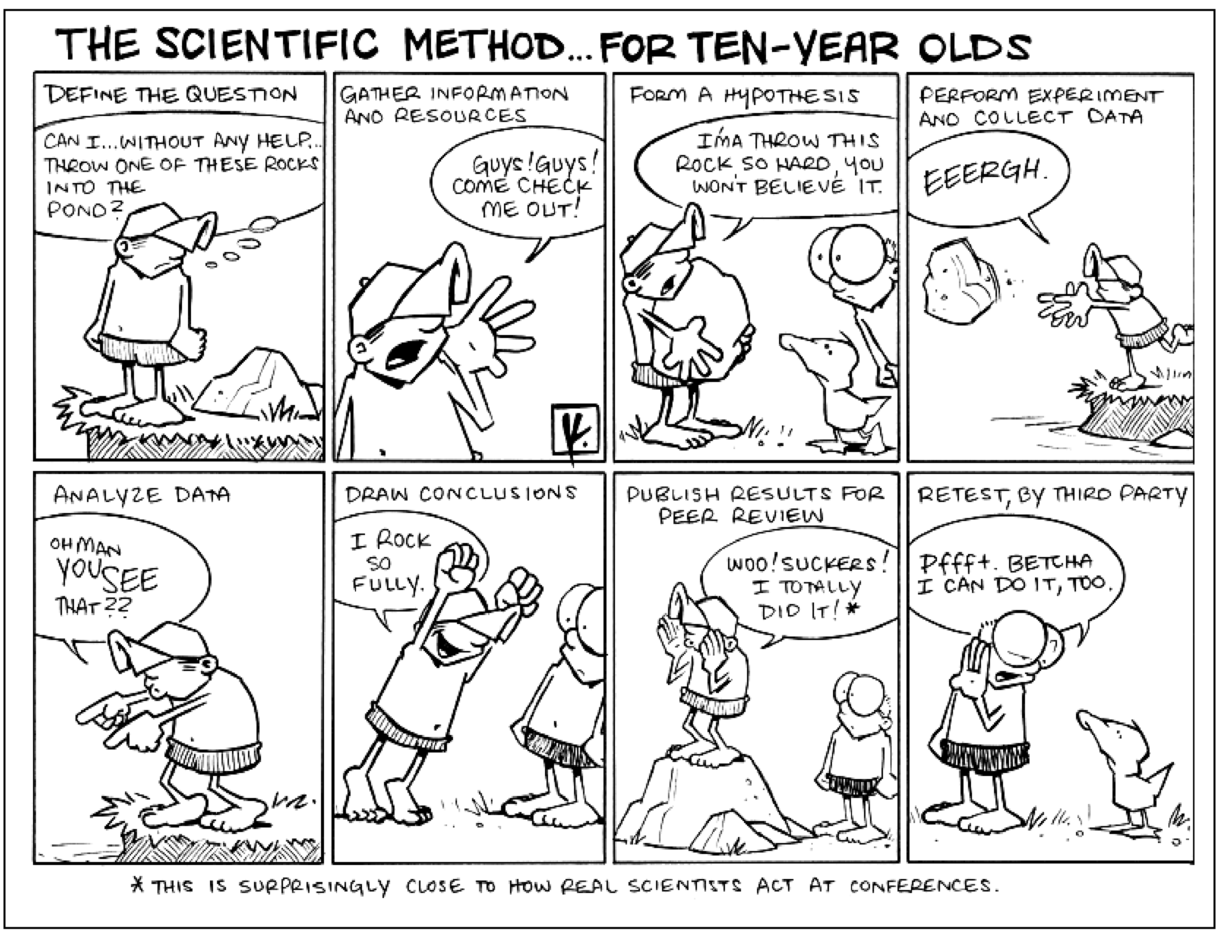
____

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⊙ :

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 ____

____

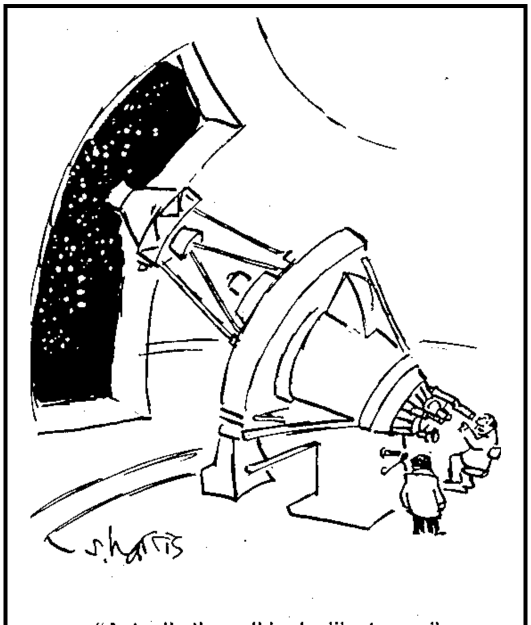
Expanding core ____

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 _________________

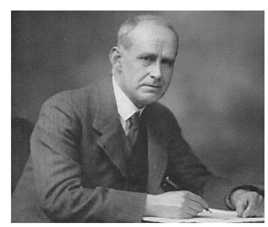
3. Period-luminosity relationship:____

____

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 _________________________________

