# What Are Stars Made Of?

Tools used in this lab:

* PhET simulation of discharge lamps
* NAAP Astronomy Simulation: hydrogen simulator
* Image: periodic table of spectra

## Course Outcomes Met

1. Communicate scientific issues effectively in oral and written form;
2. Effectively collect, analyze and present data and correctly construct and interpret charts, graphs and tables to draw scientific conclusions;
3. Apply the fundamental concepts and methodologies of physics and/or chemistry to investigate a scientific theme.

**Strategy**

First, get a feel for the phenomenon using the hydrogen atom as a model. Then collect some experimental data and use it to deduce some general laws. Finally, apply those laws to stars to determine what they are made of. Since we do not have the equipment to do actual experiments with the required precision, we will use simulations.

## A. Atoms and Light

We’ve seen how the temperature of a star can be determined generally by its color and precisely by looking at the wavelength at which its blackbody spectrum peaks. Astronomy is almost (but not quite) entirely a science based on light. Most of the time, if you cannot learn something about an astronomical object by looking at the light is has emitted, you cannot know that thing at all. In recent years, there have been some exceptions to this rule (neutrino astronomy, gravitational waves) but they all have to do with extremely high energy events, not the everyday lives of stars.

It might seem impossible to determine what a star is made of without going there to get a sample, but it turns out that stellar composition leaves a mark on the light from that star. First, we are going to look at how atoms interact with light and see what we can learn about that process.

There are two key ideas: (1) the electrons in atoms interact strongly with light; and (2) the orbitals that electrons follow around the nucleus cannot be just any orbitals. There are specific orbitals that are at least temporarily stable, and electrons jump from one to another like going up and down the rungs of a ladder.

We’ll start with the NAAP hydrogen atom simulator. Open the NAAP labs and select number 8. Hydrogen energy levels, then select Hydrogen Atom Simulator.

There are a lot of things going on here, so lets just look at them one at a time.

1. The big black window has the hydrogen nucleus on the right (red), a green electron next to it, and a set of circles that correspond to the allowed electron orbitals. This is very much an approximation to reality but it gets at the main points.

2. Beneath that is a box labeled Photon Selection. There are three scales that display the frequency, wavelength, and energy of the photons you’ll work with. These are three different ways of looking at the same thing since the energy of a photon depends only on its frequency, and the frequency and wavelength are related because when you multiply them you get the speed of light, a universal constant.

Underneath the scales is a slider you can use to select any photon energy in the range of the scale, with indicators showing whether that photon is visible, infrared or ultraviolet (see the appendix to the How Hot Are Stars activity to remind you of where these ranges are on the electromagnetic spectrum).

At the very bottom are some buttons that allow you to select very specific energies. Each of these is a series of lines in the hydrogen spectrum that were named after their discoverers before anyone understood what was going on in the atom. The L’s are the Lyman series, the P’s are the Paschen series, and the H’s are the Balmer series.

Once you have selected a photon energy, you can fire it at the atom.

3. The box in the upper right is a diagram showing the energy levels of the atom. Each line corresponds to the energy[[1]](#footnote-1) of a different electron orbital. The bottom one is called the **ground state** (the lowest possible energy) and the rest are **excited states**. The energies are negative because they are bound states. An electron with a positive energy would be moving freely, not bound to the atom.

4. The last box on the lower right records each experiment you do and what the results were so you can refer back. It tells you whether a photon was absorbed by the atom (excitation) or emitted (de-excitation), which orbitals the electron changes between during that process, and the energy of the absorbed or emitted photon.

All science starts from playing around with the phenomenon. I know in middle school you were told it starts with a hypothesis but it doesn’t. Hypotheses emerge from experience. So let’s just play around with it for a while.

1. Let’s start with what is historically the second part of the spectrum to be discovered, the Lyman series. Try each of the Lyman series photons and observe what happens to the atom. What happens to the electron when it absorbs the Lyman series photons?

2. What happens to the atomic energy levels when the atom absorbs the Lyman series photons?

3. Does the atom that has absorbed a photon stay at an excited state? What happens to it?

4. Try the Lyman series photons several times. Does the exact same thing happen to the electron each time? Explain.

5. How are the orbitals and energy levels related?

6. How are the photon energies related to the energy levels? There is a simple mathematical relationship but you might have to play around a bit to discover it. The is useful information in the event log, especially photon energy.

7. Try the Balmer (H) and Paschen (P) series. Do they do anything? Try a Lyman first and, while the atom is still excited, follow it with a Balmer or Paschen before it falls back to the ground state.

8. In the event log, you can see the energies of each of the photons in these experiments. Use the slider to set the photon energy to one of these and press the fire photon button. Does it do what you expected? Now try setting it to a slightly higher energy and then a slightly lower energy. What happens? Can you explain why?

9. What happens when the photon energy is greater than 13.6 eV?

**Discuss your findings with your instructor at this point**

## B. Spectra of other atoms

You never get to experiment with just one atom. Instead, you’ve usually got a ton of them, each getting into its own special excited state and emitting its own special photons while colliding with other atoms.

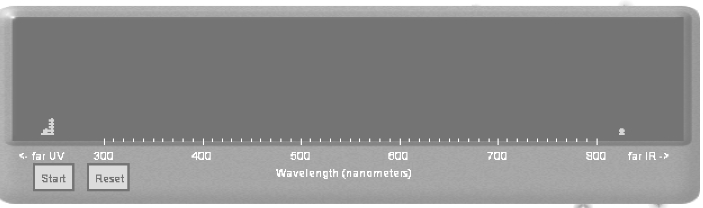
A spectrometer is a device that uses either a prism (very rare these days) or a thing called a diffraction grating (way easier to make, way cheaper and way more precise) to spread out the light according to wavelength (for visible light, the same as according to color). Each particular wavelength is bent through a specific angle so you can use the angle to measure the wavelength. The light is usually passed through a narrow slit first, so what you see is a pattern of lines that are all images of the slit in different wavelengths.

