This sheet is the lab document your TA will use to score your lab. It is to be turned in at the end of lab. To receive full credit you must use complete sentences and explain your reasoning clearly.

What’s this lab about?
This is the first lab about quantum mechanics. Your goal is to measure emission lines of the Hydrogen atom, and correlate them with transitions of the atom between different quantum states. You do this by measuring the wavelength of photons emitted by Hydrogen atoms in excited quantum states. You use a diffraction grating to disperse the wavelengths at different angles (by constructive interference), and a spectrometer to accurately measure the angles.

Why are we doing this?
Emission and absorption spectra can be a unique fingerprint of an atom or molecule. The photon energies and wavelengths are directly related to the allowed quantum energy states of the system.

What should I be thinking about before I start this lab?
Think about what happens when a quantum system makes a transition from a high-energy state to a low-energy state. Think about what the quantum states are for a hydrogen atom, and the connection between atomic transitions and photons.
A. The diffraction grating

The equipment in this lab allows for very accurate measurements of the angles for which constructive interference occurs for light passing through a diffraction grating. Remember from the first lab of the semester that a CD or DVD, consisting of many closely spaced tracks acting as slits, behaves as a reflective diffraction grating. The grating you use in the spectrometer here works in transmission, but is otherwise the same: it has many closely spaced slits, with a density of 600 slits/mm.

This is actually close to the 1.6 µm track spacing that you found for the CD. In that experiment you aimed a red laser at the CD and found that each groove acted as a source of spherical waves, and these canceled by destructive interference except at particular angles θ determined by the wavelength according to $m\lambda = d\sin\theta$. Here $d$ is the slit spacing and $m$ an integer indicating the order of diffraction.

In that experiment you had a single wavelength. Here the incoming light may be made of several different wavelengths. Each wavelength will diffract constructively at particular angles given by the above formula. The job of the spectrometer is to accurately measure those angles, and so determine the wavelengths making up the incoming light.

A1. Suppose you see only four diffracted rays from the diffraction grating, at angles of $\theta = 20^\circ$, $\theta = 23^\circ$, $\theta = 43.16^\circ$, and $\theta = 51.4^\circ$. You detect these with your eye, so you know they are all in the visible spectrum. What wavelengths are in the incoming light?
B. Measuring the diffracted angle with the spectrometer

The spectrometer has three main pieces (shown below)

1. A collimator (makes rays hitting the diffraction grating parallel)
2. Diffraction grating (discussed above)
3. An observation telescope (to accurately view the spectral lines)

There are also several mechanical adjustments, as shown in the figure above. Don’t adjust K and L. These are to make the grating perpendicular to the collimator, and to adjust the angle scale so that it indicates 0˚ when the viewing telescope is aligned exactly on the axis of the collimator.

The collimator has a slit on the far end, and a lens on the near end that makes the light rays from the slit parallel. You turn the knurled knob C) to open and close the slit. Opening the slit gives a brighter image, but less angular resolution.

The viewing telescope can be focused, and its angle can be changed.

Two adjustments to focus the viewing telescope:
   i) Slide the eyepiece tube in or out until the crosshairs are in focus.
   ii) Turn the knurled knob until the image of the slit (lit by desk lamp) is in focus

Two ways to move the viewing telescope:
   i) loosen the telescope clamp and move the telescope with your hand (coarse adjust)
   ii) tighten the telescope clamp, and turn the fine-adjust knurled knob (fine adjust)

B1) Why does the collimator improve the accuracy of the spectrometer? What would happen if it didn’t have a collimator?
C. Using the spectrometer

Make sure the grating is in place, and turn on the desk lamp so it shines through the slit. Put the black cloth over the spectrometer to block out stray light. Unlock the telescope and rotate it left and right while viewing to find the continuous spectrum on either side of the central maximum. If you can’t see the continuous spectrum, part of the black cloth may be blocking the light. Try adjusting the slit width.

1. Is the order of the colors what you would expect from \( d \sin \theta = m\lambda \) ? Explain

2. Pick a color or edge of a color in the spectrum with the telescope crosshairs and lock the telescope in place. Use the angle scale and vernier to determine the angle away from the central maximum. (Read carefully the description of measuring angles with the vernier scale on the last page of this handout.)

