ATOMIC SPECTROSCOPY:
THE LINE SPECTRA OF He AND H ATOMS

MATERIALS: Helium lamp, hydrogen lamp, lamp holder, spectroscope.

GOALS:

1. To observe a visible line spectrum emitted by an atom in a gas discharge tube with the aid of a spectroscope.
2. To use known wavelengths of He spectral lines to calibrate a spectroscope.
3. To use a calibration curve to assign accurate wavelengths of the spectral lines observed in the H atom .
4. To perform Bohr's H atom calculations and assign transition corresponding to spectral lines observed in the H atom.

INTRODUCTION:

A gas discharged tube consists of a glass tube, previously evacuated with a vacuum pump and then refilled with a low pressure gas of an element (Na, H, He, Hg,…) At both ends, there are metal electrodes that pass through the glass body. When a high voltage (≈ 5000 volts) is applied across the two electrodes, the gas inside the tube glows, giving a color characteristic of the element inside. For instance, a tube containing neon glows red; mercury tubes glow blue-violet, and so forth. These characteristic colors can be separated into into component colors using a prism or grating. These component colors can be observed through the use of a spectroscope (spectrometer). Indeed, through the eyepiece of a spectroscope, the glowing color can be seen as separated, parallel individual lines of different colors separated by dark regions. These colored lines are called **spectral lines**. Hydrogen, for example, has four spectral lines in the visible region: red, green, blue and violet.

Although spectral lines were first observed in the 1800s, their origin remained a mystery until the 20th Century. By observing the spectral lines of H, Niels Bohr (1885-1962) suggested, through complex mathematical calculations, a model of the electronic structure of the atom. He explained spectral lines in terms of the movement of the electron in the H atom from one orbit (allowed energy level) to another (**see lecture notes**). Using his model, Bohr derived some simple formulas to calculate the radius and energy of a given orbit within the H atom.

According to Bohr, the radius of an allowed energy level within the H atom is given by:

$$\mathbf{r_n = (5.29405 \times 10^{-2}) \times n^2 \text{ in nm}}$$

where n is called the principal quantum number. It can take values such as 0, 1, 2, 3, 4, 5, ……..

Similarly, the energy of the electron in a given orbit is:

$$\mathbf{E_n = - hcR_H} \left(\frac{1}{n^2}\right)$$

where R_H is the Rydberg constant, "h" is Planck's constant, and "c" is the speed of light. The product of these three constants is **2.18×10^{-18} m^{-1}**.

According to Bohr, when the electron in the H atom moves from a lower energy level to a higher energy level, radiant (light) energy is absorbed (Ex. 1 → 4). The process is called **absorption**. Spectral lines are only observed when **emission occurs.** Emission is the release of radiant energy when an electron moves from a higher energy level to a lower level (Ex. 2 → 1). In either case, it can be easily shown that the energy change during a **transition** (absorption or emission) is given by:

$$\Delta \mathbf{E = (-2.18 \times 10^{-18} J)}\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

Where n_f and n_i are initial and final energy levels, respectively.

Finally, the respective wavelength and frequency of the light absorbed or emitted in a transition can be calculated using the following equation.

$$\Delta E = h\nu = hc/\lambda$$

Where h is Planck's constant (**6.63×10^{-34} J·s)** and c is the speed of light (**3.00×10^{8} m/s**)

In this lab session, you will first use the spectral lines of He to calibrate a spectroscope. Using your calibration curve, you will then determine the actual wavelengths of the spectral lines observed in the H atom. Next, using Bohr's model, you will calculate radii of allowed energy levels, their energies, etc. (see Data section). Finally, you will identify the transitions that correspond to the observed hydrogen lines and represent them on a diagram.

PROCEDURE:

-To be explained by your instructor.

PART I: CALIBRATION OF THE SPECTROSCOPE

PART II: WAVELENGTHS OF THE SPECTRAL LINES IN THE H ATOM

CALCULATIONS:

PART I: CALIBRATION CURVE

Plot measured wavelengths (Y axis) vs actual known wavelengths (X axis).

PART II: ACTUAL WAVELENGTHS OF H LINES

PART III : CALCULATIONS

1. radius: $r_n = (5.29405 \times 10^{-2}) \times n^2$ in nm
n = quantum number

2. Energy: $E_n = -hcR_H(1/n^2)$
$hcR_H = 2.18 \times 10^{-18} J$

3. Energy of a transition:
$\Delta E = (-2.18 \times 10^{-18} J)(1/n_f^2 - 1/n_i^2)$

4. Wavelength: $\Delta E = h\nu = hc/\lambda$
It can be easily shown that $\lambda = hc/\Delta E$
($h = 6.63 \times 10^{-34}$ J · s; $c = 3.00 \times 10^8$ m/s)

PART IV: TRANSITION ASSIGMNENTS

Compare the actual wavelengths of hydrogen from Part II with the calculated wavelengths in PART III B to determine observed transitions.

