

Line Spectra Demonstration

Learning goals:

- Introduce the electromagnetic spectrum
- Learn the meaning of diffraction
- Learn that certain elements have certain spectral signatures, which allows us to identify different materials (stars, planets, etc)

More advanced topics to cover:

- Spectra result from atoms getting excited by collisions and electricity in the gas discharge tube so they emit light.
- Everything emits radiation, including students themselves (but it's in the Infrared which is why we can't see it without a thermal camera)
- Neon, fluorescent, etc. lighting emit discrete spectra, while incandescent bulbs emit continuous spectra

Materials:

- Gas discharge tubes & power supply
- Diffraction gratings
- Handouts
- Pens/pencils

Procedure:

We will begin as a group for about 5 minutes and have a 'lecture' format with the students. We'll introduce ourselves – name, class year and research interests – and why we're looking at line spectra today (ability to determine composition elsewhere, etc)

Then we'll break off into 3 groups i.e. 2 undergrads in each group.

As a subgroup:

Begin by asking students if they've ever seen rainbows from a CD. If they say no, don't worry. Tell them they'll get to see the effect you were describing, but even better.

Hand out diffraction gratings and a handout to each student. Explain to them that a diffraction grating is something that has lots of little grooves on the surface. Their gratings have 1000 lines/mm, i.e. 19000 lines on their tiny grating! The small spacing between grooves allows incoming light to be cut, as it goes through the grating. This 'cutting' of the light is known as **diffraction**.

The cool thing about the diffraction grating is that you can see how the incoming light has been cut up into different parts, which are different colors. Different colors come from something known as **wavelength**, which is a property of waves of light and all light can be thought of as waves. The wavelength representing each color in the visible spectrum is found on their grating. Spend a few minutes going over the concept of the electromagnetic spectrum – radio, ir, uv, visible, etc. Make the analogy of wavelengths and colors to that of different frequencies for different radio stations.

Now take time to have them look at familiar objects (ceiling lamps, etc) to see the beautiful rainbows that are produced. The 'split' light output of the gratings are known as **spectra**. Point out that looking at things of different composition will look different. Possibly mention the issue of discrete vs.

continuous spectra if there are different lamp types present.

Now introduce the gas discharge lamps. Tell them that they'll be able to see how different elements have different spectra. Start off by showing them a spectra (Neon for example). Tell them to look at the tube through their grating and point out that there are individual lines of light, in only a few colors! This is unlike what they saw in the rainbows produced by white light. Then ask them to identify the element responsible for the light by comparing what they see to the chart on the table or in their handout. Repeat the looking and finding spectra on the chart several times. Things to point out are:

Neon – Element in the signs you see all the time.

Helium – Was identified in the sun before found on Earth, just by looking at the spectra. Hence the name (helios -> helium)

Hydrogen – Lines seen could be predicted by the laws of physics nearly a century ago.

*Remember gas discharge tubes get hot after being in the power supply. Use a paper towel or the like to change tubes.

Water- note that the spectrum is a combination of hydrogen and something else.

From looking at the tubes, we can see that different elements and compounds (like H₂O) look different. That's why spectra are so important in astronomy. Since we can't always go to other planets and stars to test what's in them, we can look at these objects with machines based on the principle of the diffraction grating to see what they're made of. This technique would allow us to know which planets out there in the universe could have the chemicals necessary to sustain life.

Demonstrator's Summary – Line Spectra

Description: The students view several gas discharge tubes (hydrogen, helium, neon, and water vapor) through hand-held diffraction gratings, allowing them to see the spectral lines associated with each gas.

Physics (8th Grade-Level): A gas discharge tube is a glass tube with an electrode attached to each end (a cathode and an anode). When a voltage is applied to the two electrodes (and the pressure of the gas in the tube is reduced), a current flows between them and the gas begins to glow. This light results from collisions between atoms in the gas and electrons of the current, which accelerate away from the negative electrode and toward the positive electrode. When such an electron collides with a gas atom in its path, it may transfer some of its energy to the gas atom, producing a gas atom in an excited (high-energy) state. The excited gas atom does not remain in a high-energy state for long. It can return to its lowest-energy state, the ground state, by emitting its excess energy as light. Because atoms and molecules can exist only in certain specific energy states, the energy emitted by the excited atom is limited to differences between these states; only certain energies of light are emitted. The color of the glow is determined by the energy of the emitted light.

