Astrochemistry

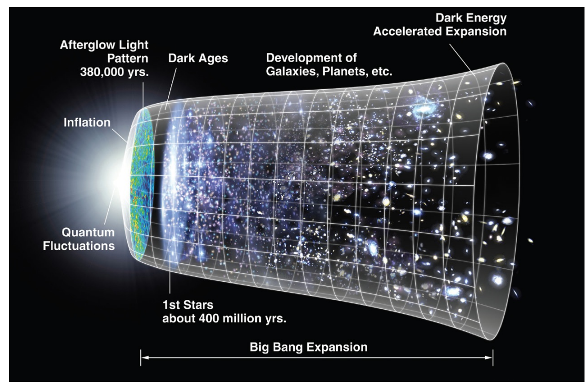
Learning Goals/Success Criteria: *At the end of this lesson, I will be able to:*

- ☐ Describe where the first elements came from
- ☐ Calculate the age of the universe based on redshift data

The amazing thing is that every atom in your body came from a star that exploded.
And, the atoms in your left hand probably came from a different star than your right hand.
It really is the most poetic thing I know about physics: You are all stardust.
— Lawrence M. Krauss, A Universe from Nothing: Why There Is Something Rather Than Nothing

News Flash: Birth of the First Elements!

The primordial (early) universe was a very eventful place. It was an incredibly hot, dense environment that cooled rapidly as the universe expanded. Three minutes after the Big Bang, the universe had cooled enough for nuclear fusion to take place. This led to the creation of the first atomic nuclei through a process called **primordial nucleosynthesis**. How did these first nuclei form in the early universe? Which elements were created? What ratios were all the elements present in?



Timeline of the Universe

Summary of the Facts

Conclusion

How were the first atomic nuclei formed after the Big Bang? Which elements were created, and how much of each element was there compared to other elements?

The Signature of the Stars

Rainbows reveal that white light is a combination of all the colours. In 1666, Isaac Newton showed that white light could be separated into its component colours using glass prisms. Soon scientists were using this new tool to analyze the light coming from several different light sources. Some scientists looked at hot objects and gases; others looked at the stars and planets. They all made observations and detected patterns, but it took about 250 years for scientists to understand the connections.

Part 1: Every Element Has a Unique Signature.

Every element *emits* a unique range of colours called an **emission spectrum**. A similar spectrum is produced when light shines through a gas; however, in this case certain colours, or wavelengths, are *absorbed* by the gas. An **absorption spectrum** is the pattern of colours and dark lines that is produced when light shines through a gas and the gas absorbs certain wavelengths. This is the same pattern that occurs in the emission spectrum for the same medium. **Figure 1** shows some simplified absorption spectral lines.

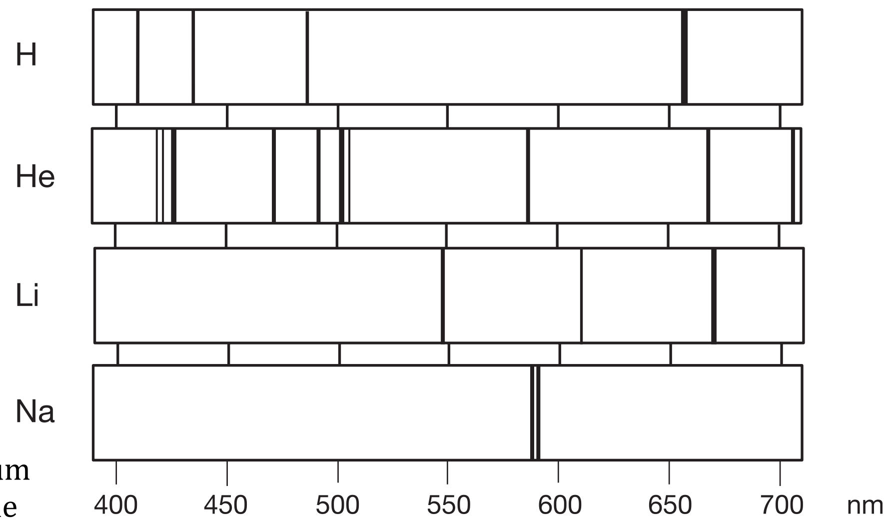


Figure 1 The lines indicate the wavelengths of light that are missing from the light after passing through the sample. The weight (thickness) of the lines indicates the amount of light absorbed at that wavelength. The heavier (or thicker) the line, the more light is absorbed.