____

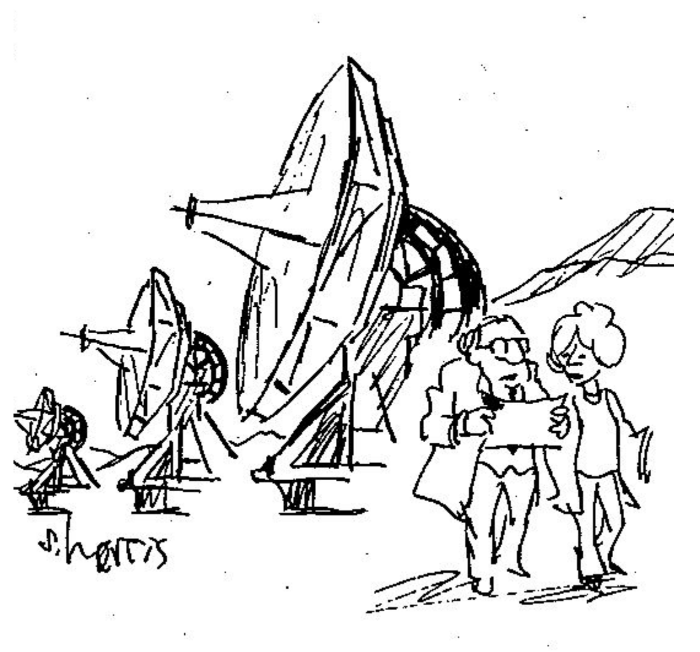
RR Lyrae Variables

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 been 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.

History of the Magnitude Scale

The **magnitude scale** began in 129 B.C., when the ancient Greek astronomer Hipparchus classified the stars. He called the brightest stars "first magnitude," meaning "the brightest." He had six rankings in his classification system, meaning the faintest stars he could see were "sixth magnitude."

Galileo Galilei

When Italian scientist Galileo Galilei turned his telescope to the sky, he discovered stars fainter than the faintest stars visible to the naked eye. Since these stars were fainter than Hipparchus's faintest stars, Galileo called them "seventh magnitude." And so as astronomers with larger telescopes discovered fainter and fainter stars, they kept classifying them into higher and higher magnitude categories.

In the 1800s, astronomers had so much data that the magnitude system confused them. They realized they needed to give the magnitude system a mathematical definition, so that two astronomers could agree on exactly how bright a star was. In 1856, Oxford astronomer Norman Pogson suggested that a star's magnitude should be defined in terms of the star's radiant flux.

In Hipparchus's ancient system, first magnitude stars emitted about 100 times as much light as sixth magnitude stars. So Pogson defined his scale such that an increase of five magnitude numbers meant a 100-fold increase in radiant flux. By this definition, Vega's magnitude fell very close to zero, so astronomers chose Vega as the reference point for the magnitude system. Later, astronomers extended the magnitude scale to brighter objects by giving them negative numbers. Today, the magnitude system has been extended so far that there are now 56 magnitudes between the brightest thing we can see (the Sun, -26) to the faintest (faint objects in Hubble Space Telescope images, +30). In terms of amount of light received on Earth, the magnitude scale spans a factor of 2.51^{56}, or 2.4×10^{22}!

The magnitude scale seems arbitrary and confusing, even to astronomers. But the scale gives a precise measurement of the brightnesses of stars, and pays tribute to the 4000-year history of astronomy as a science, so astronomers keep using it.

ASTR 100 Topic: Death of Stars

Death process determined by mass, categorized as follows:

< 0.4M⊙ ____

0.4M⊙ - 8M⊙ ____

> 8M⊙ ____

Red Dwarfs

- Recall: fusion process ____

  ____

- Once hydrogen used up, ____

Larger Stars

- **Overview:** Fusion ____

  ____

  Recall:
- **< 2M⊙** : ____
- **> 2M⊙ :** 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 2^{nd} and last time

- Star becomes ____

____

Ex 1: Sol will expand ____

Ex 2: 8M⊙ 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⊙ 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!)

