The Big Bang Theory Evidence Workbook

The Big Bang Theory

Most astronomers today accept the theory that the universe as we know it started from a single, massive "explosion" called the Big Bang. Those astronomers believe that the universe began at a specific time and has been evolving ever since.

The **big bang theory** is a scientific model that explains why scientists have observed the universe expanding. It states that the universe originated about 14 billion years ago in an explosion of energy and matter that had been condensed (packed) into a single, infinitely small space known as the primordial atom. This explosion created an small, dense, and extremely HOT universe that began to expand in all directions. As things cooled over time, tiny bits of matter began to clump together to form stars and galaxies. All of the matter and energy in our entire universe came into existence from this single event.

1. Active Reading: Underline the sentence that identifies what most astronomers believe about the beginning of the universe.

2. Explain: What is the **big bang theory**'s answer to the question, *how did the universe begin?*

Evidence for the Big Bang Theory: The Expanding universe

In 1929, Edwin Hubble observed that most galaxies are moving away from each other. Galaxies are systems of millions or billions of stars, and the dust and gas in between them, that are held together by gravity. Our solar system, the group of planets that orbit our sun, is part of the Milky Way galaxy. Our universe is made of many galaxies, and in 1929, Dr. Edwin Hubble realized that most of those galaxies were moving away from us. Moreover, the galaxies that were the farthest away were moving away the fastest.

This relationship - that galaxies that are farthest away seem to be moving away the fastest - is known as Hubble's Law.

3. Active Reading: Underline the sentence that describes what Edwin Hubble observed.

4. Explain: What is Hubble's Law?

Lab 1: Big Bang Balloon

Purpose: In this activity, you will create a simple model to learn how the universe expands over time.

Directions:

- ❏ 1. Inflate your balloon until it is about 4 inches (10 cm) in diameter, but do not tie the end.
- ❏ 2. Using a Sharpie marker, make six dots on the balloon. Scatter the dots widely. Label ONE

dot “home” and the other dots A, B, C, D, and E. The home dot represents the *Milky Way galaxy.* The other dots represent galaxies that formed in the early universe.

- ❏ 3. Without letting air out of the balloon, use the string and ruler to measure the distance from **home** to each **dot**. Record the distances in the table below under the heading “Round 1.” *This represents the galaxies initial distance from home.*
- ❏ 4. Inflate the balloon so that its diameter is about 2 inches (5 cm) BIGGER. Again, measure the distance from **home** to each of the **dots**. Record the distances under “Round 2” on the table. *This represents the distance of the galaxies from home after the universe has expanded.*
- ❏ 5. Inflate the balloon in 2 inch (5 cm) increments two more times. After each time, measure the distance from the **home** dot to the other **dots** and record your measurements on the table. *This represents the universe continuing to expand. You should notice the dots move farther and farther away from the home dot.*

5.	Round 1 distance from home	Round 2 distance from home	Round 3 distance from home	Round 4 distance from home	Total Distance Calculate Time 4 - Time 1
Dot A					
Dot B					
Dot C					
Dot D					
Dot E					

Analysis:

6. How did the distance from the home dot to galaxy A change each time you inflated the balloon? How did the distance from the home dot to galaxy B change each time you inflated the balloon? Describe the pattern you observe.

7. Did the galaxies near home or those farther away from home appear to move the greatest distance?

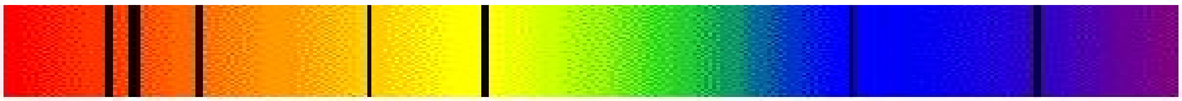
8. How did this lab demonstrate Hubble’s Law?

Evidence for the Big Bang Theory: The Doppler Effect and Redshift

Edwin Hubble observed galaxies were moving away, and the galaxies that were farthest away were moving away the fastest. But how did he know this? How did Hubble *know* the galaxies were moving away?

Hubble made his discovery about the expanding universe by studying the **absorption spectra** released by each galaxy.

By studying the light released by a star or galaxy (a group of stars), scientists can determine the elements present. They compare the absorption spectrum of a star with the absorption spectra of elements they have tested in the lab. When an element absorbs a wavelength of light, a black line appears on the spectrum. Scientists know our sun contains the elements hydrogen and helium, because the sun's absorption spectrum matches helium's absorption spectrum.