1. Scientists can use absorption spectra to analyze unknown substances. Identify the elements present in the sample that produces the spectra in **Figure 2**.

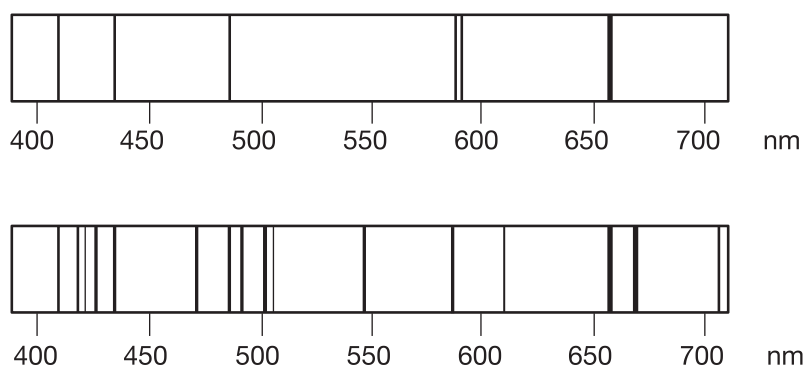


Figure 2 Simplified absorption spectra

Part 2: The Light from Stars Contains Information.

The core of a star is very hot (~15 × 10^6 K), and very hot objects glow. The light produced by a star's core contains all the colours in the spectrum. Astronomers can learn many things about a star's motion, temperature, and composition by analyzing the starlight that reaches Earth. A **spectroscope** is an instrument that separates light into its spectrum. One of the earliest uses of the spectroscope was to analyze light coming from astronomical objects. The light directed from a telescope through a **spectroscope** produces an image called a **spectrograph**.

<u>Part 3: The Spectra from Galaxies Are Redshifted.</u>

In 1912, American astronomer Vesto Slipher began to observe more distant objects using a spectrometer, and he noticed that most of them had a distinct shift toward the red end of the spectrum. He recognized this as a Doppler shift caused by the motion of the objects. A redshift means that the source of light is moving away from the observer.