Meanwhile, Oog continues his investigation…

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 - ____

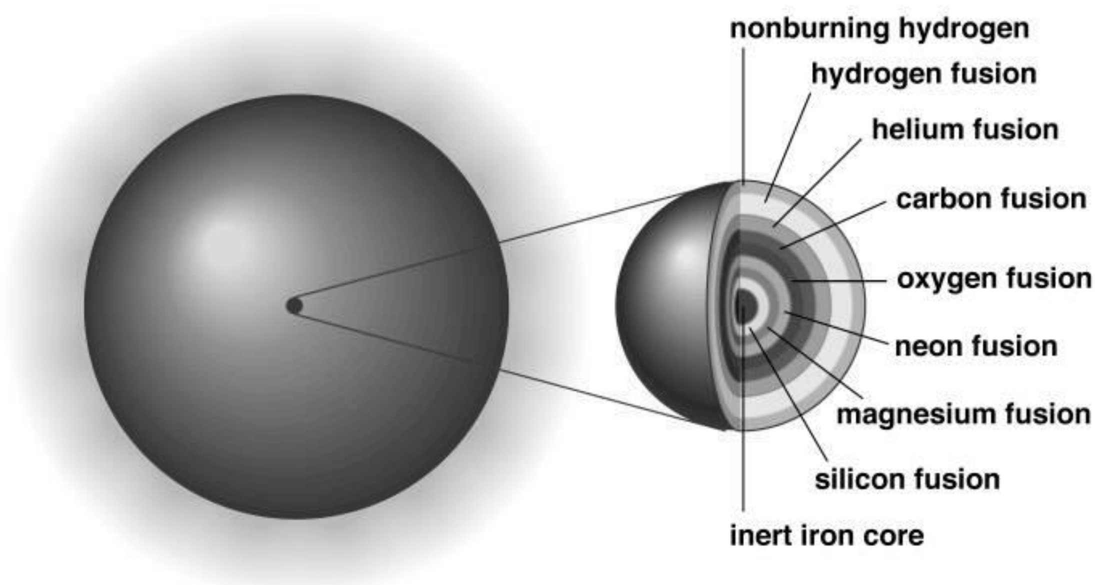
Silicon fusion - ____

*** 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 ________________________
____

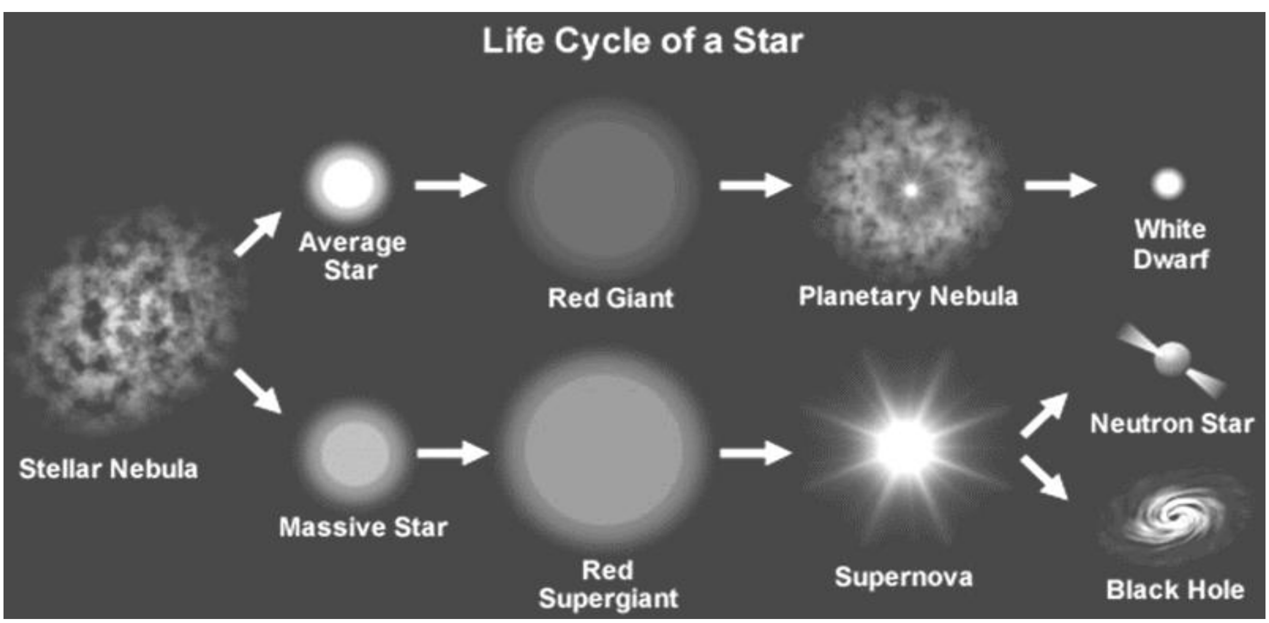
5. Therefore, neutron stars can exceed __________________________
____

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

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

r = radius in meters

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

Calculate Escape Velocity (V_{esc}) for Earth

Given:

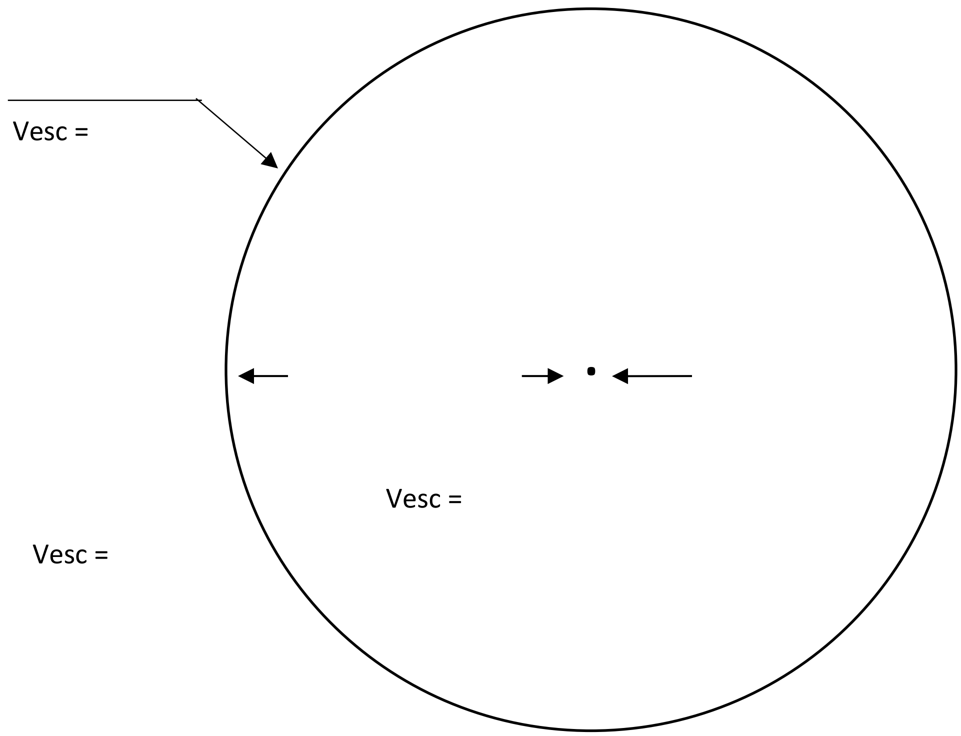
Radius of Earth: 6378 Km

Mass of Earth: 6.0×10^{24} Kg

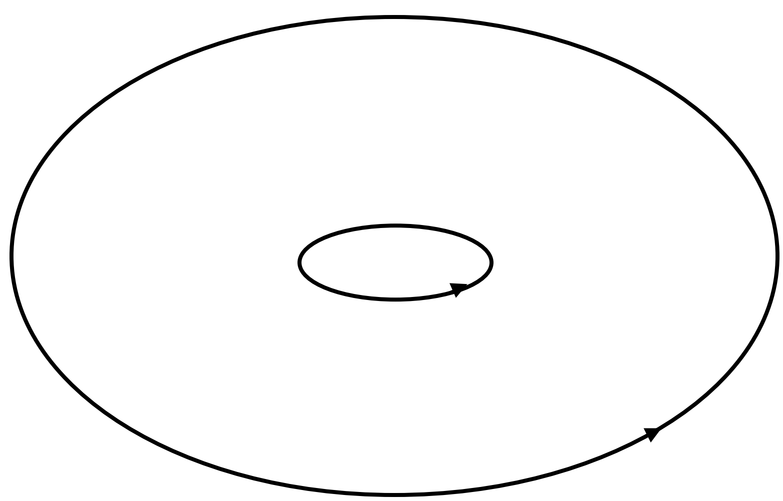
Universal Gravitational Constant (G): 6.672×10^{-11}

