The Signature of Stars

Would you pick up a glowing red piece of metal? Of course not—you know that any object that glows red is probably very hot. You learned as a young child that hot objects glow, but did you know that everything glows? In fact, you are glowing, but you aren't warm enough to emit a colour of light that your eyes can detect. We can learn about the infrared light that you emit using special cameras, like the one in an ear thermometer.

Another way to study light is with an instrument called a spectroscope, or spectrometer. A **spectrometer** spreads light out into a continuous rainbow, or spectrum. Astronomers study astronomical objects with spectrometers. Each object produces a unique spectrum that is often called its signature or fingerprint. By studying starlight, for example, we can discover many properties about stars.

Figure 1 - How can you tell these objects are extremely hot?

Spectrum = Content

When astronomers look at stars, the light they see was emitted by a very hot core. The core is so hot that it produces a complete spectrum of light, and that light travels through the layers of gas in the star. As light makes its way to the surface, it collides with the gases in the outer layers. Each collision changes the light slightly. By the time the light leaves the star, it contains a description of what elements are in the star. Knowing which elements are in the star allows astronomers to estimate how old the star is and where it came from.

Some stars, such as our Sun, have lots of metals in them (Figure 2). These metals were produced by a different star that exploded in a supernova billions of years ago, seeding the nebula in which the Sun formed. Older stars have less metal because either they formed before the nebula was seeded by a supernova, or they formed in an area where no supernovas had happened. Astronomers theorize that there were stars very early in the universe that contained only hydrogen, helium, and lithium, but they have all since burned out, contributing to subsequent populations of stars.

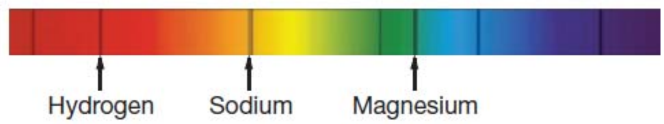
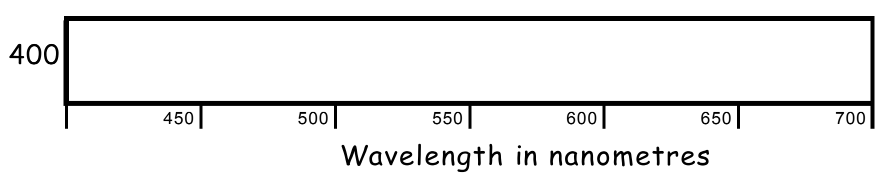


Figure 2 - This is a spectrum of the Sun. The dark bands are called absorption lines–each element in the Sun's outer atmosphere absorbs a certain wavelength (colour) of light, represented by the absorption lines. Some of the metals in the Sun are shown here.

Part 1 – Spectrum Observations

You will be exploring light in much the same way as the scientist do. An important part of scientific understanding comes from making and recording careful observations. This will be an important part of your scientific discovery and information gathered will be used throughout this activity. Using a spectroscope, look at as many light sources as you can find. When doing a spectral analysis of a light source, try to be as close to the light source as possible or darken the room. This prevents "contamination" from other light sources. Be sure to carefully colour in the exact spectrum you see above the corresponding numbers (wavelengths of the light waves). Start with looking at sunlight.

Light source: ______________________________



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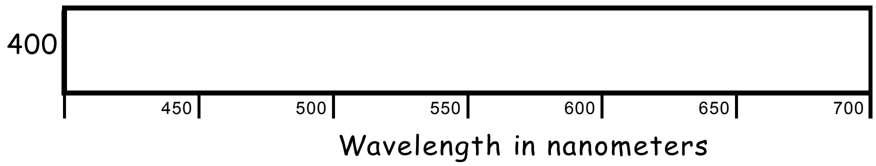

