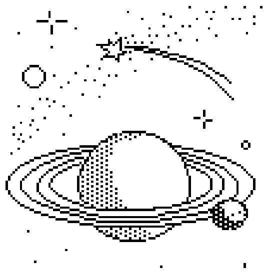
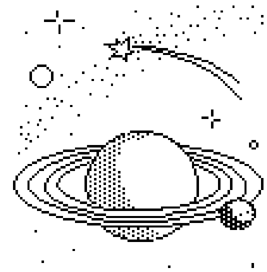


Physical Science 21

Laboratory



Lab 5: Spectra, Fingerprinting the Elements

Before coming to lab: Read Chapter 2.1 to 2.9 (on pages 30-36) and particularly Chapter 3.2 to 3.5 (on pages 63-67) of Astronomy (6th ed.) by Dinah Moché.

Objectives: This lab will introduce spectra, an important tool of astronomy. It will show that each element has a characteristic spectrum, which is unique to that element. Astronomers can therefore use spectra to tell what stars are made of—without having to travel to the stars. This lab will also show the difference between continuous, emission, and absorption spectra, which are made by planets, nebulae, and stars, respectively.

Introduction: When white light passes through a prism, it breaks down into its component colors. A rainbow is an example of this in nature: after a rainstorm, the air is still full of drops of water, which break sunlight down into its colors. This band of colors is called a spectrum. The plural of "spectrum" is "spectra." Using spectra to learn about light is called spectroscopy.

Gustav Kirchhoff and Robert Bunsen were two German chemists. (Bunsen invented the Bunsen burner, the gas burner still used in chemistry labs today.) In 1860, they found that different hot gases gave off different colors of light, which they could distinguish clearly in spectra. Kirchhoff summarized their findings into Kirchhoff's laws:

(1) Hot gas that is transparent, such as a nebula, gives off light of only certain colors. Often the gas emits only thin bands, or lines, of colors. This pattern of colors is called an emission spectrum, or bright-line spectrum. Gases of different chemical composition make different patterns of lines (emission spectra).

(2) A hot object that is opaque (not transparent to light), such as a planet, most solids, liquids, and dense gases, gives off a continuous spectrum. A continuous spectrum is just a continuous band of color with no lines, such as a rainbow.

(3) When a continuous spectrum shines through a transparent gas, dark lines appear in the spectrum. This is an absorption spectrum, or dark-line spectrum. An absorption spectrum can be thought of as a continuous spectrum, minus an emission spectrum. A star is made of gas that is held together by its own gravity. Because a star is dense and opaque inside, but is transparent outside, stars have absorption spectra.

Light has properties of both waves and particles. So do atoms and electrons: the realization that everything smaller than a molecule has properties of both waves and particles is a central finding of the modern science of *quantum mechanics*. In this experiment we will use both the wave and particle properties of light:

(1) Wavelength is the distance from one crest of a wave to the next crest. The symbol for wavelength is λ.

(2) The color of light depends on its wavelength. Visible light has wavelengths between 400 nanometers (for violet light) to 780 nanometers (for the deepest red the eye can see.) (1 nanometer = 1 nm = 1 billionth of a meter = 1×10^{-9} m.) White light is all the colors, mixed together. A spectrum made from white light has the colors red, orange, yellow, green, blue, and violet. (To remember the colors in order, remember ROY G. BV.)

(3) Particles of light are called photons. The energy, E, of a photon is related to its wavelength, λ, such that:

$$E = hc/\lambda$$

where h is Planck's constant and c is the speed of light in a vacuum. Notice that there is an inverse relation between energy and wavelength: high-energy photons have short wavelengths, and low-energy photons have long wavelengths. In other words, photons of violet light have higher energy than photons of red light.

To understand how we can "fingerprint" the elements, we need to know how atoms emit light. In 1897, J. J. Thompson showed that atoms are not indivisible, as was previously thought. Thompson found that atoms have inside them even smaller particles, which are now called electrons. In 1911, Ernest Rutherford found that nearly all the mass in an atom is concentrated in its center, which is called the nucleus. In 1913, Niels Bohr found that the electrons in an atom orbit the nucleus, in a way that reminded him of how the planets in the Solar System orbit the Sun. However, Bohr soon realized that the electrons can travel only in certain allowed orbits. This was the beginning of quantum mechanics: "quantum" means "an allowed amount."