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

Schwarzschild 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:

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

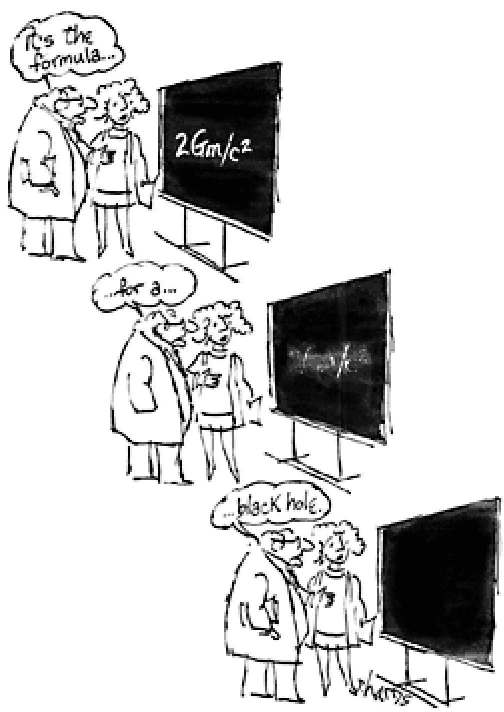
Where:
c = 3.0 x 108 m/sec
G = Universal Gravitational Constant = 6.672 x 10^{-11} Nm2/Kg^2
M = mass in kilograms
r_{sch} = Swarzchild Radius in meters

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

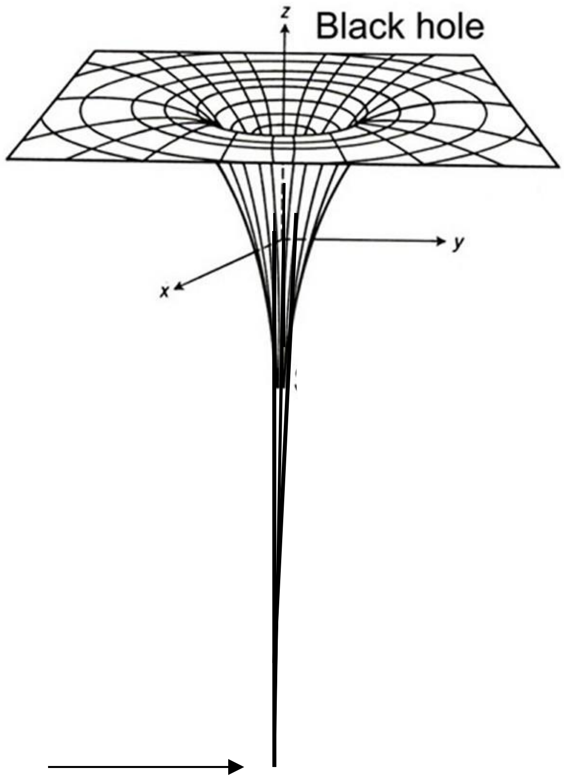
Ex. 1:

