Name ____________________________ Section _____________________

Period 13: Energy and Matter in the Universe

13.1 Origin of Matter in the Universe- the Big Bang

1) The Big Bang Theory and the Early Universe

a) How do scientists believe that the Universe began?

b) In what form was the energy of the early Universe?

c) How much energy was contained in the initial Universe as compared to the amount of energy and energy that has condensed into matter in the Universe today?

d) Any source of radiation is characterized by a temperature.

i) What temperature characterizes radiation from the Sun? ______________

ii) What temperature characterizes radiation from the Earth? ____________

iii) What temperature is believed to have characterized the early Universe? ______

e) In our study of gases, we saw that the average energy and temperature of gases are related by the constant k. (k = 1.38×10^{-23} J/Kelvin or 8.62×10^{-5} eV/Kelvin). Use this relationship to find the average energy per photon in the early Universe in units of joules and in electron volts.

f) Group Discussion Question: How does the energy of an early Universe photon compare to the energy of a visible light photon from the Sun?

2) The Expanding Universe

Following the Big Bang, the Universe began expanding. We will represent the expanding Universe with an inflating balloon.

a) Mark several large dots several centimeters apart on a deflated balloon. Blow up the balloon. If each dot represents a galaxy, what happens to the galaxies as the universe expands?

b) Consider the view of the Universe as seen by an observer on each galaxy. Do **all** the galaxies appear to be receding from the observer as the Universe expands? __________

c) An elastic band attached to a board can illustrate the rate of expansion of the Universe. Initially the distance between marks on the unstretched elastic band is 1 inch. Stretch the elastic band until the 1 inch mark on the band lines up with the 2 inch mark on the ruler.

When the 1 inch mark on the band is stretched to 2 inches, how far has the 2 inch mark on the band stretched? ____________________________________

If this band represented the expansion of the Universe, how would the rate of expansion of distant galaxies compare to the rate of expansion of closer galaxies?

d) The size of astronomical objects is measured in light years – the distance photons of light travel in one year. If the speed of a photon is 3×10^8 m/s, how many meters does a photon travel in one year?

e) Light from objects at the edge of the expanding Universe takes an estimated 13 billion years to reach the Earth. Approximately how many meters is this?

f) Group Discussion Question: The radius of the very early Universe is estimated to have been 10^{-35} meters. By how many factors of ten has the Universe expanded?

3) Formation of Matter in the Early Universe

a) What happens to the temperature of the Universe as it expands?

b) As the early Universe cooled, the first particles to form were quarks and antiquarks. With further cooling, these particles combined to form protons, neutrons, antiprotons, and antineutrons.

The rest mass of a proton is 938.3 MeV. To what temperature must the Universe have cooled for the conversion of energy into protons to stop?

c) When the temperature of the Universe cooled further, protons and neutrons combined into nuclei of deuterium. If the binding energy of deuterium is 2.22 MeV, at what temperature did deuterium nuclei become stable?

d) How long did it take for the Universe to cool to this temperature?

e) In the early Universe, both matter and antimatter where formed. When a proton and an antiproton collide, they are annihilated and their mass is converted into energy. What form did much of this energy take?

4) Remnants of the Big Bang

a) What remnants of the Big Bang can we detect?

Can sound waves from the Big Bang be detected? ________ Why or why not?

Can waves of electromagnetic radiation from the Big Bang be detected? ______ Why or why not?

b) Visible light from a distant star be observed on Earth. Hold a small lens up to one of your eyes. Place a large lens in front of the small lens. Move the large lens away from your eye until objects in the room come into focus. How do the lenses change an image?

c) Which forms of radiant energy from stars, in addition to visible light, are detected on Earth?

d) What evidence of microwave radiation do we observe?

13.2 Formation of Galaxies

5) Clumping of matter into galaxies

a) At the time of the Big Bang, energy was distributed fairly uniformly in a very small volume. How is energy and matter distributed throughout the Universe today?

b) Which force caused matter to form clumps that became galaxies?

c) Which force binds protons and electrons into atoms?

d) Observe the demonstration of the hanging cans. Which force is stronger – the gravitational attraction or the electromagnetic attraction between the cans?

e) Slowly pour "magic" sand from one beaker of water into a second beaker of water. What force causes the sand grains to clump together?

f) If the gravitational force is so weak, how can the gravitational force be responsible for binding matter into galaxies and stars?

