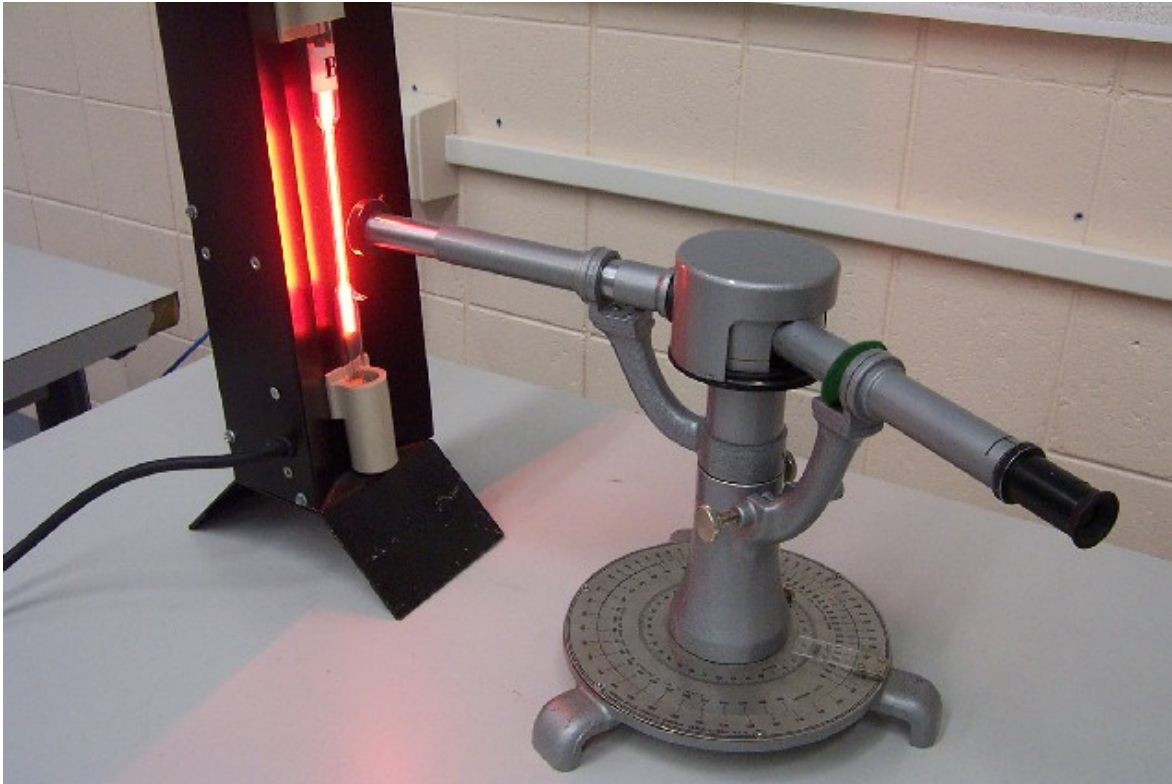


ATOMIC SPECTRA



Objective:

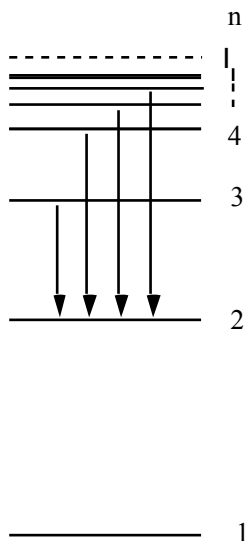
- To measure the wavelengths of visible light emitted by atomic hydrogen and verify the measured wavelengths against those predicted by quantum theory.
- To identify elements through their emission spectra.
- To examine an absorption spectrum.

Apparatus: spectrometer, spectral tubes, power supply, incandescent lamp.

Introduction Using a grating spectrograph to separate the colors of light emitted from hot, glowing hydrogen gas, you see bright emission lines and not a continuous spectrum (rainbow) of colors. Observed (inverse) wavelengths of the lines are given by:

$$1/\lambda = 0.01097 (1/n_1^2 - 1/n_2^2) \text{nanometers}^{-1}$$

Eq. 1



The numerical constant, 0.01097, is called the Rydberg constant and the n 's are “principal” quantum numbers. n_l (lower level) is smaller than n_u (upper level); both n 's are integers equal to 1,2, 3... By trying various values for n_u and n_l , we find that the only transitions we see with our eyes have $n_l = 2$ and $n_u = 3,4,5,---$. This set of visible transitions with $n_l = 2$ is known as the Balmer series. These are shown in the figure above. Each transition down to a lower energy level (orbit) emits a photon of energy equal to the difference between those of the upper and lower levels. Note that some Balmer lines lie in the near-ultraviolet beyond the eye's sensitivity limit at 380 nm.