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 5.7×10^6 $M_\odot$

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: ____

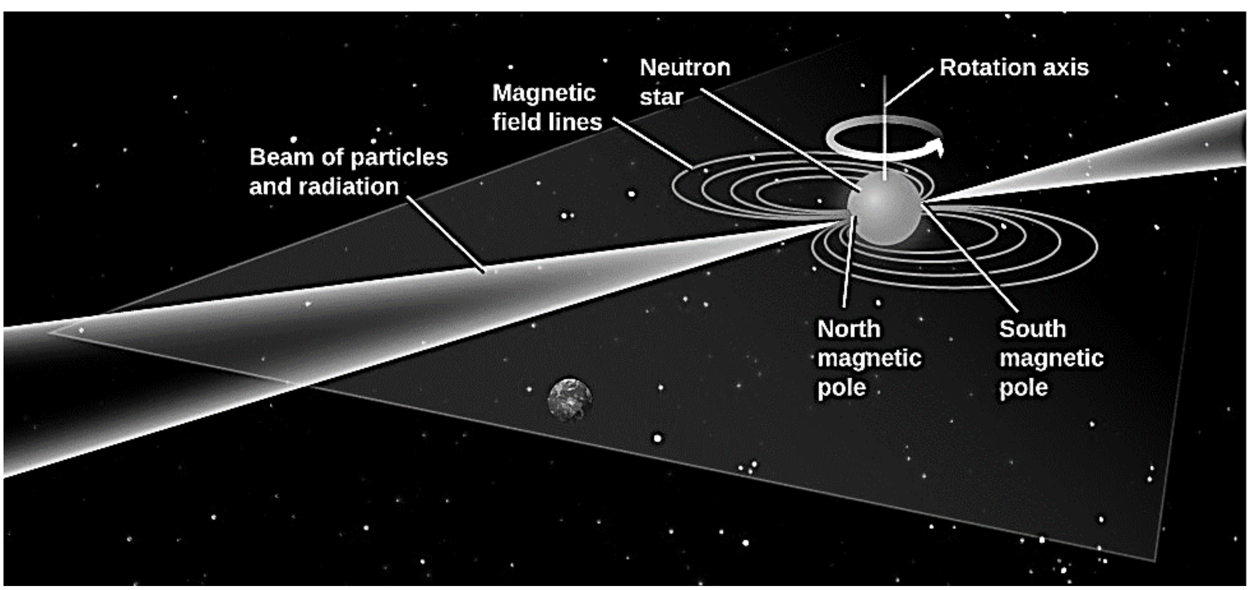
____

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.**

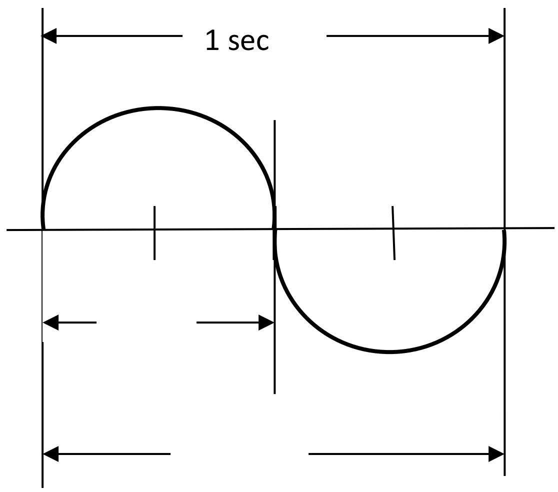
LAB: Doppler Effect, Relativistic Redshift, and Hubble Law

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)

$$v = f\lambda$$

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

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

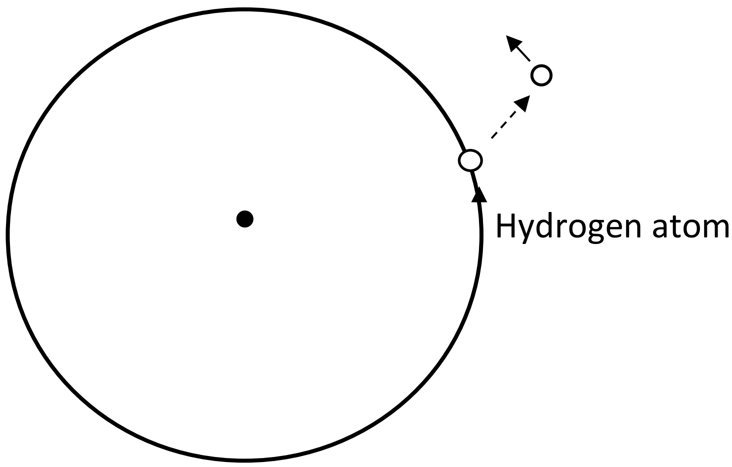
IMPORTANT:
Frequency is
____________________ ____________________
to wavelength

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?

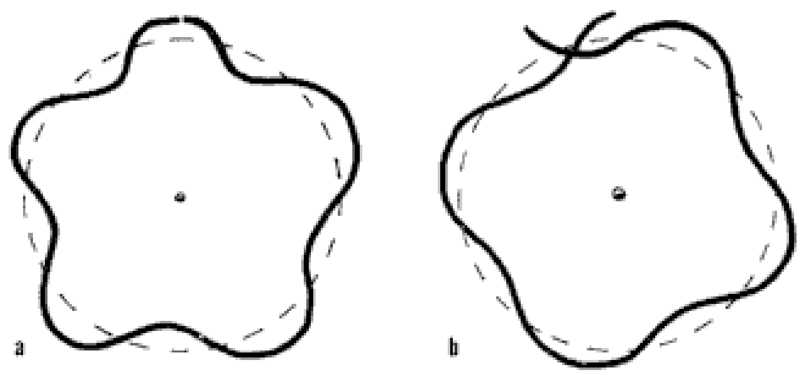
The Nature of Light Waves

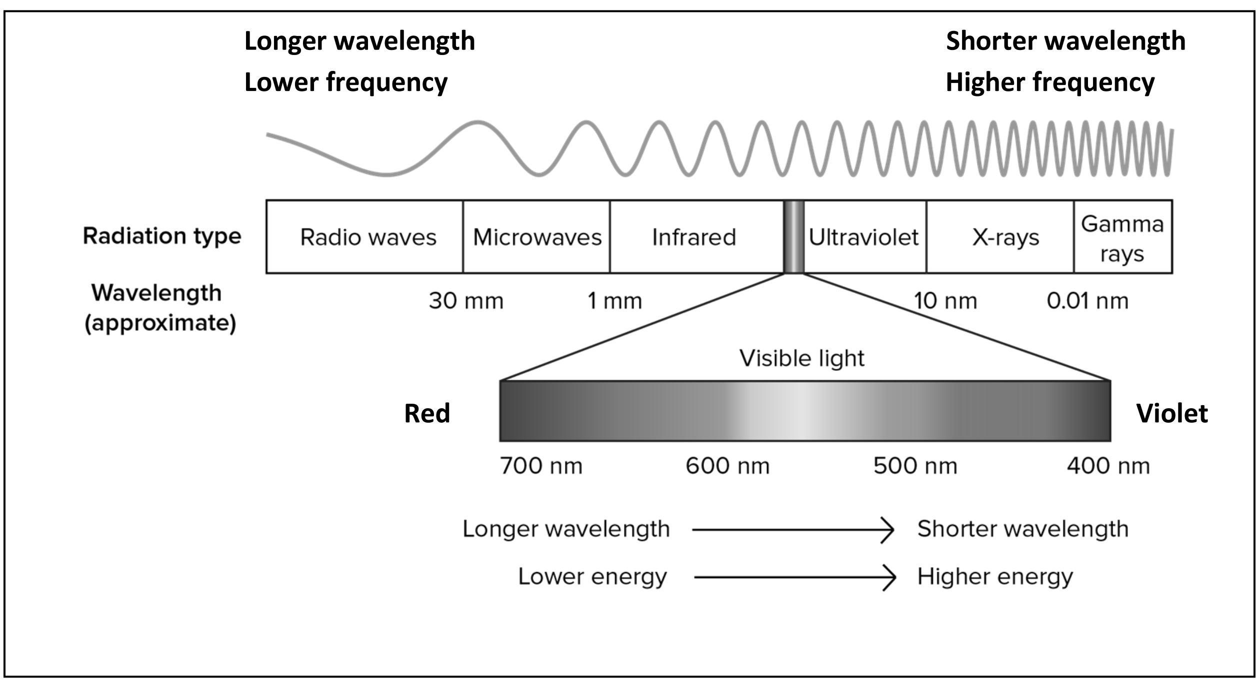
Structure of the atom and the nature of light

