

Planck's "quantum of action" from the photoelectric effect (line separation by diffraction grating) with electrometer amplifier

1. PURPOSE

- Verify the photoelectric effect.
- Do measurements that enable us to calculate the kinetic energy of the electrons as a function of the frequency of the light.
- Calculate Planck's constant h from these results
- Show that the kinetic energy of the electrons is independent of the intensity of the light.

2. PRINCIPLE

A photocell is illuminated with monochromatic light of different wavelengths. Planck's quantum of action, or Planck's constant h , is determined from the photoelectric voltages measured.

3. THEORY

In 1887, Heinrich Hertz found that when electromagnetic radiation (light) fell on a metallic surface, the surface emitted electrical charges. Experiment by Phillip Lenard in 1900 confirmed that these electrical charges were electrons. These electrons were called photoelectrons. This process, whereby light falling on a metallic surface causes the emission of electrons, is called photoelectric effect.

The Photoelectric Effect: If monochromatic light (light of a single frequency ν) of intensity I is allowed to shine on a metallic plate (cathode) of a phototube, electrons will be emitted as shown in Fig.1.

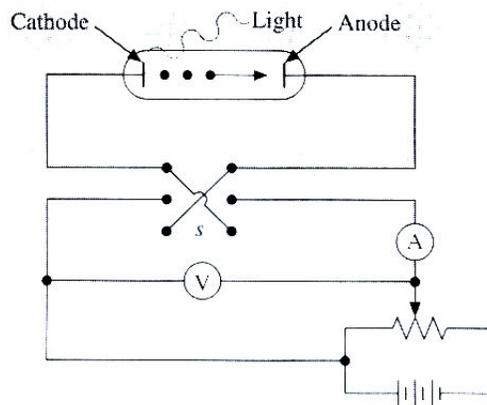


Figure 1: Schematic diagram for the photoelectric effect.

Initially, the switch s is thrown to make the anode positive and the cathode negative. Light is then shone on the cathode of the phototube, causing electrons to be emitted. The positive anode attracts these electrons, and they flow to the anode and then through the connection circuit. The ammeter in the circuit measures the current. Starting with a positive potential V the current is recorded for decreasing values of V . When the potential V is

reduced to zero, the switch s is reversed to make the anode negative and the cathode positive. The negative anode now repels the photoelectrons as they approach the anode. If the electrons have sufficient kinetic energy, they can overcome this repulsion and still land on the anode. If this potential is made more and more negative, however, a point is eventually reached when the kinetic energy of the electrons is not great enough to overcome the negative stopping potential, and no more electrons reach the anode. The current i , therefore, becomes zero.

A plot of the current i in the circuit, as a function of the potential V between the plates as shown in Fig.2. If the intensity of the light is increased to I_2 and the experiment repeated, second curve shown in the figure is obtained.

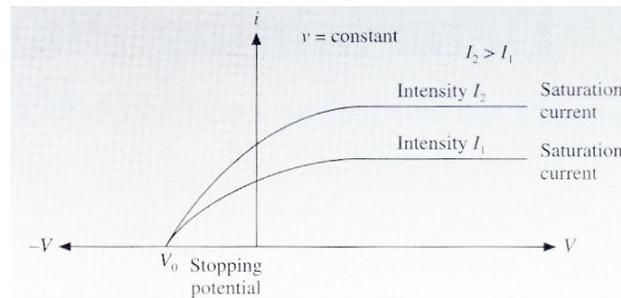


Figure 2: Current I as a function of voltage V for the photoelectric effect.

As can be seen on the graph in Fig.2, when the value of V is high and positive, the current i is a constant. This occurs because all the photoelectrons formed at the cathode are reaching the anode. By increasing the intensity I , a higher constant value and current is obtained, because more electrons are then being emitted.

It can also be observed that when the potential is reduced to zero, there is still a current in the tube. Even though there is no electric field to draw them to the anode, many of the photoelectrons still reach the anode because of the initial kinetic energy they possess when they leave the cathode. As the switch s in Fig.1 is reversed, the potential V between the plates becomes negative and tends to repel the photoelectrons. As the potential V is made more negative, the current I decreases, as seen in Fig.2, indicating that fewer and fewer photoelectrons are reaching the anode. When V is reduced to the value V_0 , there is no current at all in the circuit; V_0 is called the stopping potential. Note that it is the same value regardless of the intensity (both curves intersect at V_0).

The potential V is related to the kinetic energy of the photoelectrons. For the electron to reach the anode, the kinetic energy must be equal to the potential energy between the plates.

$$E_k (\text{electrons}) = E_p (\text{between the plates}), \quad (1)$$

$$E_k = e V, \quad (2)$$

Where e is the charge on the electron and V is the potential between the plates.

The potential V will act on electrons that have less kinetic energy than that given by Eq.2. When $V=V_0$, the stopping potential, even the most energetic electrons (those with maximum kinetic energy) do not reach the anode. Therefore,

$$E_k (\text{max}) = e V_0. \quad (3)$$

If we change the frequency of the incident light we get the graph in Fig.3.

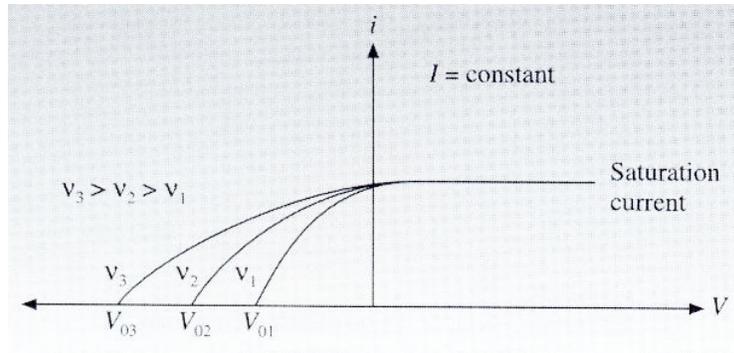


Figure 3: Current I as a function of voltage V for different light frequencies.

As the plot in Fig.3 shows, the saturation current (the maximum current) is the same for any frequency of light, as long as the intensity is constant. But the stopping potential is different for each frequency of the incident light. Since the stopping potential is proportional to the maximum kinetic energy of the photoelectrons, through Eq.3, the maximum kinetic energy E_k (max) of the photoelectrons is plotted as a function of frequency ν and the graph in Fig.4 is obtained.

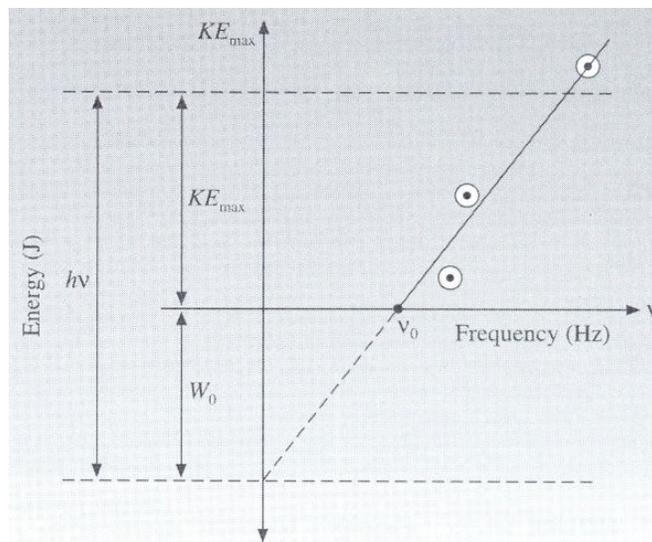


Figure 4: Maximum kinetic energy $E_{k(max)}$ as a function of frequency ν for the photoelectric effect.

The first thing to observe is that the maximum kinetic energy E_k (max) of the photoelectrons is directly proportional to the frequency ν of the incident light, that is,

$$E_k \text{ (max)} \propto \nu . \tag{4}$$

The second thing to observe is that there is a cutoff frequency ν_0 , below which there is no photoelectric emission. That is, no photoelectric effect will occur at all unless the incident light has frequency higher than the threshold frequency ν_0 . For most metals, ν_0 lies in the ultraviolet region of the spectrum, but for the alkali metals it lies in the visible region, and for cesium it lies in the infrared region.

Einstein's Theory of the Photoelectric Effect

In 1905, Albert Einstein proposed a revolutionary solution for the problem of the photoelectric effect. Einstein assumed that the energy of the electromagnetic wave was not spread out equally along the wavefront, but rather it was concentrated into little bundles of energy called photons. As the wave progressed, the energy did not spread out with the wavefront, but stayed in the photon bundle. Max Planck had earlier formulated the quantization of radiant energy in bundles of photons each possessing energy such that,

$$E = h \nu, \quad (5)$$

where ν is the frequency of the radiation and, h is a new universal constant, called Planck's constant, which has value $h = 6,626 \times 10^{-34}$ J.s. Einstein assumed that this concentrated bundle of radiant energy struck an electron on the metallic surface. The electron then absorbed this entire quantum of energy ($E = h \nu$). A portion of this energy is used by the electron to break away from the solid, and the rest shows up as the kinetic energy of the electron = incident absorbed energy – energy to break away from solid.

The energy for the electron to break away from the solid is called the work function of the solid is denoted by W . Therefore, the final maximum kinetic energy of the photoelectrons

$$E_k (\text{max}) = h \nu - W, \quad (6)$$

Which is known as Einstein's photoelectric equation.

This equation can be plotted if $E_k (\text{max})$ is placed on the y-axis, and the frequency ν of the incident light is placed on the x-axis. The result is a straight line, the same as in Fig.4. Using the standard equation for a straight line, $y = a x + b$, we see that the slope of the line is Planck's constant h . The value of the intercept is found by noting that, when $E_k (\text{max}) = 0$; $\nu = \nu_0$ and, therefore,

$$\nu_0 = W/h, \quad (7)$$

Therefore, Einstein's equation can also be written as

$$E_k (\text{max}) = h \nu - h \nu_0. \quad (8)$$

For light frequencies equal to or less ν_0 , there is not enough energy in the incident wave to remove the electron from the solid, and hence there will be no photoelectric effect. This explains why there is a threshold frequency, below which there is no photoelectric effect. Einstein's theory of the photoelectric effect is outstanding because it was the first application of quantum mechanics. Light should now be considered as having not only a wave character but also a particle character.