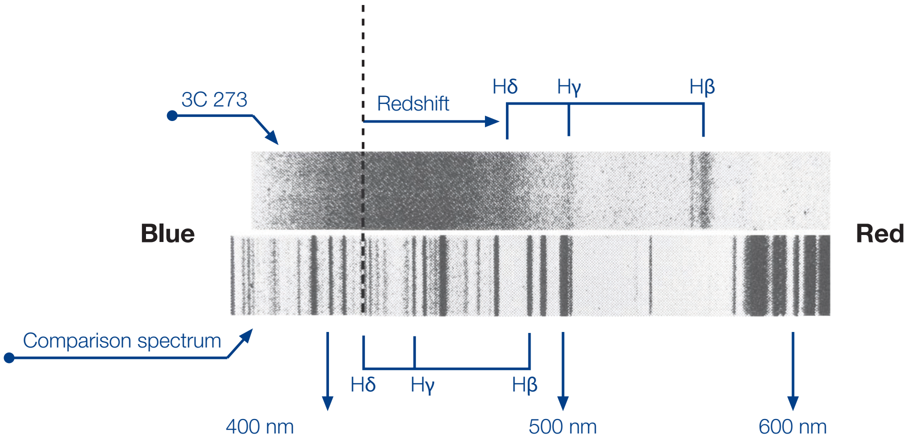


Figure 3 Redshifted spectrum from quasar 3C 273

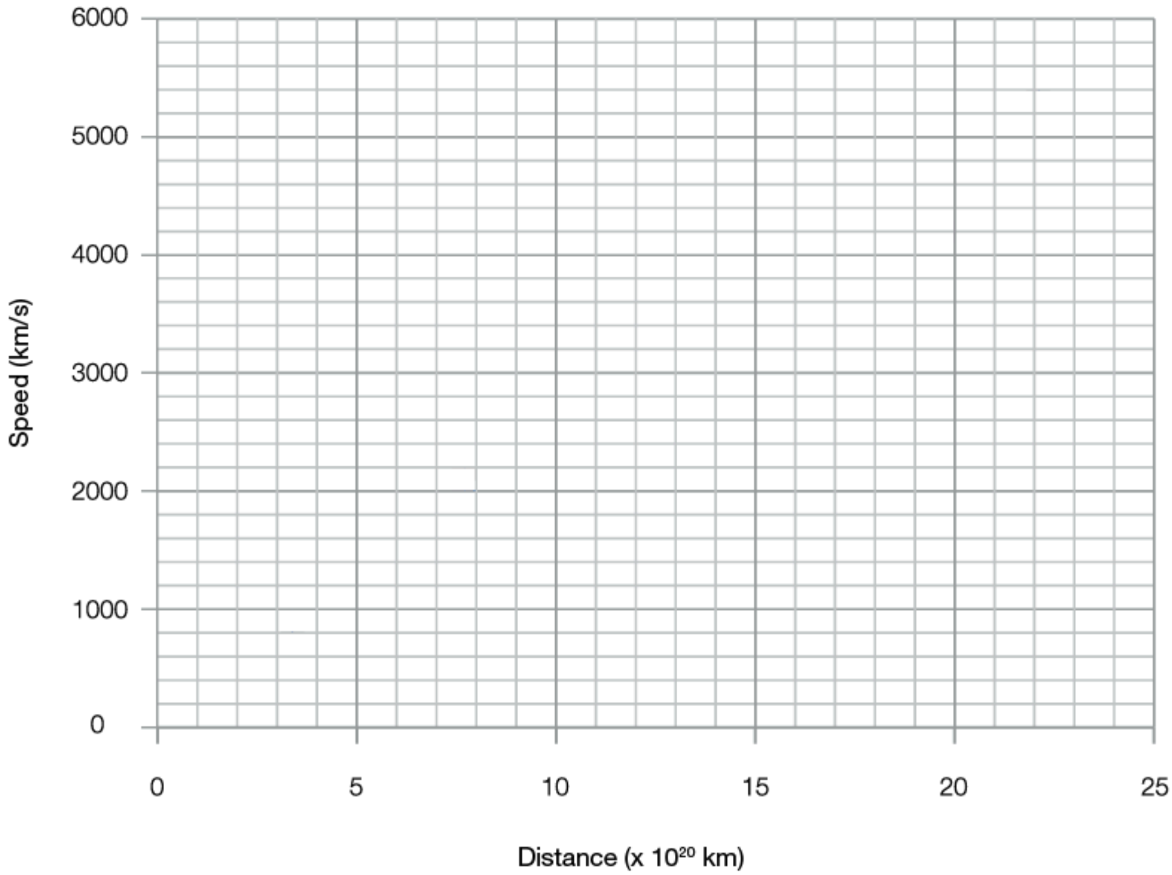
Figure 3 shows an emission spectrum from the quasar called 3C 273. We see that the emission lines due to hydrogen are shifted to the red end of the spectrum. The larger the redshift, the greater the relative motion.

2. Edwin Hubble extended this observation to more objects, and for several objects plotted the redshift versus the distance to the object. Try it for yourself. In Table 1, use the redshift of the spectral lines to determine the speed of each galaxy. To do this, use a ruler to align the leftmost spectral line provided with each galaxy with the speed scale at the bottom of the table.

Table 1

Galaxy	Distance (x 10^{20} km)	Calcium Reference Lines 395 400 405 nm	Speed (km/s)
NGC 1357	7.7		2100
NGC 1832	8.2		
NGC 2276	11.4		
NGC 3147	13.6		
NGC 3368	3.4		
NGC 3627	3.1		
NGC 4775	8.2		
NGC 5548	22.1		
NGC 6764	10.0		
NGC 6745	19.7		
Speed scale (km/s)		0 2000 4000 6000	

3. Plot the speed of each galaxy in Table 1 on the y-axis and the distance to the galaxy on the x-axis. Draw a line of best fit.



4. Calculate the slope of the line. What is the unit for the slope?

5. The slope of this line is called the **Hubble constant**, H_0. Write the equation for this line using H_0 as your slope. What does it tell you about the relationship between the speed of galaxies and their distance? This relationship is called **Hubble's law**.

6. The age of the universe, T, can be approximated by taking the reciprocal, or inverse, of H_0. Take the reciprocal of your slope. How old is the universe (in years)?