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:

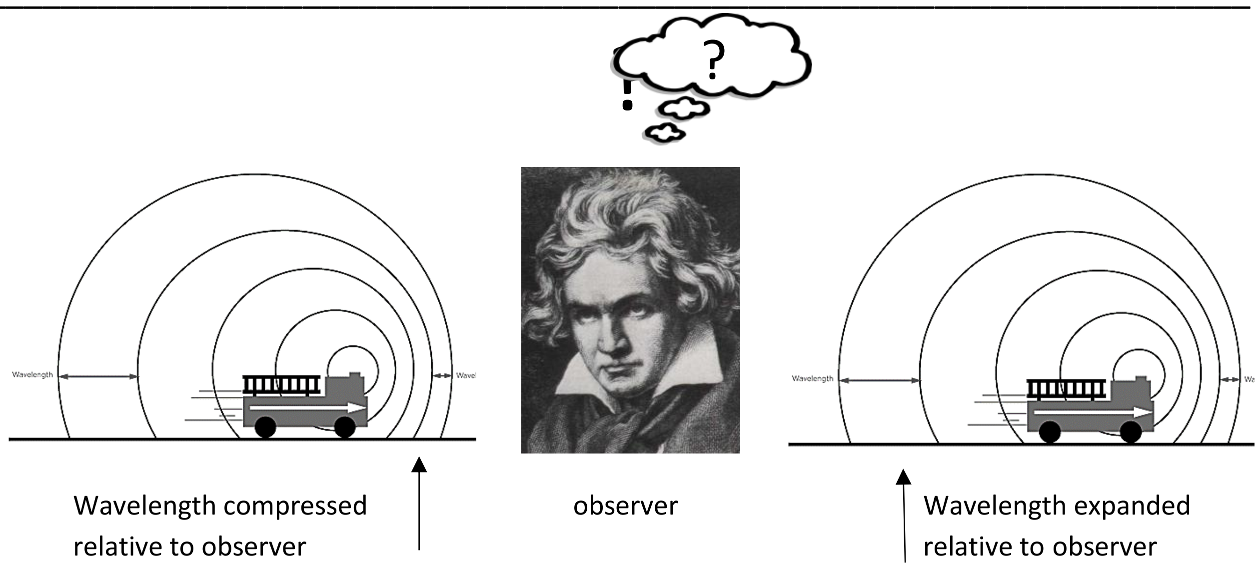
Hydrogen emits visible light at 410.2 nm (λ). What is the frequency?

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 $v = H_0 D$, with H_0 the constant of proportionality (the **Hubble constant**) between the "proper distance" *D* to a galaxy and its velocity *v* (see *Uses of the proper distance*). H_0 is usually quoted in (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: $V = H_o D$

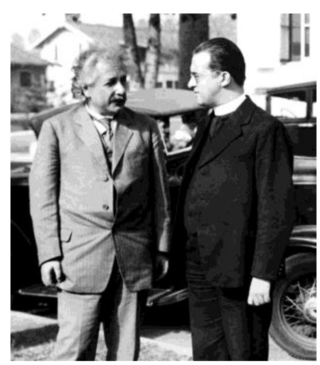
Where:

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

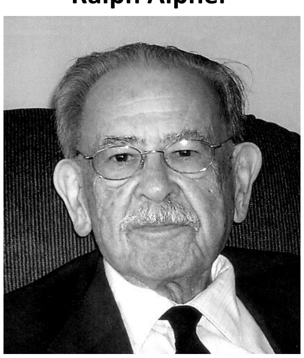
The cosmic microwave background (CMB) is thought to be leftover radiation from the Big Bang, or the time when the universe began. As the theory goes, when the universe was born it underwent a rapid inflation and expansion. The CMB represents the heat left over from the Big Bang.
You can't see the CMB 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

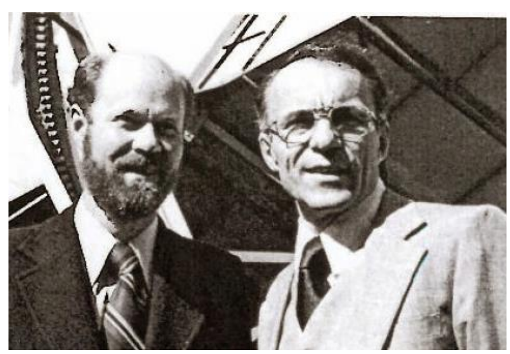
About 380,000 years after the Big Bang, the universe was cool enough that hydrogen could form. Because the CMB photons are barely affected by hitting hydrogen, the photons travel in straight lines. Cosmologists refer to a "surface of last scattering" when the CMB photons last hit matter; after that, 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