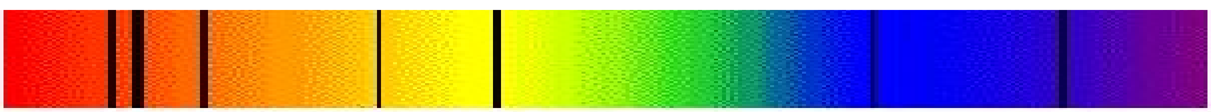


Spectrum of the sun

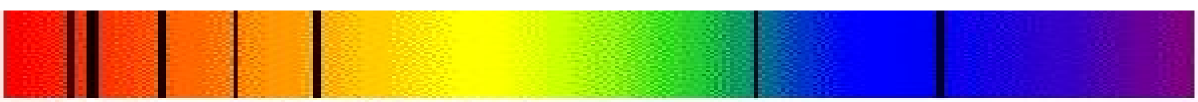
9. Explain: Why do black lines appear on the absorption spectrum of the sun?

10. Infer: How could a scientist determine what elements are present in a distant star by looking at its absorption spectrum?

By looking at absorption spectra of stars, scientists know that all stars contain hydrogen and helium, as well as other elements. Because they contain the same elements, all stars should have the same pattern of absorption lines as our sun's spectrum. But when Hubble looked at the spectrum of a distant star, he saw something different.



Spectrum of the sun



Spectrum of a distant star

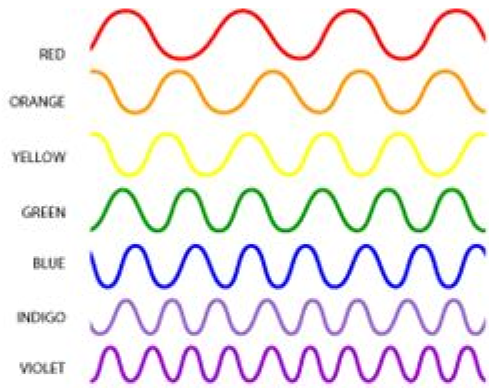
11. Observe: How many black lines are on the spectrum of the sun? How does this compare to the number of black lines on the spectrum of a distant star?

12. Compare: How do the black lines on the spectrum of a distant star compare to the black lines on the spectrum of the sun?

13. Infer: Why do the number of black lines on the two spectrums match?

Like you may have noticed, Hubble found that the pattern of distant stars was shifted towards the left end of the spectrum. While distant stars' spectra had the same pattern of lines as that of our sun's, all of the lines were shifted toward the red end.

This is called **red shift**. It is a change in the frequency, and therefore, the position of the lines.



The picture to the left shows different wavelengths of visible light. Trace each line with the appropriate color.

14. Contrast: Describe how the waves change as you move from red to violet light.

15. Conclude: If the wavelengths of light absorbed by hydrogen and helium are shifted toward the red end of the spectrum, are those wavelengths becoming shorter or longer? Explain your reasoning.

Astronomers have found that the further from us a star is, the more its light has shifted toward the red end of the spectrum. They have used this knowledge to conclude that these stars (and the galaxies they are in) are moving away from us.

How can they conclude this? Take a look at the example below. Sound and light are forms of energy that move in waves. You may have noticed that as an ambulance approaches you, it has a high pitch siren. High pitch sounds could be described as squeaky or screechy. However, as the ambulance passes you and moves away, the siren seems to have a lower pitch. Low pitch sounds could be described as deep. This is because the apparent wavelength of the sound is "stretched" and becomes longer. The longer the wavelength, the lower the pitch of the sound.

16. Observe: Is the apparent wavelength of the ambulance's siren shorter or longer as it approaches you? Is it shorter or longer as it moved away from you?

Light energy works the same way. As the stars and galaxies move away from us, the wavelengths of light energy that they absorb or emit are "stretched" and appear longer. A wavelength of light that has been stretched appears to change color to our eyes -- blue may shift to green, and orange may shift to red.

The shift of light energy toward the red end of the spectrum tells us that distant galaxies are moving away from us. Because the most distant galaxies are shifted the most toward the red end of the spectrum, we know that those galaxies are moving away the fastest. Their wavelengths are being “stretched” the most.

17. Explain: If the absorption spectrum of distant stars are shifted towards the red end of the spectrum, what can you conclude about the wavelength of light absorbed by those stars?

18. Model: Draw a model that illustrates what happens to the wavelengths of light emitted and absorbed by stars as they move away from an observer. (See illustration above).

19. Infer: Explain what would happen to the wavelength of light if its source was moving TOWARD an observer. Toward which end of the spectrum would the light be shifted?

20. Model: Draw a model that illustrates what happens to the wavelengths of light emitted and absorbed by a star that is moving TOWARD an observer.

21. Conclude: How does knowing that the light from distant galaxies is red-shifted support the premise that these galaxies are moving away from us?

22. Conclude: How does knowing that distant galaxies are continuing to move away from us support the **big bang theory**?