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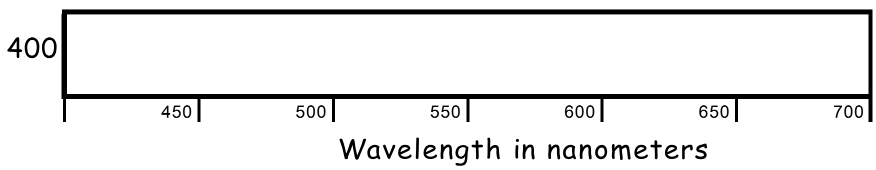

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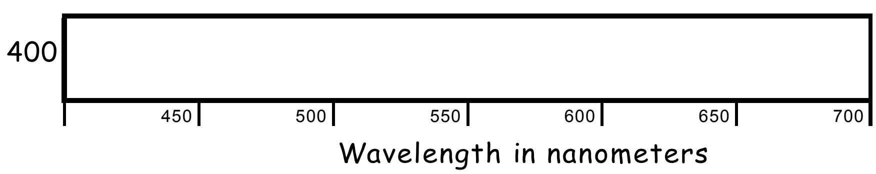

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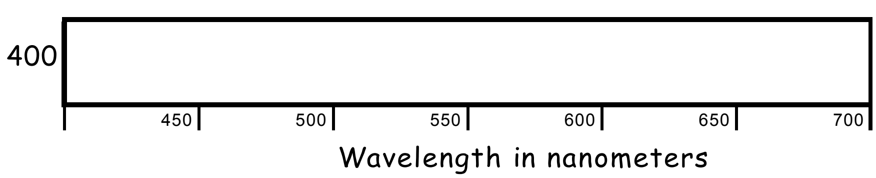


Part 2 - Every Element Has a Unique Signature

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.

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.

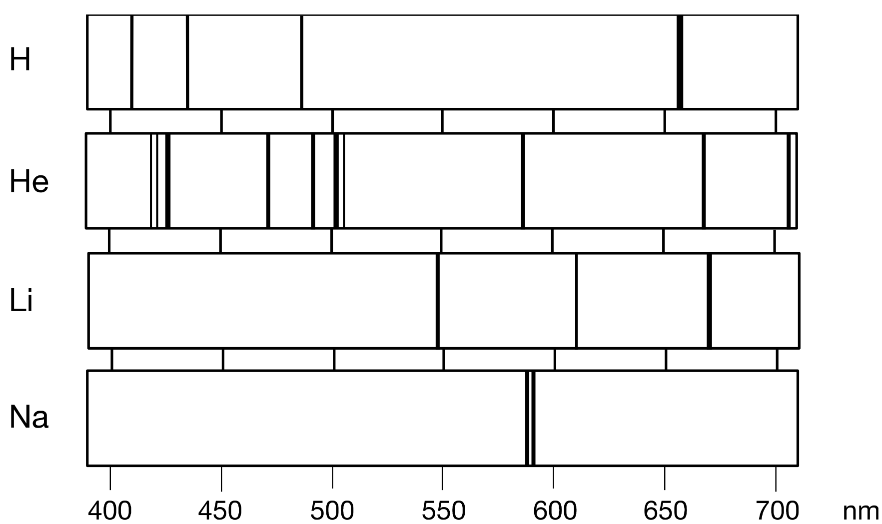


Figure 1 - The lines indicate the wavelengths of light that are missing from the light after passing through the sample. The weight (thickness) of the lines indicates the amount of light absorbed at that wavelength. The heavier (or thicker) the line, the more light is absorbed.

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

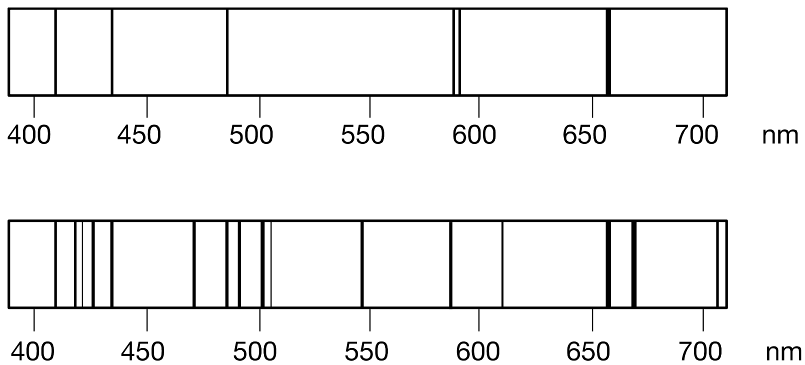


Figure 2 - Simplified absorption spectra.