4.PROCEDURE

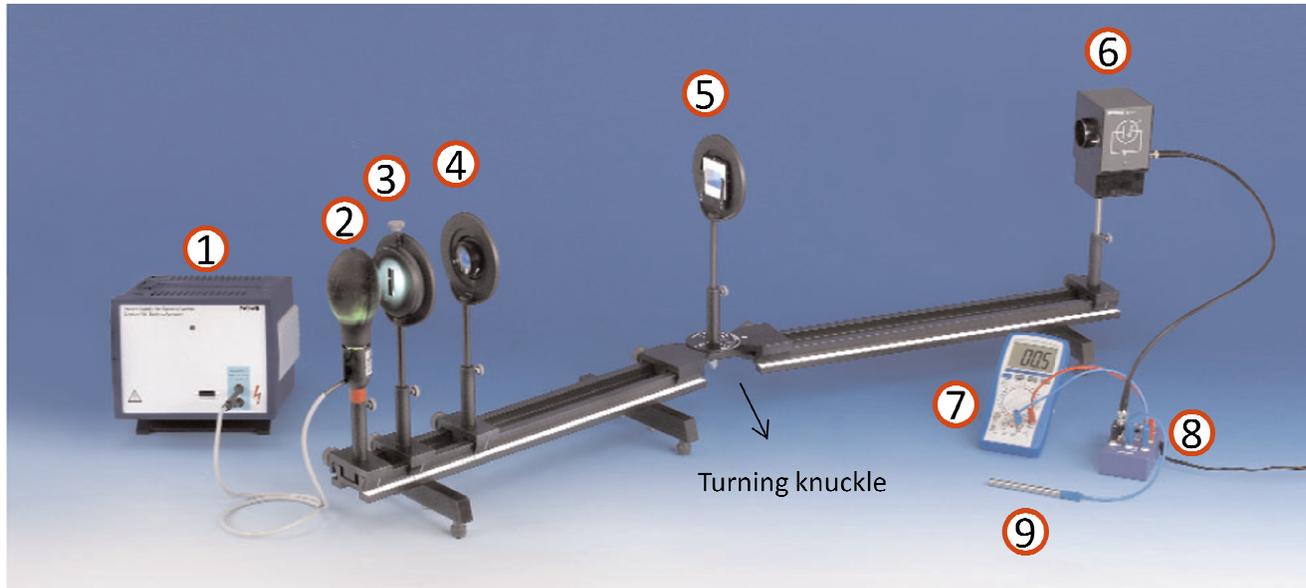


Figure 5: *Experimental set-up*

1. Power Supply
2. Mercury high pressure lamp 80 W
3. Adjustable slit
4. Lens , $f=+100$ mm
5. Diffraction grating, 600 lines/mm
6. Photocell
 - The detector will use the photoelectric current to charge a capacitor. This will eventually cause the capacitor to reach the stop voltage, and the current will cease.
7. Digital multimeter
8. Electrometer Amplifier
9. Support rod, 100 mm with axial hole

Set up the equipment as seen in Fig. 1.

- Place the high pressure mercury vapor lamp and the photocell at opposite ends of the optical bench.
- Place the diffraction grating into a diaphragm holder and mount it with a lens holder to the turning knuckle.
- Place the optical slit at 9 cm and the lens at 20 cm from the end of the bench, where the lamp is. Adjust the lens in a way that the slit's image is focused on the photocell housing's entrance.
- Set the slit width such that its image matches the photocell's entrance width.
- A piece of white paper fixed with adhesive tape to the photocell housing will help with adjusting. The white paper's fluorescence will also help finding the ultraviolet lines.
- Connect the electrometer amplifier as seen on Fig. 2. To avoid problems with electrostatic influence, it is better to plug the end of the cable used to bring the electrometer amplifier entrance on ground potential into the support rod with hole and to plug a connecting plug into the socket of the electrometer amplifier entrance. If you hold the rod firmly in your hand, your body is brought to the same potential as the experiment and touching the connecting plug with the rod will discharge the amplifier's entrance properly. Otherwise the electrostatic charge of your body will cause an influence charge on the amplifier's entrance in the moment of unplugging the ground cable from the electrometer.



Figure 6: Connection of the electrometer amplifier

- Set the digital multimeter's range to 2 V.
- By turning the arm of the optical bench, bring the photocell entrance to the first slit image.
- Discharge the electrometer amplifier entrance and open the light entrance of the photocell housing. Wait until the voltage reading is steady – or if not, discharge again.
- Bring the photocell entrance to the different slit images successively and note down light wavelength and corresponding voltage. To avoid having the UV fractions from second order diffraction falsify the measured values for the yellow and red spectral lines, place colour filters in front of the entrance diaphragm with the aid of an attachable diaphragm holder (525-nm coloured glass for the yellow spectral line and 580-nm coloured glass for the red spectral line).
- Note down the measured voltage and the wavelength of the light.

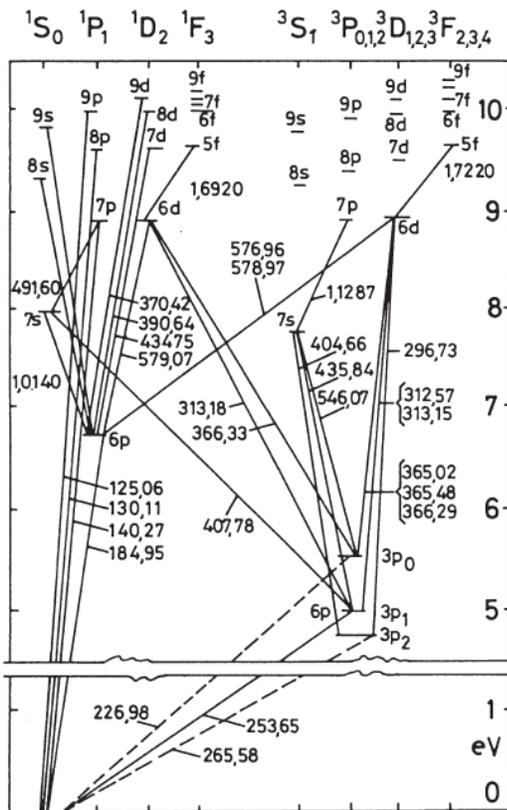


Figure 7: Atomic spectrum of mercury

The frequency f of the light is calculated from the wavelength λ by $f = c/\lambda$ with the speed of light $c = 3.10^8$ m/s. The wavelengths are measured by the angle ϑ at which the diffracted light appears by $\lambda = d \cdot \sin\vartheta$ for first order constructive interference with $d = 1 \text{ mm}/600$ for the 600 lines per mm grating or else are identified as the strongest emission lines of mercury in the lamp at (see Fig.3):

- | | |
|---|---------------|
| 366 nm ($6^1D_2 \rightarrow 6^3P_0, 6^3D_{1,2,3} \rightarrow 6^3P_0$) | nearly invis. |
| | violet |
| 405 nm ($7^3S_1 \rightarrow 6^3P_2$) | violet |
| 436 nm ($7^3S_1 \rightarrow 6^3P_1$) | turquoise |
| 546 nm ($7^3S_1 \rightarrow 6^3P_0$) | green |
| 578 nm ($6^1D_2 \rightarrow 6^1P_1, 6^3D_{1,2,3} \rightarrow 6^1P_1$) | yellow |

4.Experimental Determination of the Photoelectric Effect

Half of the inside of the high-vacuum photo-cell is metal-coated potassium-cathode. The anular anode is opposite the cathode. If a photon of frequency f strikes the cathode, then an electron can be ejected from the metal (external photoelectric effect) if there is sufficient energy. Some of the electrons thus ejected reach the (unilluminated) anode so that a voltage is set up between anode and cathode, which reaches the limiting value U after a short (charging) time. The electrons can only run counter to the electric field set up by the voltage U if they have the maximum kinetic energy, determined by the light frequency f ,

$$hf - W = \frac{m}{2}V^2 \quad (\text{Einstein equation})$$

where W is the work function from the cathode surface, V = electron velocity, m = rest mass of the electron.

Electrons will thus only reach the anode as long as their energy in the electric field is equal to the kinetic energy:

$$e v - W = \frac{m}{2} V^2$$

with e = electron charge: $1.602 \cdot 10^{-19}$ Js.

An additional contact potential φ occurs because the surfaces of the anode and cathode are different:

$$e U + \varphi = \frac{m}{2} V^2$$

If we assume that W and φ are independent of the frequency, then a linear relationship exists between the voltage U (to be measured at high impedance) and the light frequency f :

$$U = \frac{(W + \varphi)}{e} + \frac{h}{e} f$$

If we assume $U = \alpha + b f$ to the values measured in Fig.8 we obtain:

$$h = (6.7 \pm 0.3) \cdot 10^{-34}$$

Literature value : $h = 6.62 \cdot 10^{-34}$ J.s

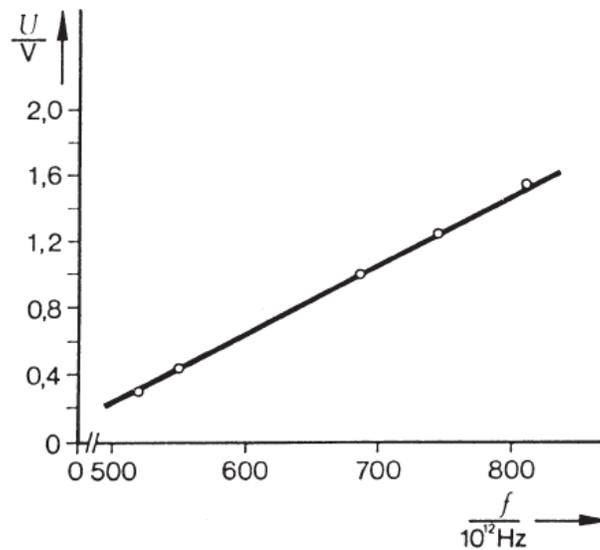


Figure 8: Voltage of the photo-cell as a function of the frequency of the irradiated light.

Summary:

The most important experimental observations must be found during the experiment:

1. The kinetic energy of the photoelectrons (as determined by the reverse voltage needed to completely stop the flow of electrons from cathode to anode) is independent of the intensity of the light, but is a liner function of the frequency of the radiation.
2. There is a maximum wavelength beyond which photoemission does not occur; the value of this maximum depends of the composition of the surface (W).
3. The saturation photocurrent is directly proportional to the light intensity.

Questions:

1. What is the most important general statement you can make from the results of your experiment?
2. Explain why the photoelectric effect is so important to quantum mechanics.
3. Explain why there is a cutoff frequency in the photoelectric effect.
4. Even if the bias voltage is zero, you can still measure a photocurrent. Explain why?
5. If a material has a work function of 2.0 eV, what is the longest wavelength to which a photocathode made of this material will be sensitive?
6. When the anode is positive with respect to the cathode, why does the current not rise immediately to its saturation value? What happens to the electrons which do not reach anode?

Reference:

1. Peter J.Nolan and Raymond E.Bigliani, Experiments in Physics (1995) p.415.
2. Alan M.Portis and Hung D.Young, Berkeley Physics Laboratory-3 p.9.
3. Phywe Laboratory Experiments "Planck's "quantum of action" from the photoelectric effect (line separation by diffraction grating) with electrometer amplifier" LEP 5.1.05-05 Lab Manual, Phywe Systeme GMBH & Co. KG D-37070 Göttingen.