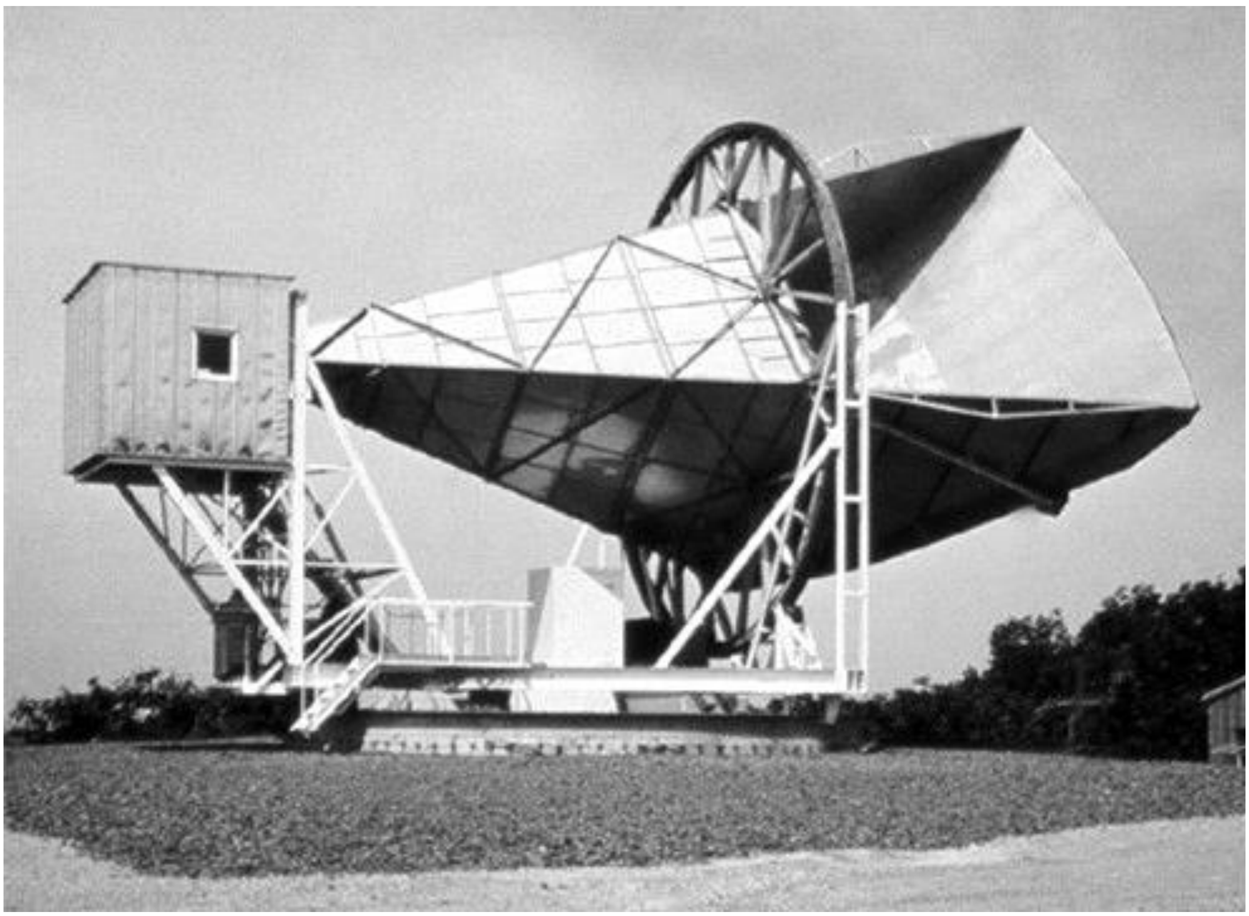
Robert Wilson and Arno Penzias



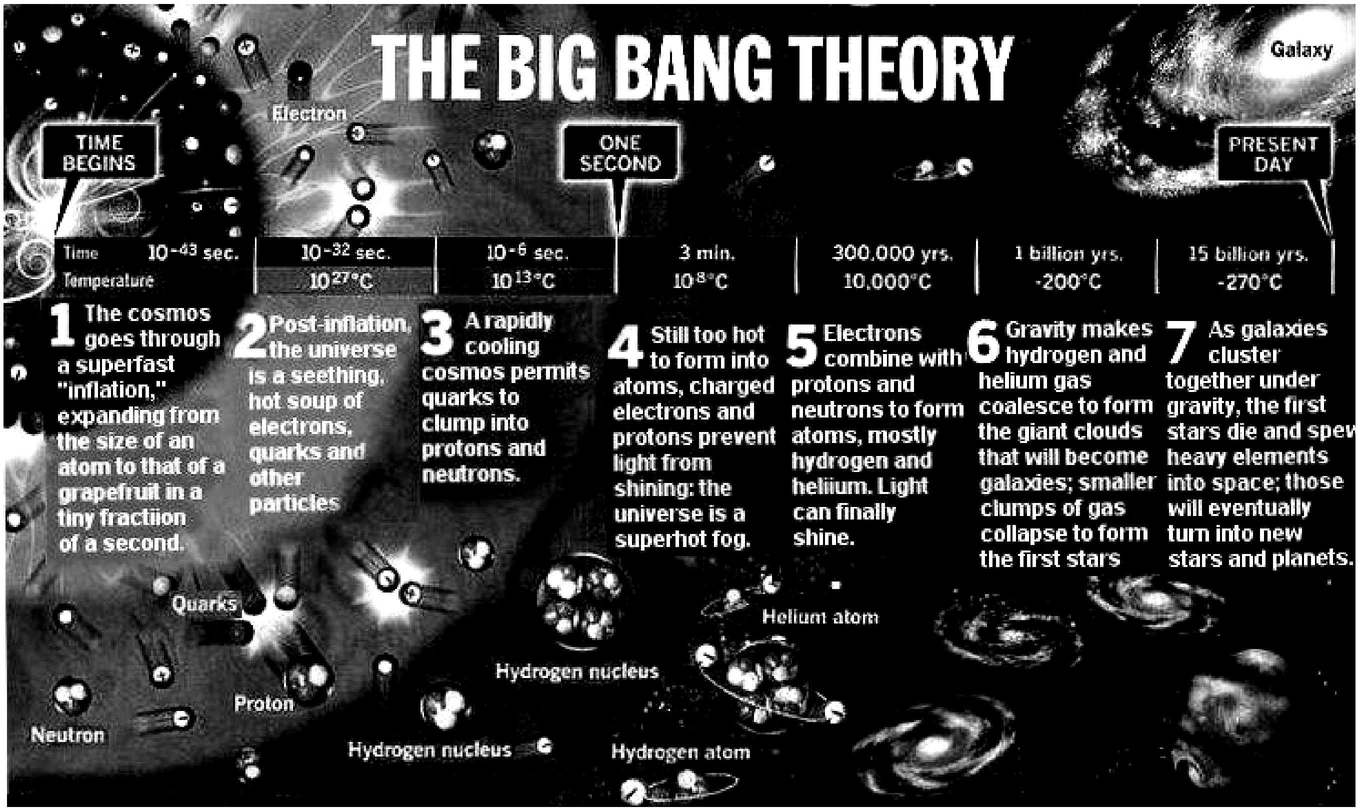
American cosmologist **Ralph Alpher** first predicted the CMB in 1948, when he was doing work with Robert Herman and **George Gamow**, according to NASA. The team was doing research related to Big Bang nucleosynthesis, or the production of elements in the universe besides the lightest isotope (type)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