The theory of the discrete spectral lines and structure of the atom was developed by Niels Bohr (1913). He postulated that the negative electron moves with discrete integer multiples of angular momentum. Thus, the electron also has quantized orbital level energies and radii, and this explained the spectral lines. It was later realized from the work of de Broglie (1924) that the electron moves as a wave (with wavelength inverse to linear momentum), along an orbit around the positive nucleus. The electron wave can “fit” around the nucleus only as a whole multiple of a wavelength - the electron wave must constructively interfere with itself over the orbital path, and only certain wavelengths qualify. Any other wavelengths result in destructive interference. This constructive interference means that the angular momentum, and correspondingly the energy and radius of the orbiting electron, are quantized, just as Bohr theorized. These discoveries were foundation stones of quantum mechanics.

Procedure

Using a diffraction grating spectrometer, you will measure some of the wavelengths of the visible members of the hydrogen spectrum Balmer series ($n_l = 2$) and compare the results with the predictions of the Bohr model of the hydrogen atom. The diffraction grating equation gives the wavelength λ in terms of the measured deviation angle and the spacing, d , between adjacent grating lines ($d = 1/(\# \text{ of lines per meter})$):

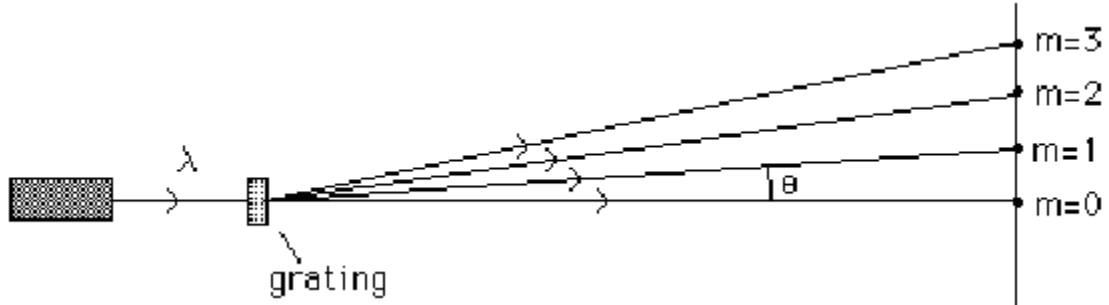


Figure 2

Eq.2: Grating equation:

$m \lambda = d \sin(\theta)$ where m is integral.

This implies that you may see more than one angle for a given wavelength or color (multiple orders of m), as long as $\sin(\theta) < 1$. (In this experiment, m is used in the grating equation to avoid confusion with the orbital momentum integer, l).