13.3 Composition of Stars

6) Emission lines in the spectra of elements

a) Observe a tube of glowing gas through a diffraction grating. The lines you see are the emission lines of the photons of the gas. Draw the lines your see and indicate their colors.

Match these lines to the lines of an element on the spectral analysis chart. The first tube contains gas of which element? ______________________

b) Observe a second tube of glowing gas and draw the lines your see.

Match these lines to the lines of an element on the spectral analysis chart. The second tube contains gas of which element? _____________________

c) Observe the glowing neon tube through a diffraction grating. What do you see?

7) The chemical composition of stars

a) Observe the long filament bulb through a diffraction grating. The continuous spectrum represents the emissions from a hot object, such as a star.

What happens when you cover the diffraction grating with a blue filter?

b) Gases in a star are very hot inside the star and cooler at the star's surface. Cool gases at the surface absorb the spectral lines characteristic of the elements within the star.

What would the spectrum of a star with hydrogen gas on its surface look like?

c) How can scientists tell which elements exist in a star?

8) Energy source of stars

a) Which nuclear reaction is the basis of the energy of stars?

b) What force provided the activation energy needed to begin nuclear fusion in a star?

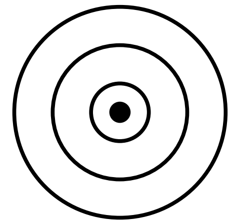
c) What holds the gas of a star into a spherical shape?

d) What happens to clumps of matter that do not reach an internal temperature high enough to begin fusion reactions?

13.4 The Universe Today

9) Doppler Shift and the Expanding Universe

Your instructor will discuss the Doppler shift of light waves from a moving source.



a) A stationery light source emits waves of light uniformly in all directions as shown in the diagram. How do the wavelengths of light from the right side of the diagram compare to the wavelengths of light from the left side?

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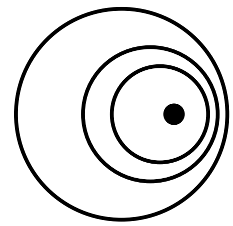
spread of waves over time



b) The same light source now moves to the right as shown in the diagram. Although the light source still emits waves uniformly in all directions, motion of the source means that the wavelengths are no longer evenly spaced. How do the wavelengths of light when viewed from the right side of the diagram compare to the wavelengths of light when viewed from the left side?

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c) What happens to the color of the light waves on the right side of the diagram? ____________________________ What happens to the color of the light waves on the left side of the diagram? ______________________________

d) What information about a galaxy's motion could this change in wavelength provide?

e) Galaxies are observed to rotate. Why would rotating matter tend to form a flattened disk?

f) Based on our experience with the solar system, which portion of a rotating galaxy would you expect to rotate faster – matter closer to the galaxy center or matter toward the galaxy edge?

g) In fact, the stars near the edges of a spiral galaxy rotate in tandem with the stars near the center. How can a galaxy that appears to contain much empty space act more like a solid disk than like the solar system?

10) The Hubble Constant and the Age of the Universe

Next, we consider supernovae and galaxies throughout the Universe.