Part 3 - The Light from Stars Contains Information

The core of a star is very hot $(\sim 15 \times 10^6 K)$, 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**. See Figure 3 below.

Wavelength (nm)

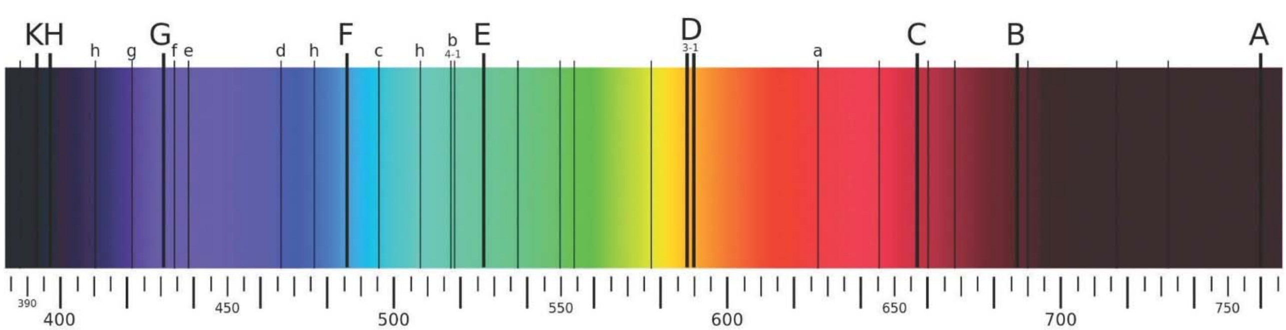


*Figure 3 A spectrograph of the Sun. **Note:** The lettered lines represent different elements. Lines A and B are due to terrestrial oxygen and are not due to the Sun.*

2. What do the dark lines in Figure 3 indicate?

3. Use Figure 3 and the simplified absorption spectra in Figure 4 to identify which elements are in the Sun, that is, which element each letter in Figure 3 represents (except for A and B).