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EP201
MOD- EXPERIMENTS-IV

THE WAVE BEHAVIOUR OF LIGHT: INTERFERENCE and DIFFRACTION

OBJECT

The object of this experiment is to study physical optics. In particular, we will (a) observe the interference pattern produced when light passes through two narrow slits; (b) determine the wavelength of laser light, using an interference pattern; (c) observe the diffraction pattern produced when light passes through a single narrow slit; (d) determine the width of the single slit, using the diffraction pattern produced when light from a laser beam passes through the slit.

THEORY

A. Interference of Light

In this experiment we will study two optical phenomena, interference and diffraction, which can be explained only by using the wave model of light. The study of optical phenomena that can be explained only in terms of the wave model of light is called physical optics.

Light waves obey the same principle of superposition associated with other wave phenomena (such as sound waves). As applied to waves of light, the principle can be stated as follows: If light waves from two or more monochromatic light sources (sources emitting the same wavelength of light) arrive at same point, the amplitude of the resulting light wave at that point is the vector ~~same~~ ^{sum} of the instantaneous amplitudes of the individual light waves.

For example, consider the case of light waves from two monochromatic light sources arriving at a point in phase - that is, in step - so that wave crests meet wave crests and wave troughs meet wave troughs, as shown in figure 1. The resulting light wave is the sum of the individual light waves; hence it will have an amplitude greater than that of either of the original light waves. These waves are said to interfere constructively with each other.

However, the light waves from two monochromatic light sources may be completely out of phase when they arrive at a point; that is, wave crests are meeting wave troughs. The amplitude of the resulting wave is smaller than the larger amplitude of either of the original waves, since the two waves tend to cancel each other out. These waves are said to be interfering destructively with each other. If the two individual waves have equal amplitudes, then they completely cancel each other out (see figure 2.)

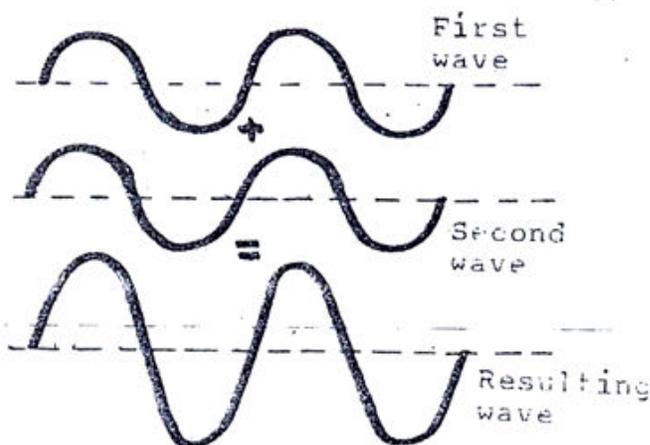


Fig.1. Constructive interference of two monochromatic light waves.

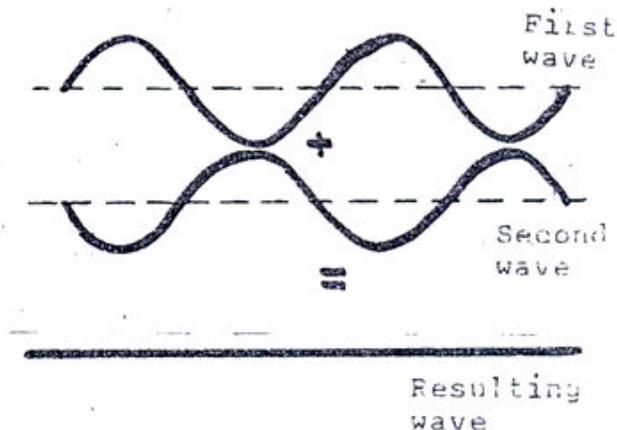


Fig.2. Destructive interference of two monochromatic light waves.

We have seen that two wave sources are needed to produce interference. However, in order to produce a stable interference pattern that can be observed in the laboratory, the individual waves must maintain a fixed phase relationship with each other. Wave sources that produce waves that maintain a fixed phase relationship with each other are called coherent sources.

A method commonly used in the laboratory for producing two coherent light source is to use monochromatic light from a single source to illuminate a screen containing two small slits. The light waves arrive at each slit in phase since they were produced by the same source. The light waves emerging from the two slits are also coherent because, according to Huygens' principle, each slit serves as a source of new wavefronts without changing the phase of the waves.

Young's Double-Slit Experiment

The interference of light was demonstrated in 1801 by Thomas Young, using an experiment similar to that shown in figure 3. A monochromatic light source is placed behind a screen having two slits S_1 and S_2 . Light waves from the source pass through the two

slits and then onto a viewing screen. According to Huygens principle, the two slits act as secondary sources of waves, which emit light of the same wavelength and phase as the initial source. The light waves leave slits S_1 and S_2 in phase since the slits act as coherent light sources. The light waves from slit S_1 and S_2 will arrive at points on the viewing screen alternately in phase and out of phase. This results in a series of alternating bright and dark spots on the viewing screen with a central bright spot directly opposite the center of the two slits (this central bright spot is labeled as point O in figure 3).

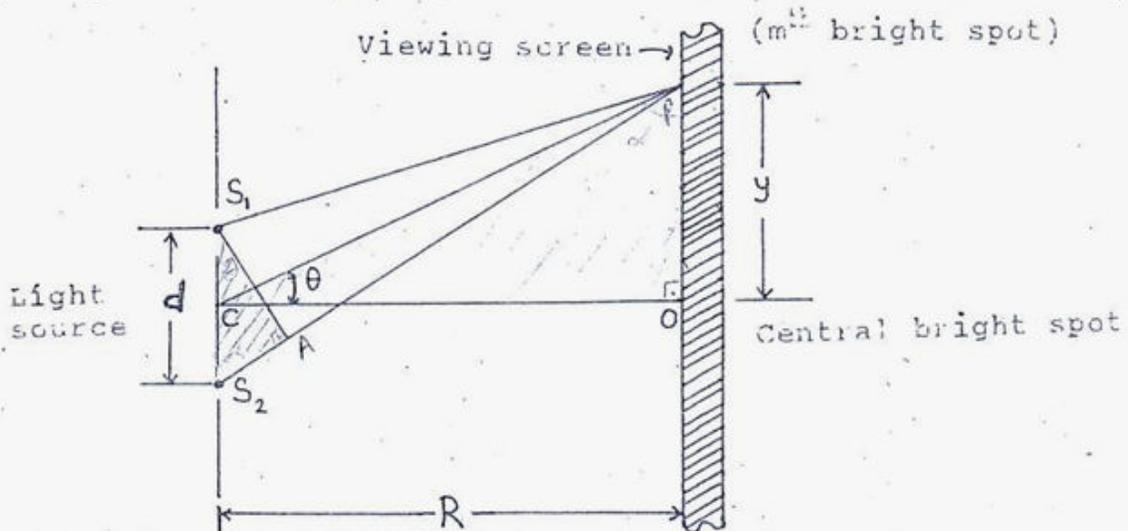


Fig.3 Young's double-slit experiment.

An arbitrary point P on the screen will be bright when light waves reaching it from slits S_1 and S_2 are in phase. That is, the path lengths from S_1 and S_2 to P are equal or differ by a whole number of wavelengths. ($\lambda, 2\lambda, 3\lambda, \dots$)

Let us refer to figure 3 (Young's double-slit experiment). The angle θ is the angular position of a bright spot with respect to the central bright spot. The condition for viewing a bright spot is that the optical path length from S_2 to P must exceed the optical path length from S_1 to P by an integral number of wavelengths. This is,

$$S_2P - S_1P = m\lambda = S_2A$$

where $m = 0, 1, 2, 3, \dots$

As we can see from figure 3, the difference in path length between waves arriving from S_1 and S_2 is S_2A . To find the difference in path lengths, we swing an arc of radius S_1P from point P. This arc intersects the line S_1P at A. The path difference between two light sources is then S_2A . If we assume that angle θ is small, we can approximate the arc by the chord S_2A and we can also assume that the chord is perpendicular to the path S_1P at A. From figure 3,

3, we see that

$$\sin \theta = \frac{S_2 A}{S_1 S_2} = \frac{m\lambda}{d}$$

where d is the distance between slits and θ is the angular of the m th bright spot (point P) with respect to the central spot.

We can also see from figure 3 that

$$\tan \theta = \frac{OP}{CO} = \frac{y}{R}$$

where y is the distance on the viewing screen from the bright spot at point C to point P and, R is the distance from slits to the viewing screen.

For small angles, $\sin \theta = \tan \theta$, so that

$$\frac{y}{R} = \frac{m\lambda}{d}$$

Thus, the condition for viewing a bright spot may be written

$$m\lambda = \frac{yd}{R}$$

where

- λ = wavelength of light
- y = linear distance from the m th bright spot to central bright spot ($m=0$)
- d = slit separation
- R = distance from the double slits to the viewing screen
- $m = 0, 1, 2, 3, \dots$

B. Experimental Determination of the Wavelength of Laser Light Using an Interference Pattern

A laser is a source of coherent monochromatic light. If from a laser is used to illuminate two slits, then the resulting bright-spot pattern can be used to determine the wavelength of laser light. In particular, if the distance y is measured from the central bright spot to the m th bright spot and if d and R are also measured, then equation (1) can be used to solve for the wavelength of the laser experimentally. That is,

$$\lambda = \frac{yd}{mR}$$

C. Diffraction from a Single Slit

When an obstacle is placed in their path, light waves will bend around the edges of that obstacle. This property of light is called diffraction. Diffraction can be studied by shining coherent monochromatic light through a narrow slit and allowing the light to fall on a screen a distance R from the slit. The pattern observed on the screen consists of a central bright image of the slit and a series of bright and dark spots on either side of the central bright fringe. The light wave is thus said to be diffracted, or spread out, when it passes through the narrow slit.

The alternating bright and dark spots on the screen can be explained if we assume that each point on the incident wavefront passing through the slit acts as a source of secondary waves. The amplitude of the light wave at some point P on the viewing screen is obtained by applying the superposition principle to the waves arriving from each of the secondary sources (see figure 4).