3. Unlock the telescope and align it with the same color or edge of a color on the opposite side of the central maximum. Record the angle away from the central maximum using the vernier. If there are two windows in which to read angles, use the one that reads zero straight ahead. But notice that if you read 20° to the left, you will read 340° to the right, (which you should record as 20°). Always use the same window (the other will be different by 180°).

4. Average the two angle readings and \( d \) from part 2, compute the wavelength of color with which you aligned the telescope. Show your calculations including how you find \( \theta \). We use the average to account for slight misalignments of the grating, which should be, but isn’t, exactly perpendicular to the collimator.
D. Accurately measuring $d$, the line spacing of the grating

Your grating is a *replica* grating. It is plastic that is stamped like a CD from a master grating. Because of this it could be slightly stretched or compressed, so that the line spacing is not exactly as written on the grating holder. Here you accurately determine the line spacing by measuring the diffraction angle of the $\lambda = 546.1 \, \text{nm}$ spectral line of mercury.

Replace the desk lamp with the Hg lamp. Make sure the green safety filter is in place (the filter blocks the UV part of the spectrum).

D1. Following the same procedure as in part B, write down the angles (left and right) for the first order line for $\lambda = 546.1 \, \text{nm}$. It is the by far the brightest green line in the spectrum. You should be able to see the green line, the doubled yellow line to the left, and some faint blue lines. If you can’t resolve the two yellow lines, reduce the slit width until you can.

D2. Use the known wavelength and your measured angle for the first order line to calculate $d$ and the lines/mm for your grating. Show all your work and compare the result to the value written on your grating. Use this value of $d$ for part E. For more accuracy you could also use the second order diffraction.
E. Measuring spectral lines of the hydrogen atom

Replace the Hg lamp with the hydrogen source and make sure it exactly in front of the slit (if it is not, the lines will not be bright enough to see). Repeat the measurement procedure for every line in the first order spectrum on both sides of the central maximum. Organize your data and calculations in the table at the end of this page.

1. Pick the line (color) farthest from the central maximum and fill in color, angle-left, and angle right in the table.

2. Determine $\theta$ from the average and write it in the table also. Show your work here.

3. Using $d$ measured in part D calculate the wavelength of the line in nm.

4. Calculate the photon energy for this line and show your work here. Use $hc = 1240 \text{ eV} \cdot \text{nm}$.

5. Before going on make sure your procedure is sound and your numbers make sense. Ask your TA before going on if you are uncertain.

6. Repeat the above process for the rest of the lines in the spectrum to fill in the table.

<table>
<thead>
<tr>
<th>color</th>
<th>angle-left</th>
<th>angle-right</th>
<th>$\theta$</th>
<th>$\lambda_{\text{photon}}$</th>
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F. Atomic energy levels for hydrogen

F1. Using \( E_n = -\frac{13.6}{n^2} \text{eV} \), mark the energy levels for hydrogen on the graph at right. Show your calculations.

F2. Determine which transitions are responsible for the spectral lines in your table. Mark those transitions on the energy level diagram with an arrow drawn from the initial state to the final state. Indicate which spectral line (color) goes with which arrow. Explain your reasoning and give examples of why other transitions cannot be responsible for these lines.
Reading the vernier scale on the spectrometer

The verniers have 30 divisions per half degree. Hence each division is \((1/30)\times(1/2) = (1/60)\)° or one minute (') of arc.

The knurled ring about the collimator, B, controls the slit opening.

Staff have already focused the collimator for parallel light and have set collimator and telescope perpendicular to spectrometer's rotation axis.

REMINDER ON READING A VERNIER

1) Position and tighten the telescope.

2) Move the magnifying glass to see the scale marking.

3) Look where the zero mark on the upper scale is located. The degree reading is the first full degree mark to the left of the zero (210° in the top figure; 229° in the bottom figure).

4) Now make the minute reading: if the zero mark on the upper scale comes after a degree mark (the short lines on the lower scale) then start at 30', otherwise at 0'.

5) Next look for the two lines which match up best between the two scales. Read the number of the appropriate line on the upper scale and add it to the zero mark is just past a degree mark so we begin with 30'. The 15' mark is the one that lines up best so we get 210°15' for the top reading and 229°146' for the bottom one.

6) Now convert to decimal degrees, in this case 15/60 = 0.25, so \(210.25°\)