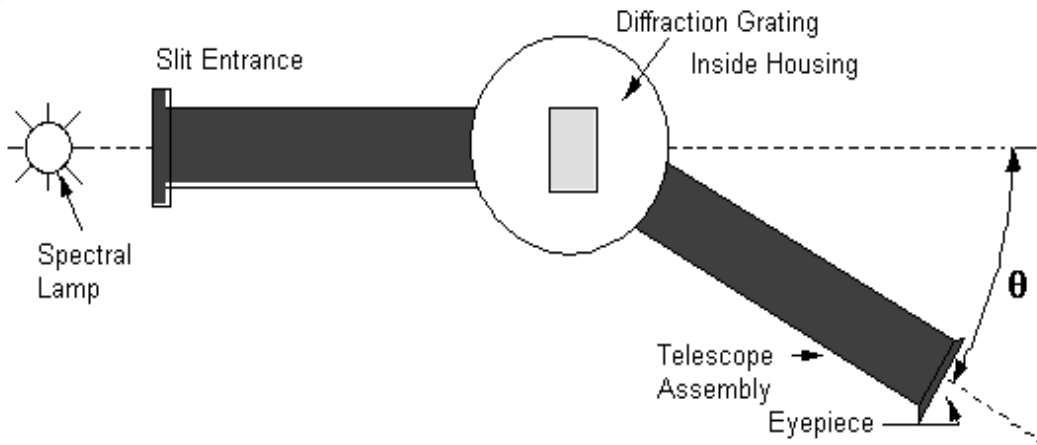
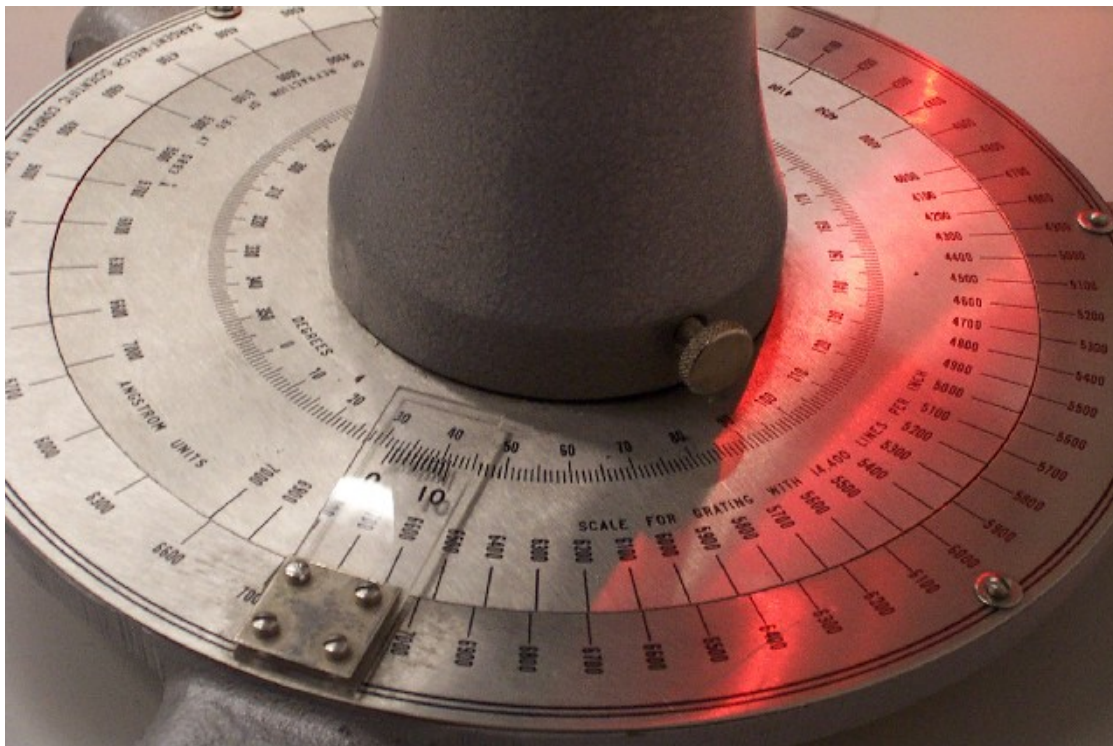


Figure 3

The essential elements of the spectrometer are shown in Fig. 3:

- * The slit entrance is pointed at the spectral lamp. The slit can be turned vertical (parallel to the grating lines), and its width is adjustable. This shapes and limits the light beam before it strikes the grating.

- * A fixed diffraction grating. Most diffraction gratings for this experiment have 6000 lines per centimeter $\implies 6 \times 10^5$ per meter. This implies that the slit separation distance is $d = 1/(6 \times 10^5)$ meter = 1.667×10^{-6} meters = 1667 nanometers.
- * A telescope tube with an eyepiece fitted with a crosshair for pointing. This assembly rotates about the grating center. The angle with respect to the slit barrel can be read to 0.1° with a vernier scale. (The Sargent-Welch spectrometers are calibrated in wavelength-but for a different grating spacing than usually used. Therefore, **the wavelength scale is not valid**. You must use the measured angle θ (see below) and the integer order number m to calculate wavelength λ from the grating equation (Eq.2)).



1. Hydrogen spectrum

- First, pull out the telescope from the viewing end. Look through and adjust the eyepiece to focus on the cross-hairs. The eyepiece slides in and out of its draw tube. Put the telescope assembly back into the spectrometer. Be careful not to disturb the focused eyepiece.
- Turn on the power supply that applies a high voltage to the tube containing hydrogen gas.

**5000 VOLTS: BE CAREFUL ABOUT
ELECTRIC SHOCKS.**

- c. Align the entire spectrometer in a straight line. Look through the eyepiece and put the slit in the center of the field. Set $\theta = 0^\circ$ on the base plate. This is the $m = 0$ maximum which occurs at $\theta = 0^\circ$ for all wavelengths; thus, you see a mix of all original colors. You may need to swivel the slit to get it upright and parallel with the grating lines.
- d. Increase θ by swinging the telescope part to the left, and locate the angular position of the first ($m = 1$) three or four lines (red, green-blue, and two (?) violet) in the visible spectrum of hydrogen. Ignore the fainter lines, which are from contamination (water and air).
- e. If the cross-hairs cannot be observed, center the slit image in the telescope eyepiece and average a few readings. Record the wavelengths of any other observed lines.
- f. Compute the wavelength of each of the three (four?) lines from the grating equation and give the differences from the wavelengths predicted from quantum theory (Eq. 1) for $n_1 = 2$ and $n_2 = 3, 4, \dots$. If there is sufficient intensity, measure the second order angle ($m = 2$) to double check your measured λ 's.¹

2. Atomic spectra of other elements

The spectrum of atomic hydrogen, an atom with just one electron, is simple and the energy levels are given by the simple relation of Eq. 1. Other elements with many orbiting electrons have more complicated atomic spectra; their electrons interact with each other, as well as with the dominant nuclear charge. Nevertheless, the spectral line pattern is unique for each element.