PART V: TRANSITION DIAGRAM

Draw transition diagrams for the H atom.

Sample calculations:

Ex1. Calculate the radius and energy of an orbit if n = 3.

$$r_n = (5.29405 \times 10^{-2}) \times n^2$$
$$= (5.29405 \times 10^{-2}) \times 3^2$$
$$= 0.476 \text{ nm}$$
$$E_n = -hcR_H(1/n^2)$$
$$= -(2.18 \times 10^{-18} \text{ J})(1/3^2)$$
$$= -2.42 \times 10^{-19} \text{ J}$$

Ex2: Calculate the energy change if an electron moves from n = 6 to n = 1.

$$\Delta E = -hcR_H (1/n_f^2 - 1/n_i^2)$$
$$= (-2.18 \times 10^{-18} \text{ J})(1/1^2 - 1/6^2)$$
$$= -2.119 \times 10^{-18} \text{ J}$$

Ex3: Find the wavelength of this transition. (Use the absolute value of the ΔE.)

$$\lambda = hc/|\Delta E|$$
$$= \frac{(6.63 \times 10^{-34} \text{ Js})(3.00 \times 10^8 \text{ m/s})}{2.119 \times 10^{-18} \text{ J}}$$
$$= 9.38 \times 10^{-8} \text{ m}$$
$$= 93.8 \text{ nm}$$

Ex4: Calculate the energy change that occurs when the electron moves from energy level 7 to level 3.

$$\Delta E = -hcR_H (1/n_f^2 - 1/n_i^2)$$
$$\Delta E = -2.18 \times 10^{-18}(1/3^2 - 1/7^2)$$
$$\Delta E = -2.18 \times 10^{-18}(1/9 - 1/49)$$
$$\Delta E = -1.98 \times 10^{-19} \text{ J}$$

Ex5: Calculate the wavelength of the spectral line observed during the 7 → 3 transition.

$$\Delta E = hc/\lambda \Rightarrow \lambda = hc/|\Delta E| \Rightarrow \lambda = (6.63 \times 10^{-34})(3.00 \times 10^8 \text{ m/s}) / |-1.98 \times 10^{-19} \text{ J}|$$
$$\lambda = 1.00 \times 10^{-6} \text{ m} = 1.00 \times 10^3 \text{ nm}$$

Ex6: Calculate the frequency of the spectral line described in Ex4 and Ex5.

$$\Delta E = hv \Rightarrow v = |\Delta E|/h = 1.98 \times 10^{-19} \text{ J}/6.63 \times 10^{-34} \text{J}\cdot\text{s}$$
$$v = 2.99 \times 10^{14} \text{s}^{-1}$$

DATA SHEET FOR THE ATOMIC SPECTROSCOPY EXPERIMENT

Name ________________________ ID# ____________

Lab Sect ____________________ Date ____________

Partner ____________________

Qz _____	/	25
Rpt _____	/	75
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Exp _____	/	100

PART I: LINE SPECTRUM OF He

Color	Known Actual Wavelength	Measured Wavelength
Red	706.5 nm	________ nm
Red	667.8 nm	________ nm
Yellow	587.6 nm	________ nm
Green	501.6 nm	________ nm
Blue-green	492.2 nm	________ nm
Violet	471.0 nm	________ nm
Violet	447.0 nm	________ nm

PART II: ACTUAL SPECTRUM OF HYDROGEN

Color	Actual Wavelength	Measured Wavelength
Red	________ nm	________ nm
Blue	________ nm	________ nm
Violet	________ nm	________ nm
Violet (faint)	________ nm	________ nm

PART III: BOHR'S MODEL CALCULATIONS

A. Radius and Energy of an orbit

Quantum number(n)	Radius	Energy
1	________ nm	____________ J
2	________ nm	____________ J
3	________ nm	____________ J
4	________ nm	____________ J
5	________ nm	____________ J