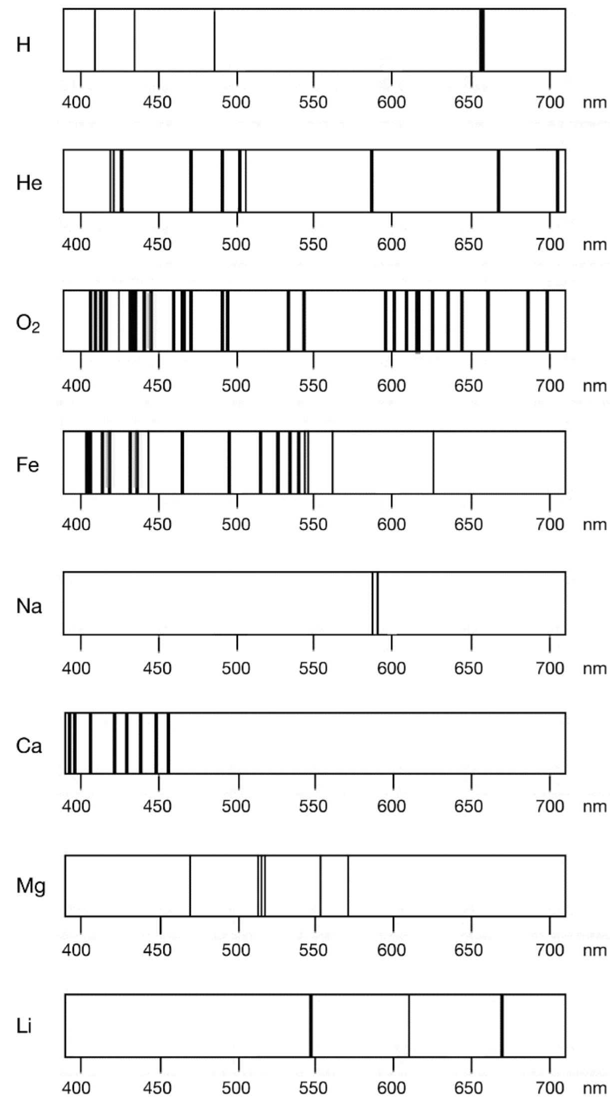


Figure 4 - Simplified absorption spectra.

Part 4: The Spectra from Galaxies Are Redshifted

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.

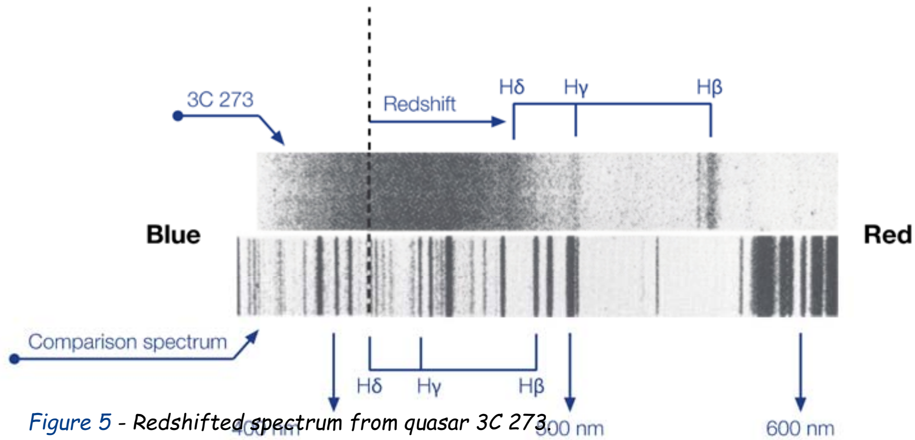


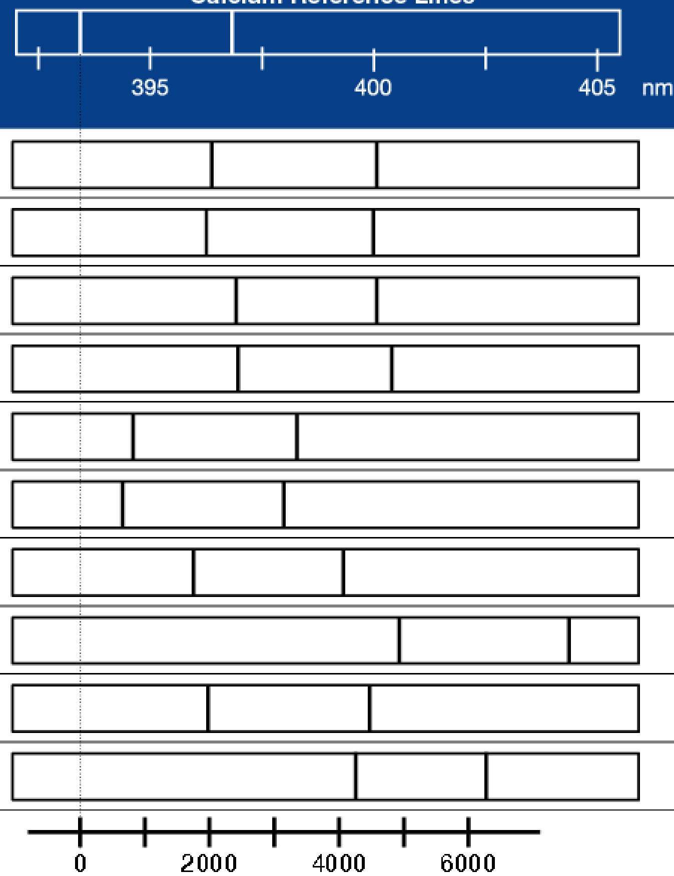
Figure 5 - Redshifted spectrum from quasar 3C 273.