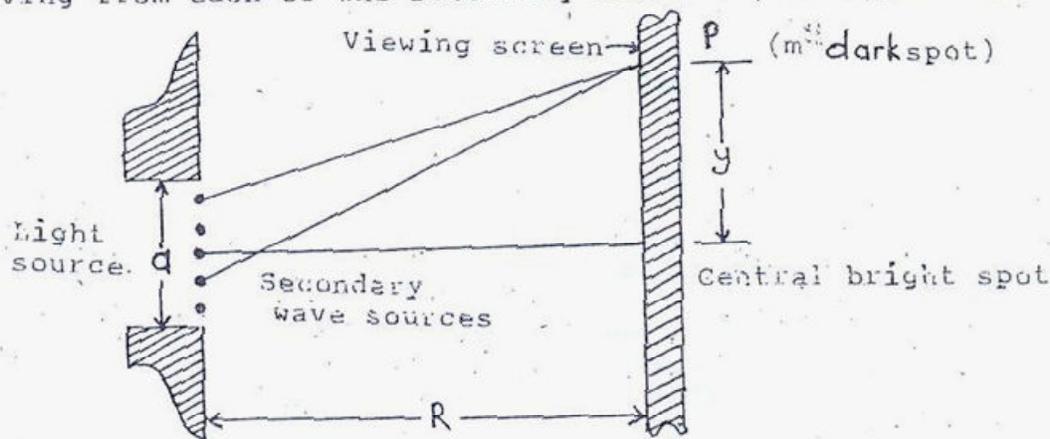


Fig. 4 Diffraction of light from a single slit.

By means of an analysis similar to the one employed for interference, the condition for viewing the dark spots in the diffraction pattern can be shown to be

$$m\lambda = \frac{ay}{R} \quad (7)$$

where

- a = slit width
- λ = wavelength of light
- R = distance from the slit to the viewing screen
- y = linear distance from the m th dark spot to the central bright spot
- $m = 0, 1, 2, 3, \dots$

D. Experimental Determination of the Width of a Single Slit Using a Diffraction Pattern

If light from a laser beam is used to illuminate a narrow slit, the resulting diffraction pattern can be used to determine the width of the single slit. In particular, if the distance y (for the m th dark spot) are measured, then equation 7 can be used to find a , the slit width. That is,

$$a = \frac{m\lambda R}{y}$$

We can assume that the value of the wavelength of light is the experimental value obtained when using an interference experiment.

CAUTION: Do not leave the laser operating and unattended. Do not look directly into the laser beam or its reflection.

PROCEDURE

A. Determination of the Wavelength λ of Laser Light, Using a Double-Slit Interference Pattern

1. Turn on the laser and shine it onto a wall about 3 m from the laser. Measure the distance R from the laser to the wall with a double meterstick. Convert this distance to meters and record on your data sheet.
2. Hold the slit film so that the column of double slits is vertical. Determine the slit separation d in millimeters of the second double slit from the top by reading the number just to the right of the double slit. Convert this value to meters and record on your data sheet.

Position the slit film so that it touches the laser. The laser beam passes through the second double slit from the top.

3. Observe the interference pattern formed on the wall. Label each bright spot with the appropriate value of m . Remember that the central bright spot corresponds to $m=0$. The first bright spots on either side of the central bright spot correspond to $m=1$, the second bright spots on either side of the central bright spot correspond to $m=2$, and so forth. Measure the linear distance y from the central bright spot ($m=0$) to the first bright spot ($m=1$) on the left side of the central bright spot. Convert this value to meters and record on your data sheet.

Measure the linear distance y from the central bright spot ($m=0$) to the first bright spot ($m=1$) found on the right side of the central bright spot.

central bright spot. Convert this value to meters and record on your data sheet.

4. Calculate the average of the two distances from the central bright spot to the first bright spot on either side. Record this value on your data sheet.

5. Use equation 6 to calculate the wavelength λ of the laser light (substitute the average distance found in step 4 as y and $m=1$).

6. Measure the linear distance y from the central bright spot ($m=0$) to the second bright spot ($m=2$) found on the left side of the central bright spot. Convert this value to meters and record on your data sheet.

Measure the linear distance y from the central bright spot ($m=0$) to the second bright spot ($m=2$) found on the right side of the central bright spot. Convert this value to meters and record on your data sheet.

7. Turn off the laser. Calculate average of the two distances from the central bright spot to the second bright spot on either side. Record this value on your data sheet.

8. Use equation 6 to calculate the wavelength λ of the laser light (substitute the average distance found in step 7 as y and $m=2$).

9. Find the average value of the laser light wavelengths found in steps 5 and 8. Record this value on your data sheet as the experimental value of the wavelength λ of the laser light.

10. Record on your data sheet the standard value of the wavelength λ of the laser light (the theoretical value of the wavelength is marked on the laser itself). ($\lambda=6.328 \times 10^{-7}\text{m}$.)

11. Calculate the percentage error in your experimental result. Record this value on your data sheet.

B. Determination of the Width of a Single Slit Using a Diffraction Pattern

1. Turn on the laser and shine it on a wall about a few meter away from the laser. Measure the distance R from the laser to the wall, using a double meterstick. Convert this distance to meters and record on your data sheet.

2. Hold the slit film so that the column of single slit is vertical. Determine the slit width of the second slit from the bottom by reading the number just to the left of the slit. Record this value in points on your data sheet. Convert this value from points to meters and record on your data sheet as the theoretical

value of slit width.

Position the slit film so that it touches the laser and the laser beam passes through the second single slit from the bottom.

3. Observe the diffraction pattern formed on the wall. Label each dark with the appropriate value of m . Remember that the first dark spots on either side of the central bright spot correspond to $m=1$, the second dark spots on either side of the central bright spot correspond to $m=2$, and so forth. Measure the linear distance y from central bright spot ($m=0$) to the center of the first dark spot ($m=1$) found on the left side of the central bright spot. Convert this value to meters and record on your data sheet.

Measure the linear distance y from the central bright spot ($m=0$) to the center of the first dark spot ($m=1$) found on the right side of the central bright spot. Convert this value to meters and record on your data sheet.

4. Calculate the average of the two distances from the central bright spot to the center of the first dark spot on either side. Record this value on your data sheet.

5. Use equation 8 to calculate the slit width a (substitute the average distance found in step 4 as y ; substitute the value of wavelength λ found in step 9 of part A, and substitute $m=1$).

6. Measure the linear distance y from the central bright spot ($m=0$) to the center of the second dark spot ($m=2$) found on the left side of the central bright spot. Convert this value to meters and record on your data sheet.

Measure the linear distance y from the central bright spot ($m=0$) to the center of the second dark spot ($m=2$) found on the right side of the central bright spot. Convert this value to meters and record on your data sheet.

7. Turn off the laser. Calculate the average of the two distances from the central bright spot to the center of the second dark spot on either side. Record this value on your data sheet.

8. Use equation 8 to calculate the slit width a (substitute the average distance found in step 7 as y ; substitute the value of wavelength λ found in step 9 of part A, and substitute $m=2$).

9. Find the average value of the slit widths found in steps 5 and 8. Record this value on your data sheet as the experimental value of the slit width a .

10. Calculate the percentage error in your experimental result. Record this value on your sheet.

QUESTIONS

- 1) Why is a coherent light source (a laser) used in this experiment?
- 2) Explain the difference between diffraction and interference effects?
- 3) Why do the phenomena of interference and diffraction themselves constitute experimental evidence supporting the wave theory of light? Explain
- 4) Suppose that white light was used to study the interference phenomenon. Describe the appearance of resulting interference pattern.
- 5) Suppose monochromatic light falls on a small circular slit. Are there any diffraction effect? If so describe the resulting diffraction pattern.

REFERENCES

- 1- Peter J.Nolan and Raymond E.Bigliani, Experiments in Phys. Wm.C. Brown Publishers, (1995). P.399

PRELAB QUESTIONS

1. What is the Huygen's theorem and how can you explain the diffraction pattern of the single slit experiment using this theorem?
2. Explain how constructive and destructive interference of two monochromatic light waves are produced? How bright and dark spots are produced on the screen? What is the importance of the interference and diffraction experiment in physics?
3. In a double slit experiment the slit separation is 5.0 mm and the slits are 1.0 m from the screen. The interference pattern can be seen on the screen due to one light of wavelength 4800\AA and another of wavelength 6000\AA . What is the separation on the screen between the second order interference fringes of the two different patterns?

EXPERIMENTAL VERIFICATION OF DE BROGLIE'S HYPOTHESIS

ELECTRON DIFFRACTION

Purpose: With the electron diffraction tube, the particle and wave characteristics of electrons can be demonstrated and studied. In comparison with other experiments in the Quantum Physics of electrons, the method of electron diffraction on a crystal grid proves particularly advantageous because; the diffracted image can be made directly visible with the help of a fluorescent screen and only one simple compact test instrument to operate is required. The electron diffraction tube enables the de-Broglie's principle to be proved experimentally and with considerable accuracy, as a basis for a wave particle dualism (wavicle) applicable to electrons.

Theory: Max von Laue, in 1912, suggested that because of their regular arrangement of atoms, crystals might be used as diffraction gratings for X-rays. X-rays are electromagnetic radiation of about 1 \AA in wavelength, the same order of size as the inter atomic spacing in a typical crystal.

The theory of X-ray diffraction was developed by Sir William H. Bragg in 1913. Bragg showed that a plane of atoms in a crystal, called a Bragg plane, would reflect radiation in exactly the same manner that light is reflected from a plane mirror, as shown in Figure 1.

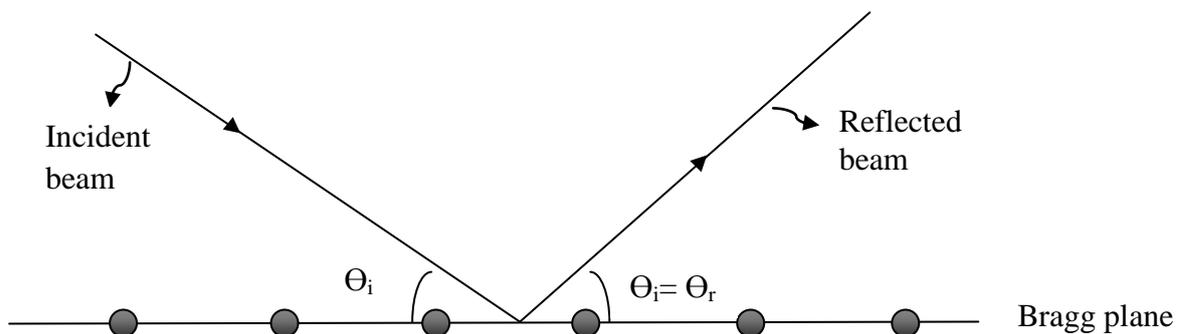


Figure 1

If one considers radiation that is reflected from successive parallel Bragg planes spaced a distance “d” apart, it is seen from Figure 2 that it is possible for the beams reflected from each plane to interfere constructively to produce an enhanced overall reflected beam. The condition for constructive interference is that the path difference between the two rays $n\lambda = 2d\sin\theta$ be equal to an integral number of wavelengths, thereby giving Bragg's law as