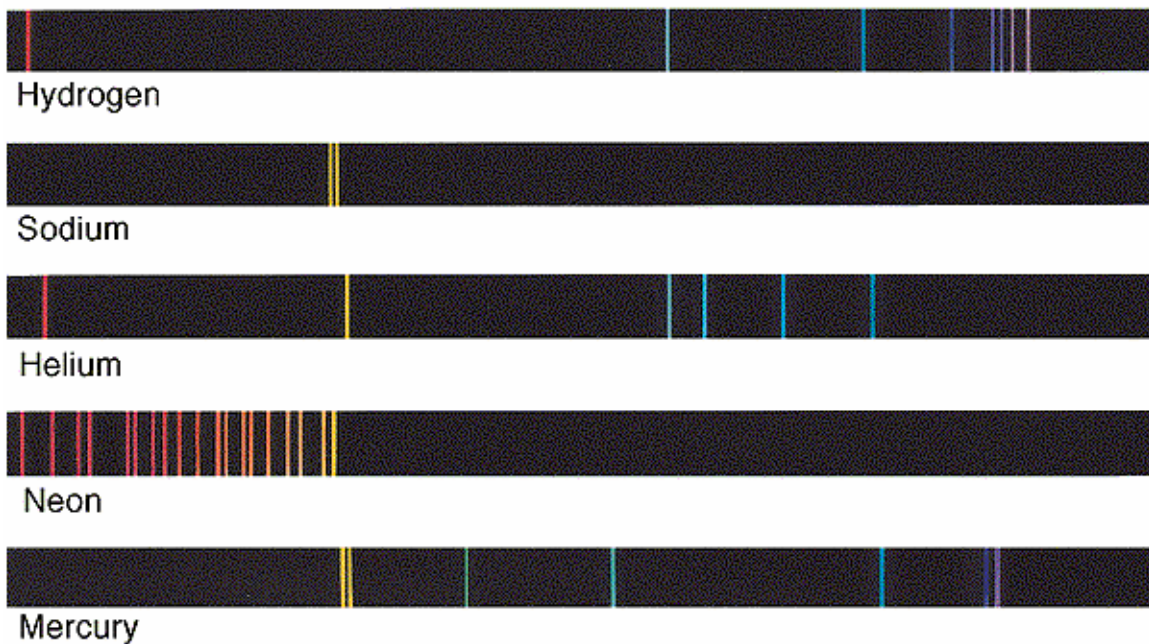
A diffraction grating has a surface covered by a regular pattern of parallel lines (separated by a distance comparable to the wavelength of visible light). Light rays passing through the grating then undergo diffraction (similar to a water wave that passes around an object placed in the water). This leads to interference that causes the light rays to be bent by a characteristic angle. This angle depends on the light's wavelength (i.e., energy), which explains why the gratings separate out the light of various energies produced by the gas discharge tubes.

Relation to Astronomy: The lines observed in this demo are known as an “emission spectrum”, because they result from light emitted by the gas atoms. In a very similar way, gas atoms can absorb light that has been produced by another source, which leads to an “absorption spectrum” (a continuous spectrum with a few missing lines). Both emission spectra and absorption spectra are used to identify the atoms and molecules that make up astronomical objects, such as stars, dust, and interstellar gas. Astronomers look at these spectra and match the lines they see with the lines of atoms and molecules that have already been observed. In fact, helium was first discovered in an emission spectrum of the Sun before its presence on Earth was known.

Other Information: In contrast to these discrete spectra (individual lines), one can observe a continuous spectrum by looking at an incandescent light bulb. This is because incandescent lamps operate by heating a tungsten filament so hot that it glows, which is a very different process than that used in the gas discharge tubes. Moreover, this process is much less efficient than that used in the gas discharge tubes: only about 18% of the energy consumed by a typical 100-watt incandescent light bulb is converted into visible light, while gas discharge tubes convert over 50% of the energy they consume into visible light. The inefficiency of incandescent light bulbs is the major reason that they are being phased out in favor of new, more efficient types of lighting (e.g., fluorescent).

Line Spectra Matching

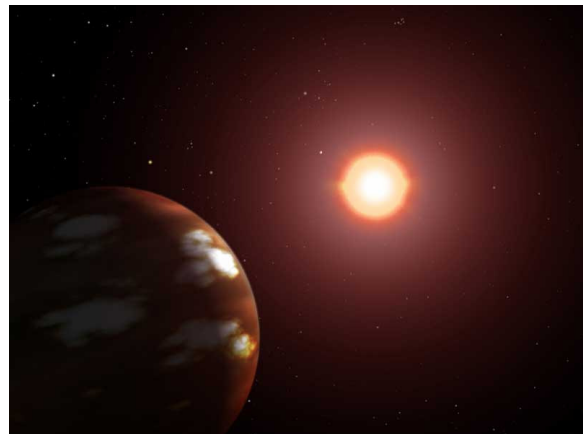
Can you match the line spectra below to those that you are observing?
Beware of the extras!



Astronomers use line spectra like these every day to determine the atoms and molecules that make up astronomical objects, such as stars and interstellar gas. They simply match the lines they see with the lines of atoms and molecules that have already been observed. Helium was actually first discovered in a spectrum of the Sun before it was found on Earth. Soon, we may discover planets around other stars with the elements necessary for life!



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