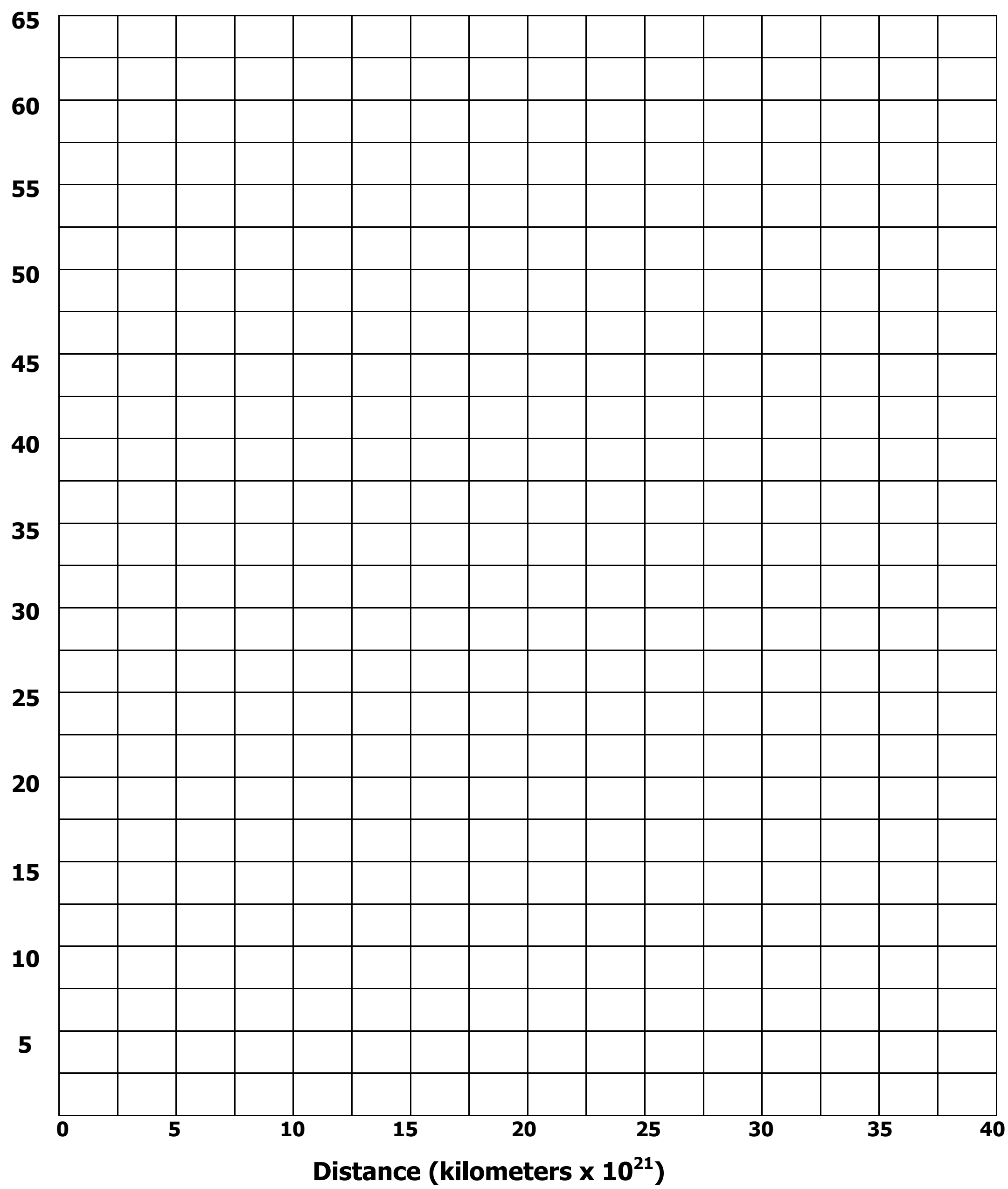
a) Light from supernovae stars appears reddened as observed from the Earth. What does that indicate about the motion of the stars?

b) Light from stars further from the Earth appears more reddened than light from stars nearer to the Earth. What does this indicate about the rate of expansion of the Universe?

c) The data shows the velocity at which four stars in galaxies appear to be receding when viewed from the Earth and the distance of these galaxies from Earth.

Galaxy cluster in	Recessional velocity (thousands of km/sec)	Distance (km x 10^{21})
Ursa Major	15.0	9.41
Corona Borealis	21.6	13.7
Bootes	39.3	26.0
Hydra	61.2	37.6

d) Plot the recessional velocity versus distance on the grid below.



e) Find the slope of your graph. The slope of this graph is known as the Hubble constant (H_O).

f) Estimate the age of the Universe by calculating the inverse of the Hubble constant, $1/H_O$.

g) Convert your answer into years.

h) How does your value for the age of the Universe compare to Hubble's own value of 19.6 billion years?

i) The actual age of the Universe is estimated by other means at 13.7 billion years. What could account for the difference in values?