$$n\lambda = 2d\sin\theta \quad n=1,2,3,\dots \quad (1)$$

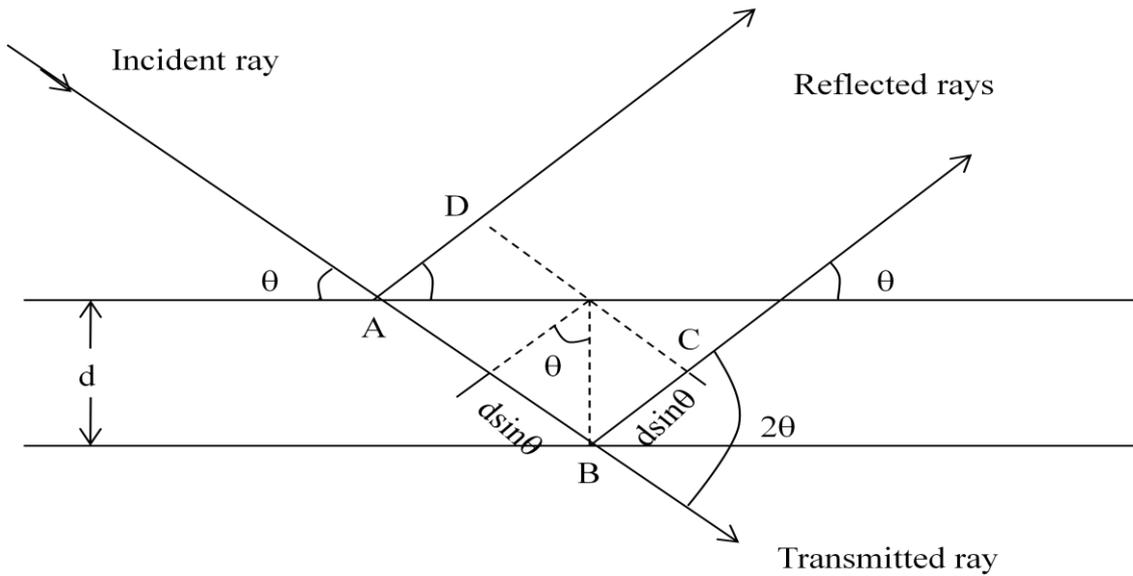


Figure 2

The first experiments to observe electron diffraction were performed by C.J. Davisson and L.H. Germer. Shortly after this experiment, G.P. Thomson, in 1927, studied the transmission of electrons through thin metal foils. If the electrons behaved like particles a blurred image would have resulted in the transmitted beam. Instead, Thomson found circular diffraction patterns, which can be explained only in terms of a wave picture, further confirming de-Broglie's hypothesis. Subsequently, thermal (low energy) neutron diffraction experiments were performed that further upheld the de-Broglie hypothesis.

Example: A narrow beam of 50 keV electrons passes through a thin silver polycrystalline foil. The interatomic spacing of silver crystals is 4.08 \AA . Calculate the radius of the first order diffraction pattern from the principal Bragg planes on a screen placed 40 cm behind the foil.

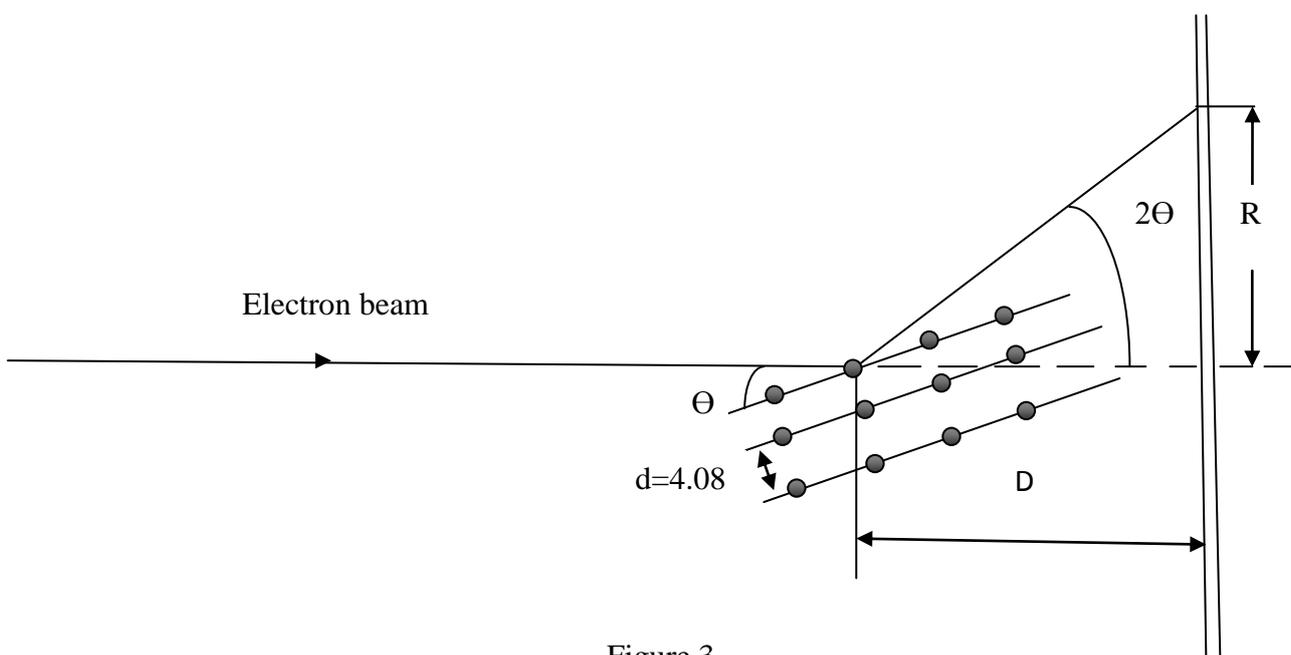


Figure 3

The de-Broglie's wavelength for the electron beam is

$$\lambda = \frac{hc}{pc} = \frac{hc}{\sqrt{E^2 - E_0^2}} = \frac{hc}{\sqrt{(K + E_0)^2 - E_0^2}} \quad (2)$$

$$= \frac{12.4 \times 10^3 \text{ eV } \text{Å}}{\sqrt{(60 \times 10^3 \text{ eV} + 511 \times 10^3 \text{ eV})^2 - (511 \times 10^3 \text{ eV})^2}} = 0.0487 \text{ Å}$$

For first order Bragg reflection;

$$\sin\theta = \frac{\lambda}{2d} = \frac{0.0487 \text{ Å}}{2(4.08 \text{ Å})} \quad (3)$$

From which $\sin\theta = 0.342$ from figure 3 the radius of the first order diffraction pattern is given by

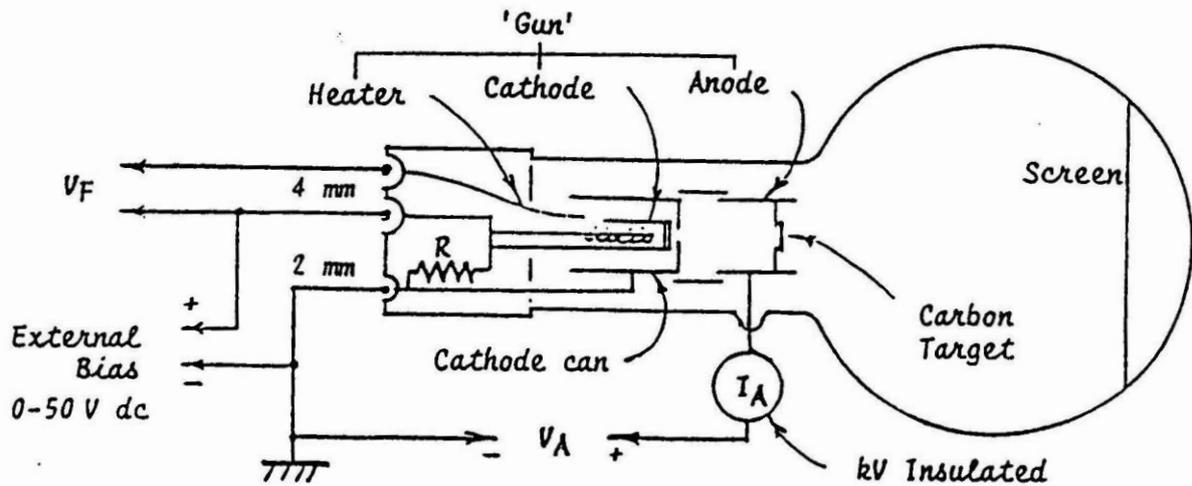
$$R = D \tan 2\theta = (40 \text{ cm}) \tan 0.648 = 0.478 \text{ cm}$$

Procedure: A similar calculation can be made using Carbon and assuming that its atomic system is cubic, 12 gms of Carbon contain 6×10^{23} atoms (Avogadro's number), the density of Carbon is about 2 gms per cm^3 , 1 cm^3 contains 10^{23} atoms so that adjacent Carbon atoms will be $3\sqrt{10}$ or a little over 0.2nm apart. It is thus reasonable to expect that Carbon should provide a grating of suitable spacing for a diffraction experiment. Because a calculation using de-Broglie's equation shows that electrons accelerated true a potential difference 4 kV has a wavelength of about 0.002 nm.

Connect the electron diffraction tube in to the circuit shown in Fig. 4 switch on the heater supply and wait 1 minute for the cathode to heat stabilize. Adjust the E.H.T setting to 4.0 kV.

Specification:

Filament Voltage (V_F)6.3 V ac/dc (8.0 V max.)
 Anode Voltage (V_A).....2500 - 5000 V dc
 Anode Current (I_A)..... 0.15 mA at 4000 V (0.20 mA max.)



Note that connect the E.H.T negative to the 2mm socket only

Figure 4.

Two prominent rings about a central spot are observed, the radius of the inner ring being in fair agreement with the calculated value of 14 mm. Variation of the anode voltage causes a change in diameter, a decrease in voltage resulting in an increase in diameter. This is in accord with de-Broglie's suggestion that wavelength increases with decrease in momentum. Evidence of the particulate nature of the electron has been previously obtained and so this demonstration, which so closely resembles the optical one, reveals the dual nature of the electron.