Evidence for the Big Bang Theory: The Composition of the universe

Another piece of evidence for the **big bang theory** comes from the composition of matter in the universe. As we have learned, scientists have determined that galaxies are moving away from us, and the most distant galaxies are moving the fastest. With Hubble's data about the movement of galaxies, scientists could calculate how much smaller the universe was long ago. Scientists have even traced the expansion of the universe back to a time when it was all smaller than an atom.

Scientists have pieced together a timeline of the expansion of the universe using their understanding of the laws that govern all matter. You can see this timeline below.

Time	Description of Universe	Average Temperature of Universe
0	the universe is packed into a singularity (a tiny, infinitely dense point)	
less than .01 seconds	fundamental particles form, such as electrons, positrons, and neutrinos; radiant energy is released	100 billion *C
1 second	protons and neutrons form; radiant energy is released	10 billion *C
1.5 - 10 minutes	nuclear fusion begins; helium and deuterium nuclei form	below 1 billion *C
300,000 years	stable atoms form	a few thousand *C
1 billion years	the oldest stars form; clouds of gas begin to form galaxies	?
today (about 14 billion years)	today's universe is filled with galaxies	-275 *C

23. Identify: When did electrons, protons, and neutrons form?

24. Identify: For how long was nuclear fusion able to turn deuterium nuclei (hydrogen) into helium? Show your calculations.

Within the first second of the Big Bang, the temperature in the universe had dropped enough for protons, electrons, and neutrons to form. By 100 seconds into the Big Bang, the temperature had fallen enough for nuclear fusion to occur. Neutrons and protons began to stick together to form the nuclei of **deuterium**, a type of **hydrogen.** When the deuterium collided with other deuterium, they began to form **helium.** Occasionally, the collisions continued and were able to form another element, **lithium.** While these collisions were occurring to form the elements **hydrogen, helium, and lithium**, the universe was continuing to cool. Within ten minutes, the universe was so cool that nuclear fusion could no longer occur. Scientists have concluded that this early universe was about 95% hydrogen, 5% helium, and a just trace amounts of lithium.

25. Active Reading: Underline the sentence that answers the question, *Why did nuclear fusion stop in the minutes after the Big Bang?*

26. Identify: What three elements were formed within the first minutes of the Big Bang?

Obviously, humans were not around to measure the composition of matter in the early universe. But scientists can calculate what they would *expect* to find in today's universe, if the big bang theory were accurate. If their calculations of the expected composition of matter in our universe match up with what we actually see in our universe today, their measurements of the early universe as 95% **hydrogen** and 5% **helium** are probably accurate.

So is that the case? Do the scientists' calculations match up with the conditions of the universe we can measure today?

Yes, they do. When scientists calculate the expected ratio of **hydrogen** to **helium** in the modern universe based on the conditions of the early universe described above, they arrive at a number that almost exactly matches what they can observe today! This provides the third line of reasoning to support the big bang theory.

27. Active Reading: Underline the sentence that answers the question, *How do scientists confirm that the early universe was made of 95% hydrogen and 5% helium?*

28. Conclude: How can scientists use the composition of matter in today's universe to support the big bang theory, which describes a universe with 95% **hydrogen** and 5% **helium** in its infancy?

<u>Evidence for the Big Bang Theory: Cosmic Background Radiation</u>

As we have learned, the **big bang theory** states that the universe was once condensed into an infinitely small point, and it rapidly expanded and cooled in a very short period of time. Immediately after the "explosion" of energy, the universe was too hot to contain atoms. They would have broken up. As it cooled, nuclear fusion began to occur. For less than ten minutes, hydrogen nuclei were able to fuse together into helium atoms. As these atoms formed, they released energy uniformly throughout space.

Had we been there, we may have seen this energy released as light. However, as the universe has expanded, those light waves have stretched -- or been *redshifted* -- into radio waves. They are just reaching us now -- 13.7 billion years later.

In 1964, a scientist named Arno Penzias detected this energy, which is called **cosmic background radiation.** It began traveling through space when the universe was only 300,000 years old, but now it fills all areas of the universe. The **big bang theory** is the only current theory that explains the presence of **cosmic background radiation** in our universe, and so it is an important piece of evidence to support the idea of a "big bang."

29. Active Reading: Underline the sentence that explains why atoms did not exist immediately after the “big bang.”

30. Define: What is cosmic background radiation?

31. Identify: Why is cosmic background radiation an important piece of evidence to support the **big bang theory**?

<u>Conclusion: Evidence for the Big Bang Theory</u>

Evidence	What does it tell you about the “big bang”?
The light from other galaxies is red-shifted.	
The farther away a galaxy is, the more its light is red-shifted.	
The composition of the universe today (the amount of hydrogen and helium in it) matches what scientists would predict if the **big bang theory** were indeed accurate.	
Cosmic background radiation exists.	