So let’s use a simulated spectrometer to look at the light from some atoms. Use the PhET simulation of discharge lamps found here: <https://phet.colorado.edu/en/simulation/legacy/discharge-lamps>

A discharge lamp passes an electric current through a gas filled tube to generate light. A current is a stream of electrons that have a certain range of energies depending on the voltage of the source.

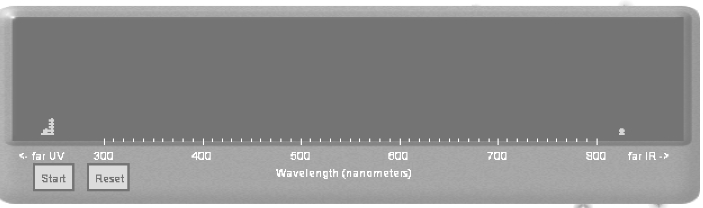
1. Check the boxes for spectrometer and squiggles and let it run for a while. In the hydrogen atom sim, you got the atom into an excited state by firing photons at it. How is this atom being excited? Now we have two ways to get an atom into an excited state. Try higher electron production rates and see what happens. The checkbox “Run in slow motion” can help you to see the less frequent events that happen at a high productions rate.

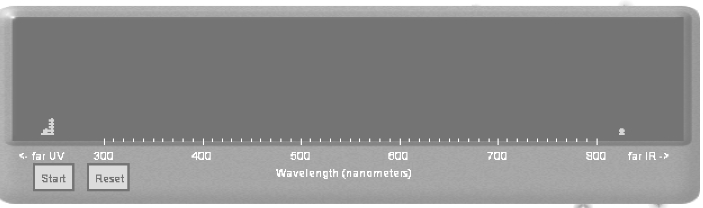
2. It takes a long time to build up a spectrum from a single atom, and that isn’t how the real world works anyway. So change to the Multiple Atoms tab, turn on the spectrometer again, and select hydrogen, since we have already looked at it. Let it run for a minute or so and copy the spectrum here:



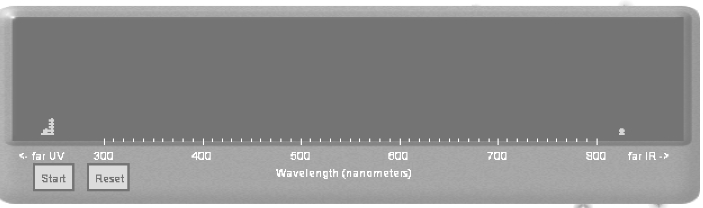
Why do you think there are only specific colors at specific wavelengths? How is the spectrum connected to what you previously observed going on in the atom?

3. As it happens, the spectral lines in the visible are the Balmer series. The Lyman series is in the ultraviolet and the Paschen series is in the infrared (these are shown as gray lines). Let’s see if we get the same thing from other elements. Record the Mercury spectrum here. You’ll have to reset the spectrometer after choosing Mercury.



4. Now try Sodium.

5. And Neon.



6. At the very bottom of the screen is a button you can click to view actual pictures of the discharge lamps. Can you explain why they have the colors they do? Is it the same reason we saw with star spectra in the How Hot Are Stars activity?

7. Why do you think the spectra of these elements look so different? What does it tell you about the electron orbitals inside these atoms?

8. Comparing all these spectra, do any of them have the same pattern of lines? Are there any lines in common that are exactly the same wavelength?

9. On D2L, you’ll find an image called Periodic Table of Spectra. It contains small versions of all the spectra from all the elements we have access to (some are very radioactive and don’t live long enough to get a spectrum). Do any two look the same? Based on what you’ve learned about the relationship between spectra and what is going on inside the atom, could you make a guess as to why?

**Discuss your findings with your instructor at this point**

## C. Stars at Last!

1. Here are the spectra of three different stars. Their names have been changed to protect the innocent. Following them are the spectra of several elements taken in the lab. For each star, which of these elements would you say are present in it? Explain your reasoning. Using a ruler or the edge of a sheet of paper will help.

Made up star spectrum alphaStar Alpha

Made up star spectrum BetaStar Beta

Star Gamma

Made up star spectrum Gamma

Carbon

Spectrum of carbon

Nitrogen

Spectrum of nitrogen 

Oxygen

Spectrum of Oxygen

Xenon

Spectrum of Xenon

Hydrogen

Spectrum of Hydrogen

Helium

Spectrum of Helium

B. What do you think the background smear is in each of the star spectra? (Hint: there are similar spectra, in color, in the How Hot Are Stars activity.)

C. Why do you think the lines in the star spectra are dark on a bright background whereas the lab spectra are bright on a dark background? Think carefully about what you’ve learned about the relationship between spectra and what electrons are doing inside atoms.

**Discuss your findings with your instructor at this point**

1. There are several units that can be used for energy measurements. Joules are the most common, but atomic energies are tiny, tiny fractions of a Joule. For that reason, it is convenient to use a much smaller unit, the *electron volt*, symbol eV. It takes 1019 eV to equal 1 Joule. [↑](#footnote-ref-1)