The de-Broglie wavelength of a material particle is

$$\lambda = \frac{h}{mv} \quad (4)$$

Where "h" is Planck's constant. The velocity, "v" can be obtained from the classical expression

$$eV_a = \frac{1}{2}mv^2 \quad (5)$$

And substituted into the de-Broglie relation, obtaining

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2emV_a}} = 1.23V_a^{-1/2}nm \quad (6)$$

The condition for first order (m=1) diffraction for small angles is

$$\lambda = d\theta \quad (7)$$

Where the small angle θ can be calculated from the geometrical relationship of Figure 5

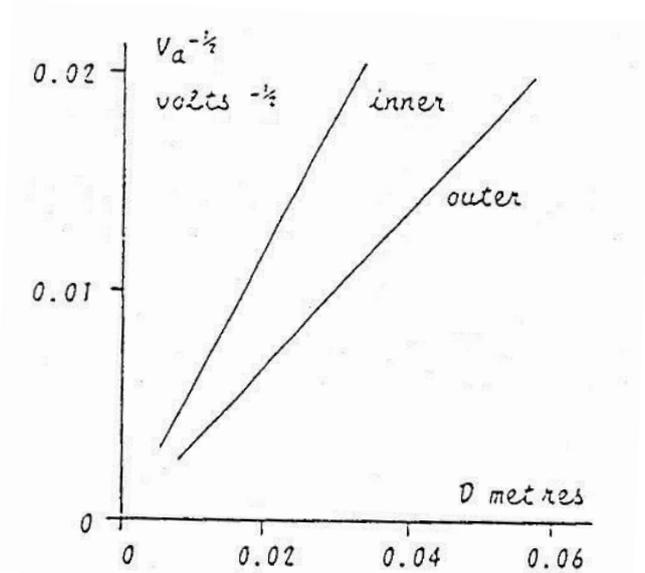
$$\theta = \frac{D/2}{L} \quad (8)$$

And so from Eq.6

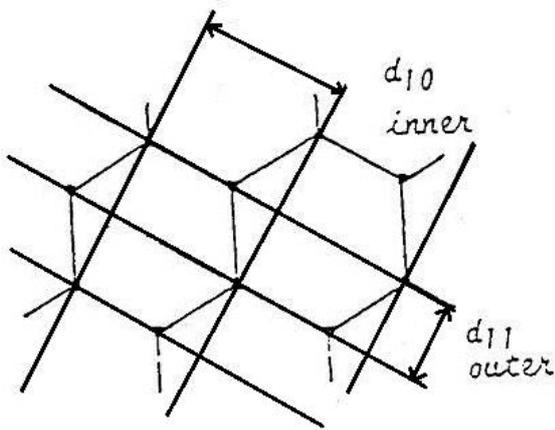
$$D \frac{d}{2L} = 1.23V_a^{-1/2}nm \quad (9)$$

D and V_a are the only variables; tabulate D for different anode voltages V_a and plot the graph D proportional to $V_a^{-1/2}$.

(kV)	()	D (meters)	
		Inner	Outer
2.5	0.0200		
3	0.0183		
3.5	0.0169		
4	0.0158		
4.5	0.0149		
5.0	0.0141		



Measure the pathlength from the carbon target at the gun exit aperture to the luminescent screen L m, as accurately as possible using back-reflection technique ($0.140 \pm 0.003m$).

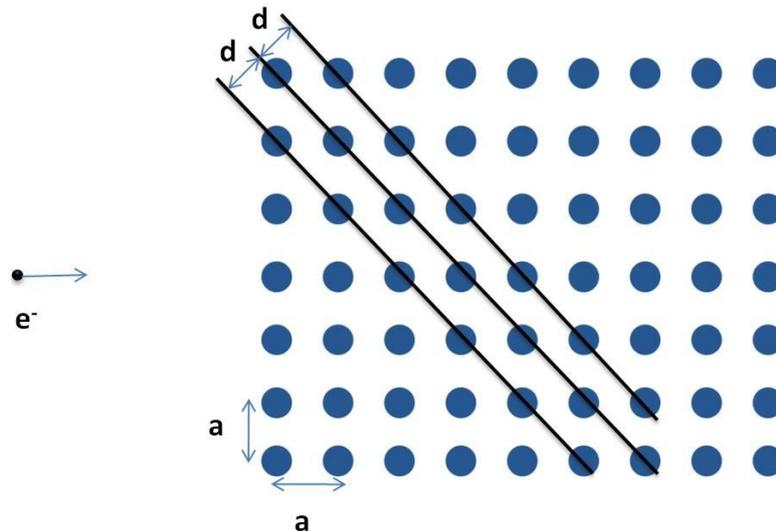


Rearrange the Eq.9 and evaluate the interatomic spacing d using the gradients of the graphs of the outer and inner circles, compare with the established figures of $d_{11}(0.123)$ and $d_{10}(0.213)nm$.

These result verify the theory and substantiate the de Broglie hypothesis, note the arrangement of the spacing is $\sqrt{3}:1$ which suggests that the arrangement of the Carbon is most likely to be hexagonal rather than the assumed cubic.

QUESTIONS

1. A 0.083 eV neutron beam scatters from an unknown sample and Bragg reflection peak is observed centered at 22° . What is the Bragg plane spacing?
2. A crystalline material has a set of Bragg planes separated by 1.1 \AA . For 2 eV neutrons, what is the highest order Bragg reflections?
3. Rock salt forms a cubic lattice with the sides of each plane having a length $a=5.68 \text{ \AA}$. An electron beam is incident on a rock salt as shown in the figure below:
 - a. What is the spacing between the lattice planes indicated by dashed lines?
 - b. Through the smallest potential should the electrons be accelerated if they tend to be reflected strongly off the planes indicated by the dashed lines?



REFERENCES

1. The manual on the electron diffraction tube prepared by Teltron Limited.
2. R.Gautream and W.Savin, Modern Physics (Chapter 16). McGraw-Hill (1978)

PRELAB QUESTIONS

1. Prove that the formulation for the Bragg law is $2 d \sin\phi = n \lambda$
2. What is the aim of the electron diffraction experiment? What is the De Broglie hypothesis? In which part of the experiment we use de Broglie hypothesis and in which part we use Bragg law to explain the experiment. What is the relationship between wavelength and applied voltage?
3. Is this experiment valid only for electron or is it valid for different particles too? For example can we use proton instead of electron in this experiment, in that case what do we observe in the screen? Please explain.

Uncertainty Principle

OBJECT: Investigation of the minimum uncertainty in the position of a beam, diffracted at a slit, as a function of the slit width.

THEORY:

The uncertainty principle is often explained as follows: Dynamical variables such as position, momentum, angular momentum etc., must be defined operationally, i.e., in terms of the experimental procedures through which they are measured. If we now analyze realistic procedures of measurement in microphysics, it turns out that a measurement will always perturb the system; there is characteristic unavoidable interaction between the system and the measuring apparatus. If we try to measure the position of a particle very accurately, we will perturb it in such a way that its momentum after the measurement is very uncertain. If we try to measure momentum very accurately we perturb it in such a way that its position will be very uncertain. If we try to measure both the position and the momentum of the particle simultaneously, then these two measurements will necessarily interfere with each other in such a way that the accuracy of the final result will be subject to the

$$\Delta p \Delta x \geq \frac{\hbar}{2} \quad (1)$$

Inequality. Here Δp is the root-mean-square error in p and Δx is the root-mean-square error in x and the inequality thus asserts that the two variables p and x can not be known more accurately than the product of the uncertainties of the two variables is of the order of Planck's constant. So, the position and momentum of a particle cannot be simultaneously measured with arbitrarily high precision. There is a minimum for the product of the uncertainties of these two measurements as seen in Eq (1). This is not a statement about the inaccuracy of measurement instruments, nor a reflection on the quality of experimental methods; it arises from the wave properties inherent in the quantum mechanical description of nature. Even with perfect instruments and technique, the uncertainty is inherent the nature of things.

To illustrate the implications of the uncertainty relations let us study to what precision a classical trajectory can be assigned to a light beam in a particular case. The situation is illustrated in Fig.1 (a through d). A beam of light, it is described by a plane wave, is incident from the left on the screen at left. The screen has a slit of width "a". We wish to select d in such a way that the spot produced on the screen at right by beam passing through the slit is as narrow as possible. The distance between the two screen is "L".

We assume that the beam has the incident momentum "p". If the beam passes through the screen at left, the uncertainty in its lateral position will be "a" ($\Delta x = a$). The uncertainty Δp in its lateral momentum is then given by

$$\Delta p = \frac{\hbar}{2a}, \quad (2)$$

If we suppose that Δp is small compared to “p”, we can restate Eq. (2) in terms of the uncertainty $\Delta\theta$ in the angle “ θ ” (with respect to the incident direction) with which the beam emerges, and we have

$$\Delta\theta = \frac{\Delta p}{p} = \frac{\hbar}{2 p a}, \quad (3)$$

Let Δx measures the size of the spot produced on the screen at right. The magnitude of the Δx is determined by two things; the size of the opening in the screen at left, and the spreading of the wave by diffraction at the slit (See Fig.1). We can therefore write

$$\Delta x = a + L \Delta\theta = a + \frac{\hbar L}{2 p a}, \quad (4)$$

Since the wavelength λ is given by $\lambda = h/p$, we can rewrite Eq.(4) in the form

$$\Delta x = a + \frac{\lambda L}{4 \pi a}, \quad (5)$$

We see that if we make “a” too small, the second term in Eq.(5) will become large because of the diffraction effects, whereas the first term is large if the width “a” of the slit is large. It is a simple problem in calculus to determine the value a_0 of “a” for which the estimate (Eq.5) for Δx assumes its minimum Δx_{min} and we find

$$\frac{d(\Delta x)}{d(a)} = \left(1 - \frac{\lambda L}{4 \pi a^2}\right) \Big|_{a=a_0} = 0, \quad (6)$$

$$a_0 = \sqrt{\frac{\lambda L}{4 \pi}}, \quad (7)$$

and finally

$$\Delta x_{min} = 2 a_0 = \sqrt{\frac{\lambda L}{\pi}},$$

In the optimum case the spot on the right screen is twice as large as the slit opening in the left screen.

Performace of the Experiment

Using the different slit openings and gratings with laser of known wavelength (632.8 nm), try to prove the Eq. (5) for each case as a function of the “L” and “a”.

WARNING: Do not stare into beam. Te laser beam may cause retinal damage if you have prolonged viewing down the beam. Under no circumstances view the laser directly.

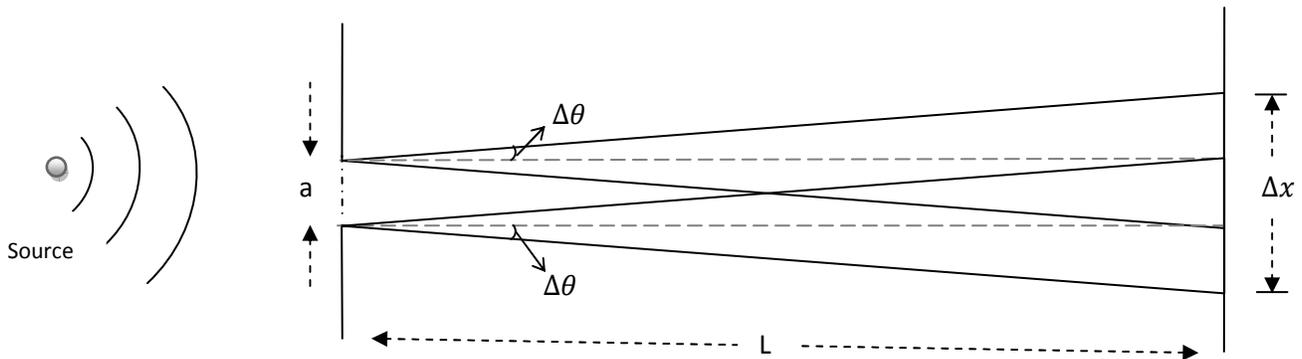


Figure 1: Experimental Setup

In Figure 1 it is attempted to produce a narrow beam of light by limiting a broad beam incident from the left by the slit in the screen at left. The beam is diffracted at the slit, and the uncertainty $\Delta\theta$ in the angle at which the light beam leaves the slit is inversely proportional to the width “a” of the slit. The size of the spot on the screen at right is given by $\Delta x \sim (a + L \Delta\theta)$. The smallest spot is obtained by selecting $a \sim \sqrt{\lambda L}$, in which case the size of spot is of the same order magnitude.