You will be given spectral tubes of "unknown" elements, helium (He), neon (Ne), or mercury (Hg), which you must identify. Measure the wavelengths of the lines in the emission spectrum of each. Identify each element by referring to the list of wavelengths of prominent spectral lines in the table below. Use your wavelength measurements, not chart colors. Note that some lines will be brighter than others.

Observe also, qualitatively, the sodium (Na) yellow "doublet" line, in first and second order.

Be careful when changing spectral tubes: they become hot. It is best to hold them at the larger ends, which are cooler.

3. Absorption spectrum

¹ You know the grating spacing d and you will obtain a wavelength λ for each color (line), from your first order ($m = 1$) angle, θ_1 . Using these and then setting $m = 2$, you can calculate from the grating equation where to look for each second order line. But $\sin(\theta_2)$ greater than one is unphysical – no line.

An emission spectrum is caused by electrons “dropping” to lower atomic energy states; electromagnetic energy in the form of photons of light is given off in each transition “downwards”. The electrons got into the higher energy states by collisional excitation, namely atomic collisions with other energetic free electrons.

Now, we are going to investigate the opposite effect. Imagine an electron in a low orbital energy state, and along comes a photon of energy that the electron absorbs. The energy is the correct amount to boost the electron into a higher energy state. The excited atom will give up this energy very quickly in any number of ways: re-emit the same energy photon but in a direction different than the original photon; emit two or more lower energy photons as the electron "cascades" down through two or more energy levels or, before the atom can emit a photon, interact with another electron or atom with de-excitation of the atom back to its original state. The net result is that photons of a particular energy are removed from a beam of light. If we are observing a continuous spectrum (think of a rainbow) with a spectroscope, we will see a zone of relative darkness, an absorption line, superposed on the continuous bright wavelength spectrum. Remember that energy is not destroyed, just converted to other wavelengths or even thermal energy.

Procedure

Align the spectrometer to view white light from a tungsten lamp. Describe what you observe. How is it different from the light emitted by hydrogen gas? Now place one bottle filled with colored liquid between the light and the spectrometer. What do you observe? Devise an explanation for this. Repeat for the other bottles of colored liquid.

Devise a qualitative rule involving the color of the liquid and the position of the dark band. Determine the central wavelength of a few of the dark absorption "lines" by measuring the angles corresponding to the left and right fringes of the dark absorption band and averaging to estimate the center of the band.

SPECTRAL LINE WAVELENGTHS

Wavelengths are in nanometers. The colors are approximate; they should not be used to identify the elements.

Neon



489, 496 (blue-green), 534 (green), 585 (yellow)
622, 633, 638, 640, (orange-red) 651, 660, 693 (red)

Helium



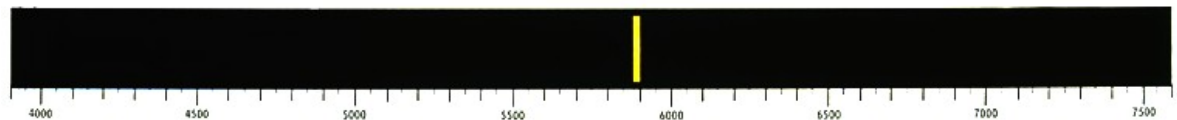
447 (blue) 471 (turquoise) 492 (blue-green)
501 (green) 587 (yellow) 667 (red)

Mercury



404 (violet) 435 (blue) 491 (green)
546 (green) 576 (yellow) 579 (yellow)

Sodium



568, 569 (green), 589, 590 (yellow), 615, 616 (red)

How to Read a Vernier Scale

A vernier scale, shown below in the dashed box, is used to interpolate an extra digit of accuracy. The position of the zero is used to read the scale to the accuracy of the drawn or "ruled" lines. The extra vernier's digit will line up with the scale's ruled lines to indicate the next digit of accuracy. Below, the vernier zero lies between 23 and 24. Notice that the vernier's "6" lines up with a ruled line on the scale. This means the answer is 23.6.