Figure 5 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.

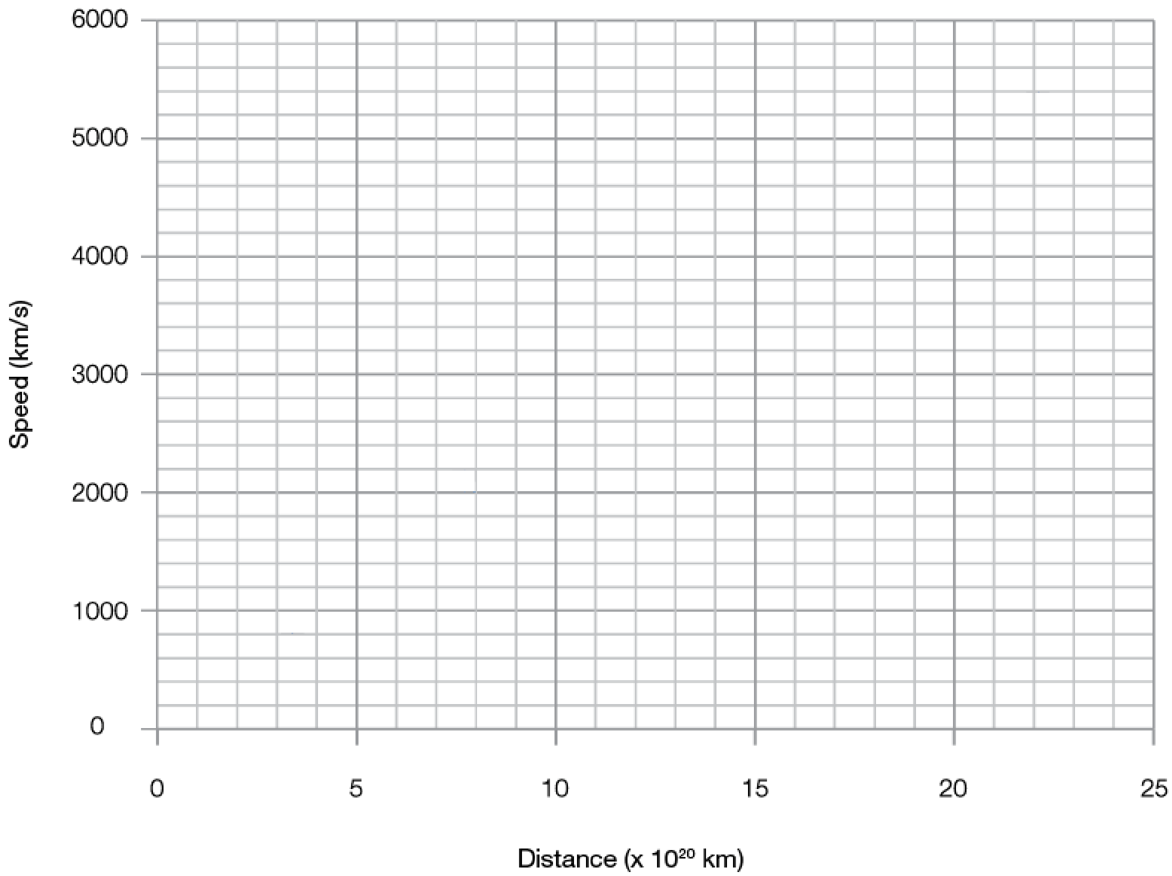
4. Edwin Hubble extended this observation to more objects, and for several objects plotted the redshift versus the distance to the object. Try it for yourself. In Table 1, use the redshift of the spectral lines to determine the speed of each galaxy. To do this, use a ruler to align the leftmost spectral 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	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)			



5. 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.



6. Describe the relationship between the speed of the galaxy and its distance.