Questions

1. Discuss the sources of the error in your experiment.
2. Why is it better to use narrow slit opening?
3. For Δx_{min} to occur in the experiment what condition must be satisfied?
4. If you were used “electron beam” instead of laser light, would there be any different in the view on the screen? What would be the minimum kinetic energy of the elcetron beam?
5. Write the other conditions of uncertainty principle.

6. Show that the Heisenberg Uncertainty Principle can be employed to accept the idea that the electron is confined in an atom. Assume that the atomic size = 0.4 nm.
7. Show that the Heisenberg Uncertainty principle can be employed to refuse the idea that the nucleus consists of protons and electrons.

Prelab Questions

1. Explain in detail the physical meaning of the Heisenberg Principle in both its energy-time and position-momentum forms.
2. Describe the change in width of the central maximum of the single-slit diffraction pattern as the width of the slit is made narrower. How can you explain this result with uncertainty principle?
3. Obtain expression for Δx_{\min} .
4. If the slit width is 1.5 mm and the laser has 6328×10^{-10} m wavelength light, what should be the minimum distance between the slit and the screen to satisfy the minimum condition for Δx_{\min} and what is your expectation if you make the slit narrow?

THE ATOMIC SPECTRA

Purpose: To study the relationship of atomic spectra to energy levels of atoms.

Theory: The main relation between the atomic structure and spectra is the existence of discrete energy levels in atoms. According to the Bohr's postulates for model of the hydrogen atom:

1. the single electron in the hydrogen atom moves around the nucleus in circular orbits in which the electrostatic attraction between the negatively charged electron(-e) and the positively charged nucleus(Ze) is exactly balanced by the centrifugal force due to the velocity of the electron in its orbit

$$\left| Z \frac{e^2}{r^2} \right| = m \frac{v^2}{r} \quad (1)$$

where $1/4\pi\epsilon_0 = 1$ in the unit system used here.

2. while in a given orbit, the energy of the electron is constant. Furthermore, the electron remains in a given orbit unless a quantum of energy the right amount is absorbed or emitted
3. only certain orbits are allowed. Such orbits are restricted to those for which the angular momentum L of the electron is an integral multiple of \hbar

$$L = mvr = n\hbar, \quad n = 1, 2, 3, \dots \quad (2)$$

4. when an electron makes a transition from an initial stationary energy level E_i to a final stationary energy state E_f , the energy difference is emitted as a single photon such that

$$E_i - E_f = h\nu \quad (3)$$

where ν is the frequency of the corresponding spectral line. Conversely, if the energy is absorbed by an electron, the same equation must apply. That is, the wavelength of the absorbed photon is given by eqn.(3).

Considering to the above postulates, we can solve the problem mathematically. The total energy E of the electron in its orbit is given as the sum of its kinetic energy T and its potential energy U:

$$E = T + U = m \frac{v^2}{2} - Z \frac{e^2}{r} \quad (4)$$

We may now substitute eqn.(1) into eqn.(4) to obtain

$$E = Z \frac{e^2}{2r} - Z \frac{e^2}{r} = -Z \frac{e^2}{2r} \quad (5)$$

Substitution of the quantum restriction eqn.(2) into eqn.(4) yields

$$v = Z \frac{e^2}{n\hbar} \quad , \quad n = 1, 2, 3, \dots \quad (6)$$

Allowed energies in each of the stationary states or orbits may be generated by squaring eqn.(6) ,

$$v^2 = \left[\frac{Z^2 e^4}{(n^2 \hbar^2)} \right] \quad , \quad n = 1, 2, 3, \dots \quad (7)$$

It is also convenient to combine eqn. (7) with eqn. (5) to eliminate E:

$$E_n = - \left(Z \frac{e^2}{2r} \right) = - \left[\frac{(mZ^2 e^4)}{(2n^2 \hbar^2)} \right] \quad (8)$$

where e is the electron charge , $\hbar = h/2\pi$, and n is a positive integer called the principal quantum number. The ground state is the lowest energy state with $n=1$. The energy $E=0$, with $n=\infty$ corresponds to a state in which the electron has been completely separated from the proton and is at rest.

If the proton were infinitely heavy, the mass m in eqn.(8) would be only the electron mass. Since the proton has a finite mass, the electron and the nucleus must each revolve about a common center of mass on a line connecting the two particles. The appropriate correction for the finite mass M of proton is obtained by replacing the electron mass m by the reduced mass μ of the atom, defined as

$$(1/\mu) = \left[(1/m) + (1/M) \right] \quad (9)$$

This replacement decreases the magnitudes of all energy levels by approximately 0.05% compared to the values they would have with $M=\infty$.

The lines in hydrogen spectrum correspond to all possible transitions between energy levels. The wavelengths of these lines are given with respect to eqn. (3) and eqn. (8), by

$$(1/\lambda) = \left[(E_i - E_f) / (hc) \right] = - \left[Z^2 \mu e^4 / (4\pi \hbar^3 c) \right] \left[(1/n_f^2) - (1/n_i^2) \right] \quad (10)$$

where n_i and n_f represent the quantum numbers of the initial and final states, respectively. The combination of constant in the first square bracket parentheses in eqn.(10) is called the Rydberg constant (abbreviated R_H). The subscript H (for hydrogen) distinguishes it from the corresponding constant containing m rather than μ , which is denoted by R_∞ (means that proton has the infinitely heavy mass).

Thus the wavelengths of the Hydrogen spectrum are given by

$$(1/\lambda) = Z^2 R_\infty \left[(1/n_f^2) - (1/n_i^2) \right] \quad (11)$$

for Hydrogen $Z=1$,

$$(1/\lambda) = R_H \left[(1/n_f^2) - (1/n_i^2) \right]$$

The numerical value of the Rydberg constant, which has been determined very precisely by spectroscopic measurements, is

$$R_H = 109677.57 \text{ cm}^{-1}$$

In particular, the transition in the Hydrogen atom from higher initial states to the final state $n_f = 2$ yields wavelengths in the visible region of the spectrum, with wavelengths given by

$$\begin{aligned} (1/\lambda) &= R_H \left[(1/2^2) - (1/n_i^2) \right] = R_H \left[(n^2 - 4)/(4n^2) \right] \\ &= R_H \left[(n^2 - 4)/(4n^2) \right] \quad ; \quad n = 3, 4, 5, \dots \end{aligned} \quad (12)$$

This series of lines are called the Balmer series (eqn.(12) was discovered empirically by trial and error in 1885, long before its relation to the structure of the Hydrogen atom was understood). Table 1. shows the remarkable agreement between observed wavelengths and those computed from the Balmer formula. This table also shows the usual spectroscopic notation used to designate these lines.

Table 1. The Observed and Computed Wavelengths of the Balmer Series

Line	n	$\lambda(\text{observed}), \text{Å}^\circ$	$\lambda(\text{computed}), \text{Å}^\circ$
H $_\alpha$	3	6562.79 (red)	6562.80
H $_\beta$	4	4861.327(blue-green)	4861.33
H $_\gamma$	5	4340.47 (blue)	4340.48
H $_\delta$	6	4104.74 (violet)	4101.75
H $_\epsilon$	7	3970.07 (ultraviolet)	3970.08
H $_\zeta$	8	3889.06 (ultraviolet)	3889.06

For more complex atoms it is not practical to calculate the energy levels, but they can be deduced from spectra. In every case there is a direct correspond between a spectrum line and a transition from one energy level to another. For example, in use of ${}^{22}_{11}\text{Na}_{11}$ we can safely assume that one proton inside the nucleus interacts through the Coulomb potential by the valence electron circulating in 3s-state in Sodium atom due to the electron cluster (other ten electrons) other ten protons interaction inside the nucleus. This picture seems exactly the Hydrogen atom, to which Bohr model can be easily applied.

PERFORMANCE OF THE EXPERIMENT

A. DIFFRACTION GRATING and SPECTROMETER:

The diffraction grating provides the simplest and most accurate method for measuring wavelengths of light and separation of the spectral lines associated with atomic transitions. It consists of a very large number of fine, equally spaced, parallel slits, usually thousands of lines (slits) per centimeter. Diffraction gratings can utilize both reflection (light reflects off the surface) or transmission (light passes through).

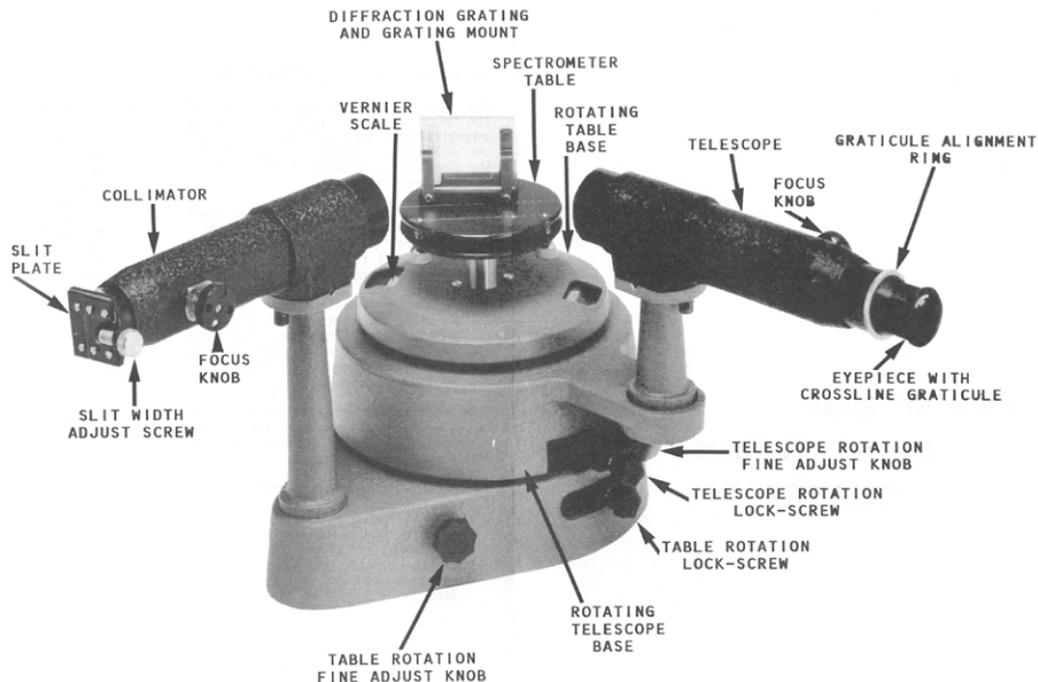
The constructive interference from all the “slits” in the grating will occur at the same angle and make the lines that much brighter. However, the destructive interference will also be more effective. Just as the double slit produces lines of higher order when the path length difference is an integer multiple of one wavelength, so will the grating. The conditions for constructive interference are given by

$$a \sin \theta = m \lambda \quad (13)$$

where m is called the order of the spectrum, λ is the wavelength, a is the spacing between grating lines, and θ is the diffraction angle measured with respect to the direction of the light incident on the grating.

The primary parts of the spectrometer are:

- **Collimator:** A slit and a converging lens are located at opposite ends of the collimator tube. When the slit is illuminated and positioned at the focal point of the lens, parallel rays of light will exit from the lens.
- **Table:** A central horizontal shelf for mounting either a prism or a grating.
- **Telescope:** An objective lens focuses the entering parallel rays in a plane so that the real image can be observed with the aid of the eyepiece. **Cross hairs** \otimes located in the focal plane of the objective lens provide a precise means for locating the direction of these rays.
- **Angular scale:** A circular scale of 360° can be anchored to the arm that supports the telescope. This allows you to determine the angular position of the telescope relative to the collimator from the reading of a **vernier** scale fixed to the base of the spectrometer.



Initial Setup and Adjustments:

Focus the telescope eyepiece on the cross hairs: Remove the telescope from the spectrometer mounting. Adjust the eyepiece until the cross hairs are in sharp focus.

Focus the telescope on an object which is "infinitely" far away: Sight with the telescope at some distant object. Adjust the **main telescope tube** until the object and the cross hairs are in sharp focus simultaneously. Thereafter, do not make any adjustments on the telescope.

Remount the telescope on the spectrometer. With the central table empty, loosen the set screw which locks the telescope in place. Move the telescope into line with the collimator. Place the mercury light source just behind the collimator entrance slit. While observing the slit through the telescope, slide the **collimator slit** tube in or out until the **vertical** slit image and the cross hairs are both in sharp focus. Thereafter, do not move the slit along the tube.

The collimator slit width is adjustable by a small screw near the slit. Use the screw to make the slit narrow enough to define the source position, yet wide enough to allow the passage of light sufficient for easy viewing. A narrow slit gives greater resolution and greater accuracy.

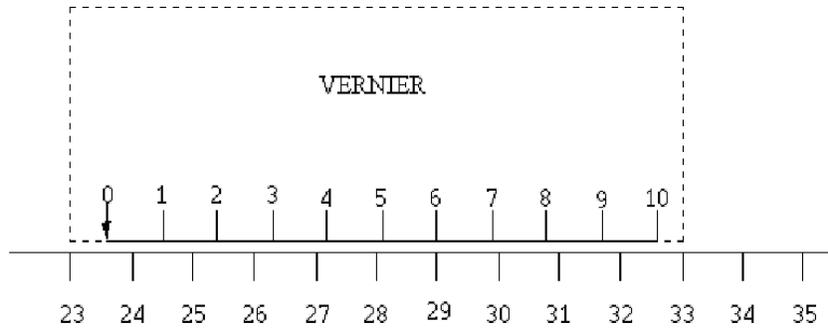
With the cross hairs centered on the slit image, loosen the set screw of the angular scale and adjust it to read 180.0 degrees for this straight through reading.

Rotate the spectrometer table so the groove across the diameter is approximately perpendicular to the light from the collimator and lock the table in this position.

Place the diffraction grating in the table groove such that the grating slits are vertical.

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.



B. HYDROGEN SPECTRUM

Hydrogen, being the simplest atom of one proton and one electron, has the simplest spectroscopic spectrum. By measuring the angles for the various spectrum lines and using the known value of the grating constant “a” the wavelengths in the hydrogen spectrum can be calculated and compared with the values in the Table I. Alternatively, if the grating constant “a” is not known, the spectrometer can be calibrated by regarding the Balmer wavelength as known and using them to determine grating constant.

We can also interpret the lines we see in the hydrogen spectrum and measure one of the most fundamental numbers of atomic physics, the Rydberg constant R.

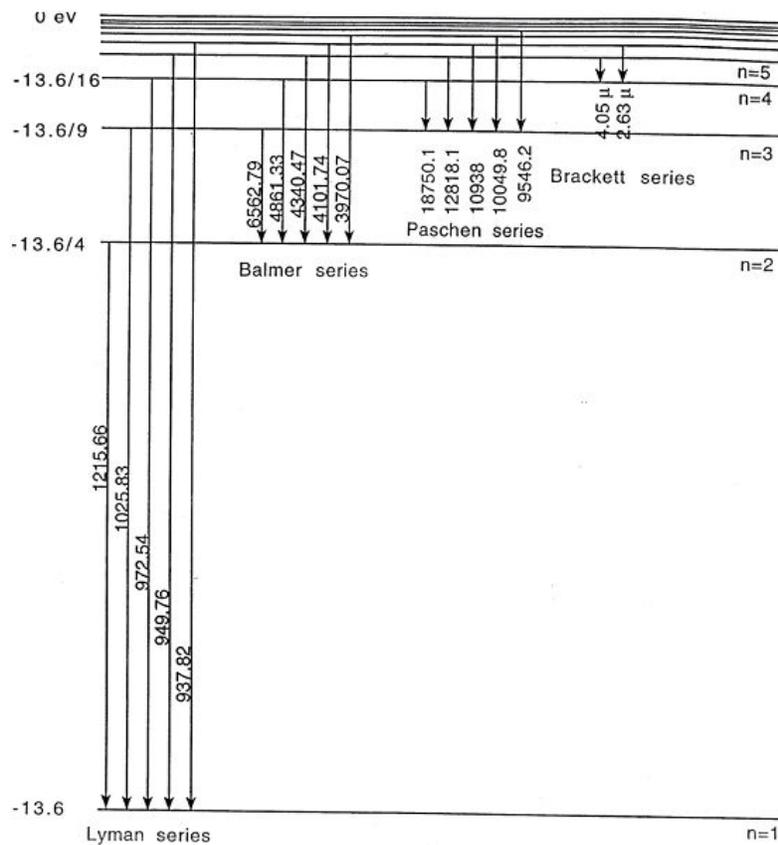


Figure 2. Hydrogen energy level diagram

Measure the position of the telescope for each of the visible lines in the hydrogen spectrum in first order. Identify each angle to indicate the corresponding color. Calculate the wavelength λ for each line observed in all orders, calculate the average wavelength value and uncertainty for each line, and then identify the initial and final electron states principle numbers (n_1 and n_2) for each line using Fig. 2.

Make a plot of $1/\lambda$ vs $1/n_1^2$ where n_1 = the principal quantum number of the electron's initial state. Put all λ values you measure above on this plot. Your data point should form a straight line. From Equation (11), determine the physical meaning of both slope and intercept, and compare the data from the fit to the expected values for each of them. The slope should be the Rydberg constant for hydrogen, R_H . The intercept is R_H/n_2^2 . From this, determine the value for the principal quantum number n_2 . Compare to the accepted value in the Balmer series.

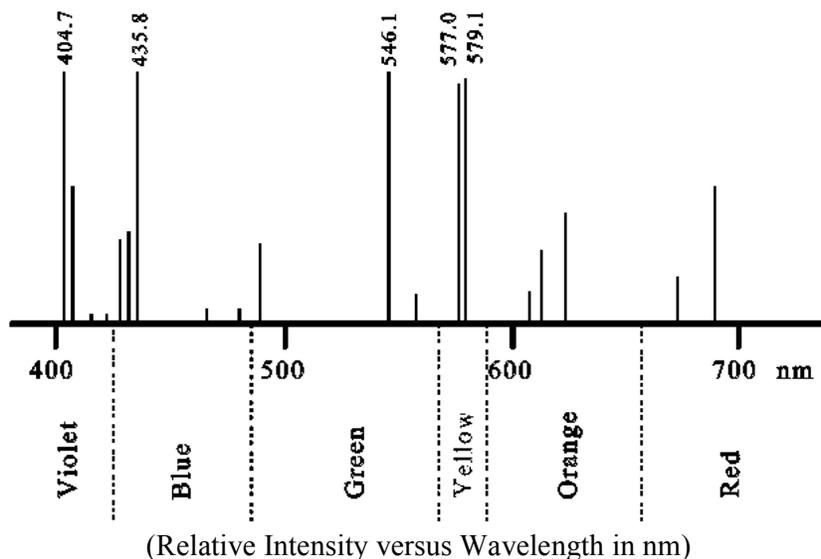
C. SODIUM SPECTRUM

Try to measure the separation of the sodium D lines. Measure the angular position for each sodium spectral line for as many orders as can be observed. At the end of this series, measure the 0th-order again and check if the cross wire and its reflection are still aligned. If the apparatus has been displaced during the experiment, this part of the measurement has to be repeated.

Sodium D lines are at $\lambda = 5889.95 \text{ \AA}$ and 5895.92 \AA . What is the angle between them in the first order spectrum? What angle has been measured? What is the angle between them in the second order spectrum? What angle has been measured? Find the percentage error of angle for first and second order diffraction.

D. MERCURY SPECTRUM

The structure and spectra of the Hg is very complicated, due to the large number of electrons ($Z = 80$).



Remove the sodium source and replace it with the mercury (Hg) source. Similarly identify each angle to indicate the corresponding color. Calculate the wavelength λ for each line, calculate the average wavelength value and then identify the initial and final electron states principle numbers (n_1 and n_2) for each line. Find the percentage error for each spectral line.

QUESTIONS

1. What is the aim and importance of the atomic spectra experiment? How many spectral lines could be produced by an atom that has four energy levels?
2. Discuss in detail the safety of using Bohr model to obtain Sodium spectrum. (Hint: Bohr model can be used for Hydrogen-like atoms)
3. Sodium (Na) lamps emit light when the atoms undergo a transition from an excited 3p level to a 3s level. There are actually two levels in the 3p group with different values of the quantum numbers m and s and with slightly different energies, explaining why sodium emits two spectral lines. The spectral line with a wavelength of $\lambda=589.0$ nm is the stronger (more intense) of the two lines. What is the energy of these photons? Express your answer in units of electron-volts and compare it with the ionization energy of a hydrogen atom.
4. Find the energy of the longest wavelength transition for the Balmer series of He^+ . ($Z=2$ for He)
5. A beam of electrons bombards a sample of hydrogen. Through what potential difference must the electrons have accelerated if the first line of Balmer series to be emitted?

References

- 1- http://webphysics.davidson.edu/course_material/py230l/spectra/spectra.htm
- 2- University of Virginia Physics Department PHYS 2040 Lab Manual, Spring 2010