Each of these orbits has an energy associated with it. An electron that orbits close to the nucleus has a low energy, and an electron orbiting far from the nucleus has a higher energy. If an electron jumps from a high-energy orbit to a low-energy orbit, it gives up its extra energy in the form of a single photon. This process is called emission, since the atom emits, or loses, energy. The energy carried away by the photon matches the difference in the energy between the two orbits. This photon has a wavelength, λ, corresponding to its energy E, such that $E = hc/\lambda$, as we've seen above.

The exact arrangement of the orbits and the energy differences between them differs, between atoms of different chemical elements. Each element therefore has a unique set of photons that it can emit. This gives each element its own spectrum: different elements show different patterns of lines in their spectra. Spectra can therefore reveal the chemical composition of things that make light, such as stars and nebulae.

Glass can bend light. The amount of bending, or refraction, depends on the wavelength of the light. This is how a prism separates white light into colors.

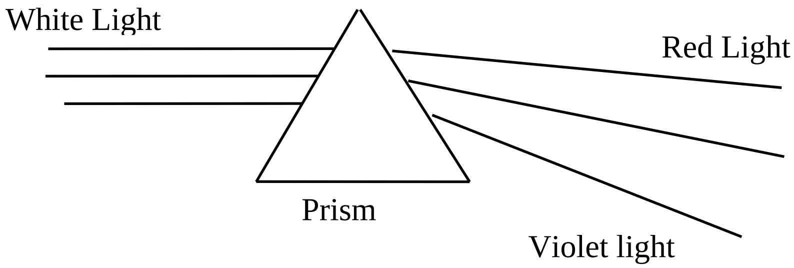


Figure 1. A glass prism disperses white light into a continuous spectrum.

A diffraction grating can also separate these colors. Gratings are easier to use than prisms, since they can be made into eyeglasses.

Procedure

Use your grating to look at an incandescent light bulb (such as in an overhead projector).

Which colors are bent most? ________________ Which are bent least? ________________

(Notice that the above diagram, while illustrative, won't necessarily work in every detail here, since we're using a grating, not a prism. This is to encourage you to try things out yourself, and to rely on your own observations!)

You will see either a continuous or a line spectrum. Which do you see? _______________

Now let's do some real spectroscopic identification of elements. In the lab, there should be several lamps of hot, transparent gas. Look at these sources with your gratings carefully. Make drawings of the lines on the form on the next page, and to try to maintain the relative separation of these lines. Most of the lamps will have labels on them that tell which gases they contain. One or two will not: use your drawings to identify the gases that made those spectra.

Mystery Lamp 1: _____________________ Mystery Lamp 2: _____________________

Are these emission spectra or absorption spectra? _________________________________

QUESTION: Hot opaque gas, such as inside a star, will produce a continuous spectrum. This light then travels through the transparent atmosphere of the star before it reaches us. Do you expect stars to have emission spectra or absorption spectra? __________________

QUESTION: Look out the window. Do the pink (or white) street lights (from mercury vapor lamps) have absorption or emission spectra? ________________________________

QUESTION: Look out the window. Do the yellow street lights (from sodium vapor lamps) have absorption or emission spectra? _______________________________________

Name: ______________________________

Day: Mon. Tues. Wed. (Circle one)

Time: 5:30 p.m. 7:30 p.m.

Drawing Spectra

Red	Orange	Yellow	Green	Blue	Violet

Element 1: ______________________________

Red	Orange	Yellow	Green	Blue	Violet

Element 2: ______________________________

Red	Orange	Yellow	Green	Blue	Violet

Element 3: ______________________________

Red	Orange	Yellow	Green	Blue	Violet

Element 4: ______________________________

Red	Orange	Yellow	Green	Blue	Violet

Element 5: ______________________________

Red	Orange	Yellow	Green	Blue	Violet

Element 6: ______________________________