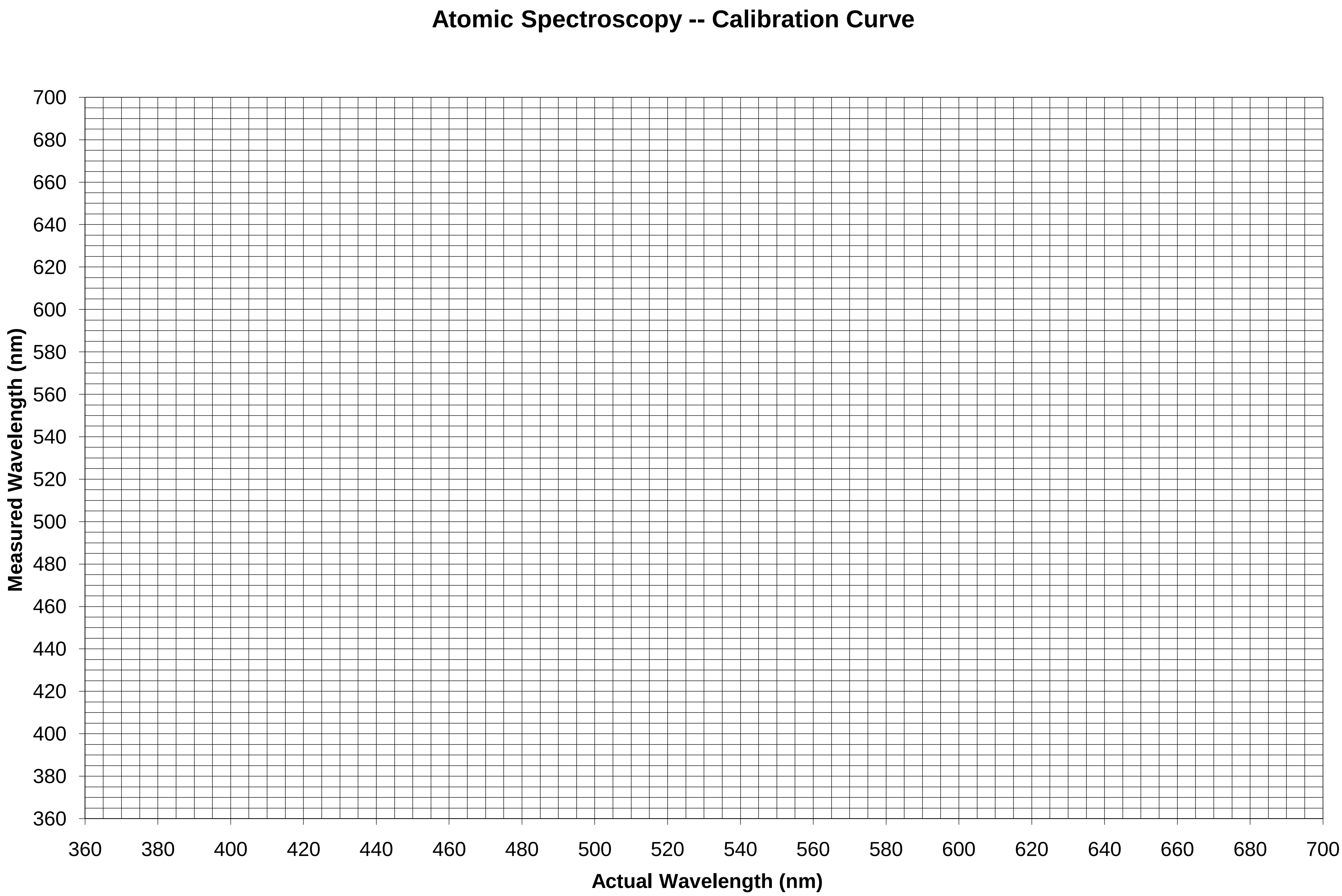
B. Energy changes and wavelengths of transitions

Final Energy level	Transition	Energy	Wavelength
1	$5 \rightarrow 1$	________ J	________ nm
1	$4 \rightarrow 1$	________ J	________ nm
1	$3 \rightarrow 1$	________ J	________ nm
1	$2 \rightarrow 1$	________ J	________ nm
2	$6 \rightarrow 2$	________ J	________ nm
2	$5 \rightarrow 2$	________ J	________ nm
2	$4 \rightarrow 2$	________ J	________ nm
2	$3 \rightarrow 2$	________ J	________ nm
3	$7 \rightarrow 3$	________ J	________ nm
3	$6 \rightarrow 3$	________ J	________ nm
3	$5 \rightarrow 3$	________ J	________ nm
3	$4 \rightarrow 3$	________ J	________ nm

PART IV: IDENTIFICATION OF OBSERVED H TRANSITIONS

Color:	Red	Blue	Violet	Violet
Wavelength: from Part II	______	______	______	______
Transition:	$\rightarrow$	$\rightarrow$	$\rightarrow$	$\rightarrow$

PART V: DRAW A TRANSITION DIAGRAM FOR THE H ATOM


Atomic Spectroscopy -- Calibration Curve
Measured Wavelength (nm)
700
680
660
640
620
600
580
560
540
520
500
480
460
440
420
400
380
360
360
380
400
420
440
460
480
500
520
540
560
580
600
620
640
660
680
700
Actual Wavelength (nm)