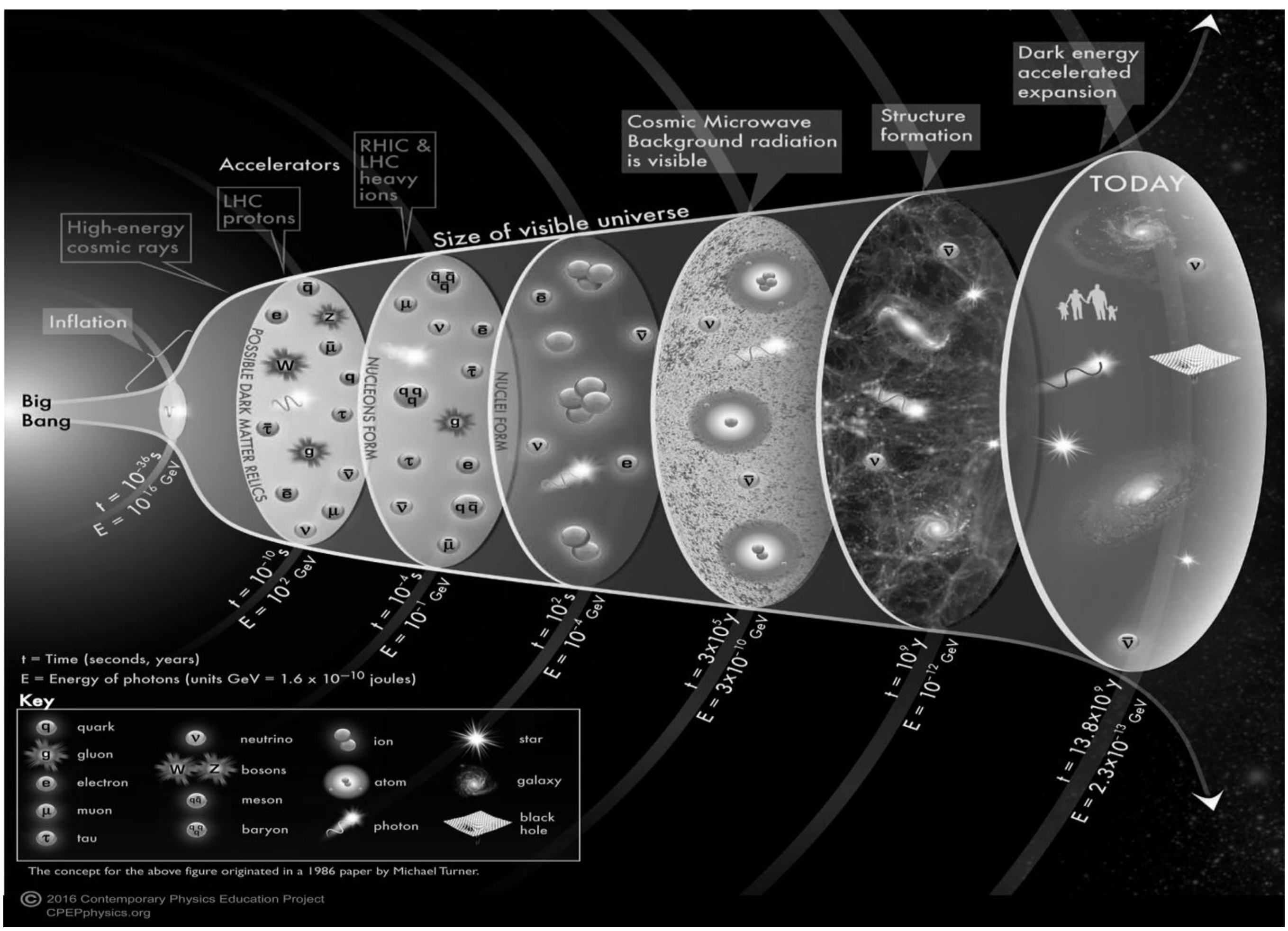
Both teams quickly published papers in the Astrophysical Journal in 1965, with Penzias and Wilson talking about what they saw, and Dicke's team explaining what it means in the context of the universe. (Later, Penzias and Wilson both received the 1978 Nobel Prize in physics).



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: