

EXPERIMENT 1

STEFAN BOLTZMANN'S RADIATION LAW

AIM: Stefan Boltzmann's radiation Law describes the total emission of a black-body radiator. It states that the total radiation energy emitted by a black body into the space in front of its opening per unit time is proportional to the fourth power of its temperature. This relationship is experimentally verified.

APPARATUS: 1 small optical bench, 1 Moll's thermocouple, 1 microvoltmeter, 1 tube oven, tube oven table, 1 Temperature sensor, , 1 large stand base, 4 Leybold multiclamps.

METHODOLOGY:

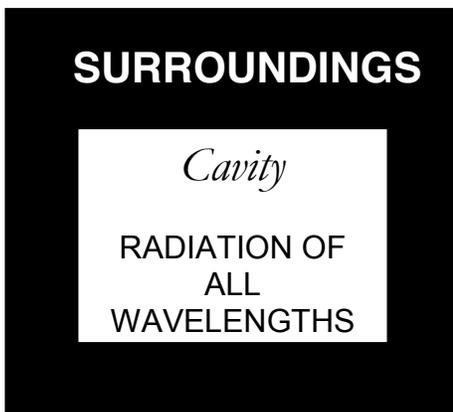
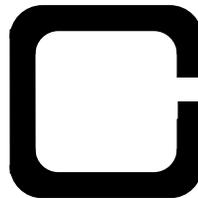


Figure 1.1. A blackbody

A blackbody absorbs all radiation incident on it. We picture it as a cavity in an enclosure where the temperature is uniform and constant. A blackbody must be in **thermal equilibrium**, emitting and absorbing radiation at the same rate with its surroundings.

In the laboratory we will approximate it as in Figure 1.2. with a hole letting out a sample of radiation to study

Figure 1.2. An approximation



According to the Stefan Boltzmann Law for a blackbody, the total energy emitted per second (power P) increases rapidly with temperature. It has been shown that the following relationship holds:

$$P = \sigma AT^4 \quad (1.1)$$

where T is the absolute temperature in Kelvin, A the surface area of the body and $\sigma = 5.6696 \times 10^{-8} \text{ Wm}^{-2} \text{ K}^{-4}$ is the Stefan-Boltzmann constant.

In this experiment the above relationship is verified. The blackened inner walls of an electrically heated tube are used as a black-body. The emitted radiation will be measured using a thermocouple.

A pinhole diaphragm, between the oven and the thermocouple restricts the view of the thermocouple to the radiating surface of the tube oven and screens environmental stray radiation (oven walls).

If the temperature of the thermocouple was absolute zero, its output voltage would be proportional to the incident radiation energy per unit of time as in (1.1).

However as it is at room temperature we have to take it into account, such that:

$$V \sim T^4 - T_o^4 \quad (1.2)$$

Where V is the output voltage of the thermocouple, T the temperature of the radiator and T_o , the room temperature. Finally V is plotted against $(T^4 - T_o^4)$.

PROCEDURE:

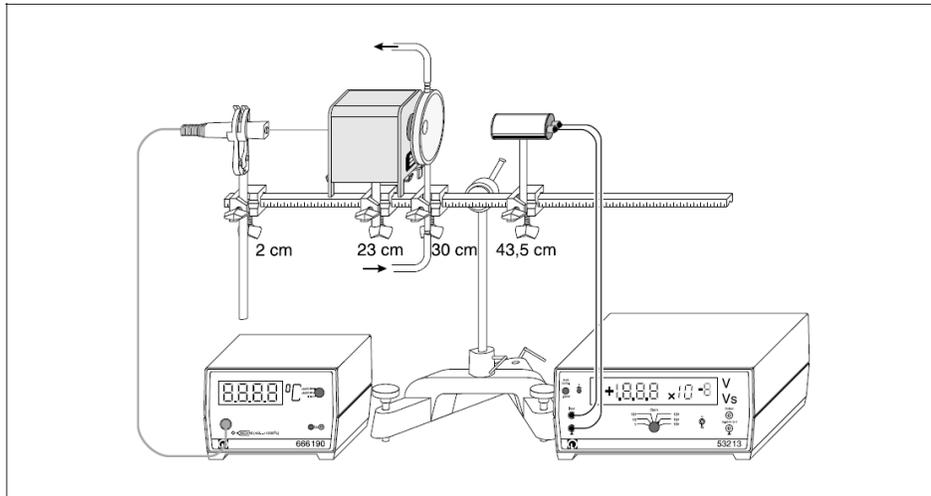


Figure 1.3: Experiment setup and electrical connections. In brackets: positions of the clamps (left clamp edge) on the optical bench.

(1) Temperature sensor, (2) oven, (3) Diaphragm, (4) Moll's thermocouple(the thermopile).

Experiment setup:

1. Make the necessary connections with regards to your experimental set up as in Figure 1.3 and take the room temperature.

Note: the glass window absorbs long-wave radiation more than short-wave radiation, and thus systematically falsifies the temperature-dependent measurement of radiant intensity.

2. Insert the temperature probe half-way through the oven and then turn on the mains supply.
3. Remove the glass window of the thermopile.
4. Mount the temperature sensor in place with the universal clamp S and switch on the digital thermometer (measuring range $> 200\text{ }^{\circ}\text{C}$).
5. Align the openings of the electric oven, the screen of the black body accessory and the thermopile so that the radiant
6. Heat is directly incident on the opening of the thermopile.
7. Connect the thermopile to the microvoltmeter as shown in Fig. 1 (measuring range 10^{-4} V); make sure the red socket on the thermopile is connected to the red socket on the microvoltmeter.
8. Compensate the offset by pressing the key “auto comp”; if necessary, carry out the fine adjustment using the potentiometer to set the digital display to zero (see Instruction Sheet for the microvoltmeter).
9. Attach the silicone tubing to the immersion pump and the screen so that the inflow is at the bottom hose nipple and the outflow is at the top hose nipple of the screen.
10. Fill the water vessel with water and attach the immersion pump to the rim of the water vessel e.g. using the mounting clamp so that the inlet opening is completely submerged and the maximum immersion depth of 17 cm is not exceeded (see Figure 1.4).

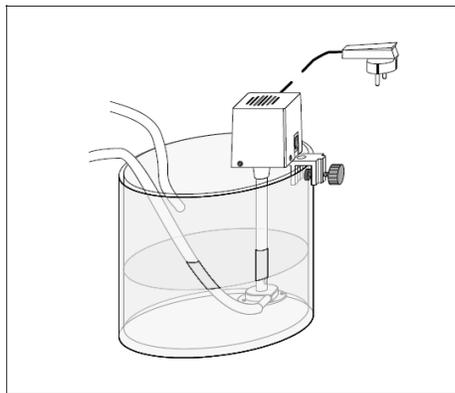


Figure 1.4: Setup example for mounting the immersion pump on the water vessel

Carrying out the experiment

- 1- Measure the temperature T of the brass cylinder and the initial output voltage U of the thermopile and write these values in your experiment log.
- 2- Switch on the electric oven; for each temperature increase of 25°C , write the measured values T and U in your experiment log.
- 3- When the temperature reaches a level between 400°C and 500°C , Switch off the electric oven; for each temperature decrease of 25°C , write the measured values T and U in your experiment log.

Name

TITLE OF EXPERIMENT

**STEFAN BOLTZMANN'S RADIATION LAW:
EXPERIMENT No 1**

MODERN PHYSICS LAB

PHYS 393 COURSEWORK

REPORTING SHEET

PART A: SCIENTIFIC KNOWLEDGE AND PLANNING [30 MARKS]

Aim:

Methodology - Draw your set up, explaining the use of the different components you will use to achieve your aim

5

How do you predict the plot between U_{therm} and T (temperature) to look like according to your knowledge of Stefan Boltzmann's radiation Law?

4

<p>Draw the intensity radiated by a blackbody versus the wavelength for different temperatures according to Wien.</p>	4
<p>Introduce graphs that describe the comparison between experimental evidence and the Rayleigh-Jeans Law in describing the black-body spectrum. What is meant by the ‘ultraviolet catastrophe’?</p>	4

<p>How did Planck explain the above controversy? Show that Planck's formula reduces to the Rayleigh Jeans law at short wavelengths.</p>	4
<p>A small hole in the wall of a cavity in an object of any kind behaves like an ideal body. At what rate does radiation escape from a hole 10 cm^2 in area in the wall of a furnace whose interior is at temperature of 700° C? You are given $\sigma=5.67 \times 10^{-8} \text{ W/m}^2 \text{ K}^2$</p> <p>(i) 53.56 W/s (ii) 13.60 W</p>	4

<p>(iii) 1.00 J/s (iv) 50.81 W</p>	
<p>Going to the lab to perform the above experiment, you found that the space was very little and had to set up the equipment vertically. Sketch the equipment and give reasons for your choice of ordering.</p>	5
PART B: OBTAINING EVIDENCE	
<p>Your data. Use the correct units and convert appropriately.</p>	

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PART C: ANALYSING AND CONSIDERING YOUR EVIDENCE

Graph (use graph paper)

Calculations

My evidence leads to the following result.

Compare your results with theoretical values.

PART D: EVALUATION [10 MARKS]	
What was good or bad about the experiment you did was ...	2
Some ways you could improve the experiment were...	2
You had the following anomalies.	2
The explanation for your anomalies was	2
You believe my evidence is reliable/unreliable for the following reasons.	2

- 4- When the temperature reaches a level between 100°C and room temperature, remove the temperature sensor from the electric oven, measure the room temperature and write this value in your experiment log.
- 5- Screen the thermopile with dark cardboard, check the zero point of the voltmeter and write this value in your experiment log.
- 6- Graph the results and find the slope

RESULTS TABLE

(T₀=.....K)

T (°C)	T (K)	T ⁴ (K)	T ⁴ - T ₀ ⁴ (K ⁴)	V (nvolt)
100				
.				
.				
.				
.				
.				
.				
.				
.				
.				
.				
400-500

SAFETY NOTE:

- Do not change the position of the apparatus or your own position when recording the measurement series so that your own body heat does not influence the thermocouple.
- Danger of burns: the outer wall of the electric oven can exceed 200 oC.
- Avoid burning your skin on the hot electric oven.
- Only operate the electric oven on its support.
- Read the Instruction Sheet for the electric oven carefully,
- and observe all instructions.

EXPERIMENT 2

THE BALMER SERIES

AIM:

In this experiment the wavelengths of the first three lines of the **Balmer series** are determined and in extend **Rydberg's constant R** .

APPARATUS:

Spectrum tube, hydrogen
Spectrum tube, mercury
Holders for spectral tubes, 1 pair
Cover tube for spectral tubes
Connecting cord, 30 kV, $l = 1000$ mm
Object holder, 55 cm 1
Diffraction grating, 600 lines/mm
High voltage supply unit, 0-10 kV
Insulating support
Tripod base -PASS-
Barrel base -PASS-
Support rod -PASS-, square, $l = 400$ mm
Right angle clamp -PASS-
Stand tube
Meter scale, demo, $l = 1000$ mm
Cursors, 1 pair
Measuring tape, $l = 2$ m

METHODOLOGY:

The spectrum of the radiation emitted by a hot body is continuous, because there are very many different kinds of oscillations in any real lump of matter, so that the precise quanta exist at all frequencies.

But there are discontinuous spectra called line spectra- the pattern of radiation emitted by pure elements, when they were heated or electrically disturbed. The spectral lines are images of the narrow slit that the light falls on in a spectrometer.

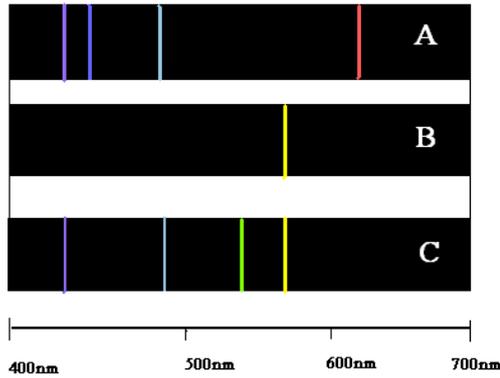


Figure 2.1: The emission spectrum of hydrogen (A), sodium (B) and mercury (C). In the Balmer Series the spacing of lines decreases steadily as they proceed into the ultraviolet toward shorter wavelengths and their intensities fall rapidly.

Each element has a unique emission spectrum. Spectra are usually produced by elements and mixtures in the gaseous form, i.e. hot gases. Solids can be vaporized in a hot flame (Bunsen Burner). Spectra can be also produced by electrically disturbing atoms, i.e. firing electrons and ions through a low pressure gas in a discharge tube.

The spectrum of the simplest atom **hydrogen** (1 proton, 1 electron) was found to have four visible lines and a large number of invisible in the ultraviolet and infrared. The total Balmer series of hydrogen (visible spectrum) is described by the following formula:

$$N = R \left(\frac{1}{4} - \frac{1}{n^2} \right) , \quad n = 3, 4, 5, 6 \quad (2.1)$$

Where $R = 109677.567 \text{ cm}^{-1}$ is Rydberg's constant and $N = \frac{1}{\lambda}$ is the wavenumber. There is a total of 4 spectral lines in the Balmer series. Nevertheless in this experiment we will see only visible lines are for $n=3, 4, 5$ as listed in the table below, since the fourth line weak and difficult to see.

Table 2.1

$n=3$	H_α	Red	656.28nm
$n=4$	H_β	Turquoise	486.13nm
$n=5$	H_γ	Blue	434.0nm

If parallel rays of light are incident perpendicularly to the plane of a diffraction grating, with uniform phase over the grating, then one will observe a diffraction pattern which will have a series of intensity maxima at angles θ satisfying the equation

$$k \lambda = g \sin\theta, \quad k = 0, 1, 2 \dots (2.2)$$

Where λ is the wavelength of the emitted light, g is the grating constant and k is the spectrum order ($k=1$ is the 1st order diffraction image). Thus the grating will allow a

determination of an unknown wavelength if the positions of the intensity maxima are measured and if g is known.

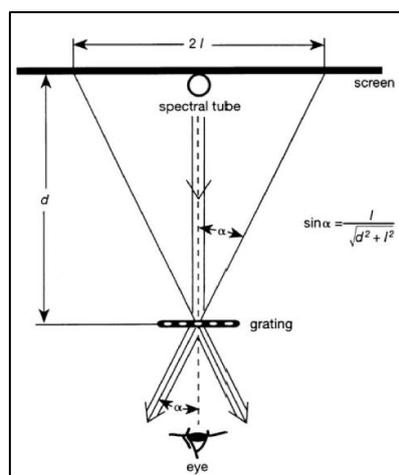


Figure 2.2: Wavelength determination using a diffraction grating. g : grating constant, d : distance from grating to screen, The distance $2l$ between spectral lines of the same colour in the right and left first order spectra are read through the grating



Figure (2.3): Set-up of experiment

PROCEDURE

The experimental set-up is shown in Figure (2.3). Hydrogen or mercury spectral tubes connected to the high voltage power supply unit are used as a source of radiation. The power supply is adjusted to about 5 kV. The scale is attached directly behind the spectral tube in order to minimize parallax errors. The diffraction grating should be set up at about 50 cm and at the same height as the spectral tube. The grating must be aligned so as to be parallel to the scale. The luminous capillary tube is observed through the grating (see Fig 2.2). The room is darkened to the point where it is still possible to read the scale. The distance $2l$ between spectral lines of the same color in the right and left first order spectra are read through the grating. The distance between the grating and the eye should be so short, that both lines are visible at the same time

without moving the head. The distance d between the scale and the grating is also measured. Three lines are clearly visible in the Hg spectrum. The grating constant g is determined by means of the wavelengths given in Table 2.1. Rydberg's constant, and thus the energy levels in hydrogen, are determined from the measured wavelengths by means of Balmer's formula.

1. Determine the distance $2l$.
2. Taking into account that the grating constant is $g = \frac{1}{600} \text{ mm}$, determine the different angles corresponding to the different spectral lines. Using equation (2.2) you should be able to work out their corresponding wavelengths.
3. Using equation (2.1), plot $1/\lambda$ for all 3 values obtained against $\left(\frac{1}{4} - \frac{1}{n^2}\right)$ and determine a value for Rydberg's constant R .

RESULTS TABLE

d

n	l (cm)	$\theta = \tan^{-1}(l/d)$ (degree)	$\sin \theta$	λ (cm)	$1/\lambda$ (cm^{-1})	$\left(\frac{1}{4} - \frac{1}{n^2}\right)$
3 RED						
4 TURQOISE						
5 BLUE						

Name:

TITLE OF EXPERIMENT

BALMER SERIES: EXPERIMENT No 2

MODERN PHYSICS LAB

PHYS 393 COURSEWORK

REPORTING SHEET

PART A: SCIENTIFIC KNOWLEDGE AND PLANNING [30 MARKS]

Aim:

Methodology - Draw your set up, explaining the use of the different components you will use to achieve your aim

5

<p>What do you predict according to quantum theory to observe on the translucent screen?</p> <p>Because... (Explain the formation of spectral lines within Quantum Theory, using also sketches)</p>	4
<p>Draw a simplified energy level diagram for a hydrogen atom, showing the Lyman, Balmer and Paschen Series. Explain</p>	3

<p>What does classical theory predict about an electron orbiting the nucleus of an atom?</p>	<p>4</p>
<p>What is meant by a) excitation b) ionisation</p>	<p>2</p>
<p>Explain the Fraunhofer lines (absorption spectrum) of the sun.</p>	<p>3</p>

<p>In a complete solar eclipse the light from the main body of the sun is cut off and only light from the corona of hot gases forming the outer layer reaches the Earth. That would have the following effect on the Fraunhofer lines:</p> <ul style="list-style-type: none">(i) Increase their visibility(ii) Make them disappear(iii) Have no effect on them	3
<p>What values do you predict to get for the (3) wavelengths and R (Rydberg's constant), according to theory?</p>	3
<p>Which factors you suggest should be controlled in order to make sure that your results are accurate and reliable?</p>	3

PART B: OBTAINING EVIDENCE	
<p>Your data. Use the correct units and convert appropriately.</p>	

PART C: ANALYSING AND CONSIDERING YOUR EVIDENCE	
Graph (use graph paper)	
Calculations	
My evidence leads to the following result.	
Compare your results with theoretical values.	

PART D: EVALUATION [10 MARKS]	
What was good or bad about the experiment you did was ...	2
Some ways you could improve the experiment were...	2
You had the following anomalies.	2
The explanation for your anomalies was	2
You believe my evidence is reliable/unreliable for the following reasons.	2

EXPERIMENT 3

THE PHOTOELECTRIC EFFECT

Equipment List

Included Equipment

1. Mercury Light Source Enclosure
2. Track, 60 cm
3. Photodiode Enclosure
4. Mercury Light Source Power Supply
5. DC Current Amplifier
6. Tunable DC (Constant Voltage) Power Supply

Optical Filters, Apertures, and Caps

7. Filter Wheel (365, 405, 436, 546, 577 nm)
 8. Aperture Dial (2 mm, 4 mm, 8 mm diameter)
- Photodiode Enclosure Cap (not shown)
Mercury Light Source Enclosure Cap (not shown)

Cables and Cords

9. Power Cord (3) (110 V version shown)
10. BNC Connecting Cable, Photodiode Enclosure
11. Connecting Cable, Red
12. Connecting Cable, Black
13. Interface Cable (3) UI-5219

Safety Information

Warning: To avoid possible electric shock or personal injury, follow these guidelines:

- Do not clean the equipments with a wet rag.
- Before use, verify that the apparatus is not damaged.
- Do not defeat power cord safety ground feature.
- Plug in to a grounded (earth) outlet.
- Do not use product in any manner not specified by the manufacturer.
- Do not install substitute parts or perform any unauthorized modification to the product.
- Line and Current Protection Fuses: For continued protection against fire, replace the line fuse and the current-protection fuse only with fuses of the specified type and rating.
- Main Power and Test Input Disconnect: Unplug instrument from wall outlet, remove power cord, and remove all probes from all terminals before servicing. Only qualified, service-trained personnel should remove the cover from the instrument.
- Do not use the equipment if it is damaged. Before you use the equipment, inspect the case. Pay particular attention to the insulation surrounding the connectors.
- Do not use the equipment if it operates abnormally. Protection may be impaired. When in doubt, have the equipment serviced.
- Do not operate the equipment where explosive gas, vapor, or dust is present. Don't use it under wet condition.

- Do not apply more than the rated voltage, as marked on the apparatus, between terminals or between any terminal and earth ground.
- When servicing the equipment, use only specified replacement parts.
- Use caution when working with voltage above 30 V AC RMS, 42 V peak, or 60 V DC. Such voltages pose a shock hazard.
- To avoid electric shock, do not touch any naked conductor with hand or skin.
- Adhere to local and national safety codes. Individual protective equipment must be used to prevent shock and arc blast injury here hazardous live conductors are exposed.
- Remaining endangerment: When an input terminal is connected to dangerous live potential it is to be noted that this potential can occur at all other terminals.

Introduction

The photoelectric effect is the emission of electrons from the surface of a metal when electromagnetic radiation (such as visible or ultraviolet light) of the right frequency shines on the metal. At the time of its discovery, the classical wave model for light predicted that the energy of the emitted electrons would increase as the intensity (brightness) of the light increased.

Instead it was discovered that the energy of the emitted electrons was directly proportional to the frequency of the incident light, and that no electrons would be emitted if the light source was not above a certain threshold frequency. Lower energy electrons were emitted when light with relatively low frequency was incident on the metal, and higher energy electrons were emitted when light with relatively high frequency was incident on the metal.

Background Information

Many people contributed to the discovery and explanation of the photoelectric effect. In 1865 James Clerk Maxwell predicted the existence of electromagnetic waves and concluded that light itself was just such a wave. Experimentalists attempted to generate and detect electromagnetic radiation and the first clearly successful attempt was made in 1886 by Heinrich Hertz. In the midst of his experimentation, he discovered that the spark produced by an electromagnetic receiver was more vigorous if it was exposed to ultraviolet light. In 1888 Wilhelm Hallwachs demonstrated that a negatively charged gold leaf electroscope would discharge more rapidly than normal if a clean zinc disk connected to the electroscope was exposed to ultraviolet light. In 1899, J.J. Thomson determined that the ultraviolet light caused electrons to be emitted from the metal.

In 1902, Phillip Lenard, an assistant to Heinrich Hertz, used a high intensity carbon arc light to illuminate an emitter plate. Using a collector plate and a sensitive ammeter, he was able to measure the small current produced when the emitter plate was exposed to light. In order to measure the energy of the emitted electrons, Lenard charged the collector plate negatively so that the electrons from the emitter plate would be repelled. He found that there was a minimum “stopping” potential that kept all electrons from reaching the collector. He was surprised to discover that the “stopping” potential, V_s , - and therefore the energy of the emitted electrons - did *not* depend on the intensity of the light. He found that the maximum energy of the emitted electrons *did* depend on the color, or frequency, of the light.

In 1901 Max Planck published his theory of radiation. In it he stated that an oscillator, or any similar physical system, has a discrete set of possible energy values or levels; energies between these values never occur. Planck went on to state that the emission and absorption of radiation is associated with transitions or jumps between two energy levels. The energy lost or gained by the oscillator is emitted or absorbed as a quantum of radiant energy, the magnitude of which is expressed by the equation: $E = h\nu$ where E equals the radiant energy, ν is the frequency of the radiation, and h is a fundamental constant of nature. (The constant, h , became known as Planck's constant.)

In 1905 Albert Einstein gave a simple explanation of Lenard's discoveries using Planck's theory. The new 'quantum'-based model predicted that higher frequency light would produce higher energy emitted electrons (photoelectrons), independent of intensity, while increased intensity would only increase the number of electrons emitted (or photoelectric current). Einstein assumed that the light shining on the emitter material could be thought of as 'quanta' of energy (called photons) with the amount of energy equal to $h\nu$ with ν as the frequency. In the photoelectric effect, one 'quantum' of energy is absorbed by one electron. If the electron is below the surface of the emitter material, some of the absorbed energy is lost as the electron moves towards the surface. This is usually called the 'work function' (W_o). If the 'quantum' is more than the 'work function', then the electron is emitted with a certain amount of kinetic energy. Einstein applied Planck's theory and explained the photoelectric effect in terms of the quantum model using his famous equation for which he received the Nobel Prize in 1921

$$E = h\nu = KE_{max} + W_o$$

Where KE_{max} is the maximum kinetic energy of the emitted photoelectron. In terms of kinetic energy,

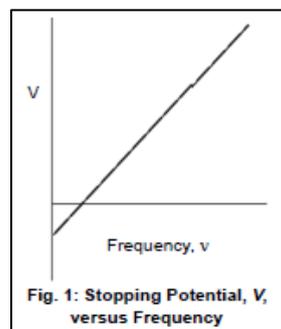
$$KE_{max} = h\nu - W_o$$

If the collector plate is charged negatively to the 'stopping' potential so that electrons from the emitter don't reach the collector and the photocurrent is zero, the highest kinetic energy electrons will have energy eV where e is the charge on the electron and V is the 'stopping' potential.

$$eV = h\nu - W_o$$

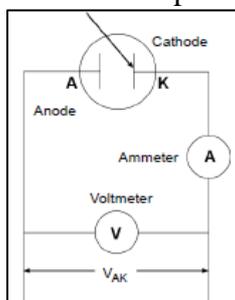
$$V = \frac{h}{e} \nu - \frac{W_o}{e}$$

Einstein's theory predicts that if the frequency of the incident light is varied, and the 'stopping' potential, V , is plotted as a function of frequency, the slope of the line is h/e (see Figure 1).



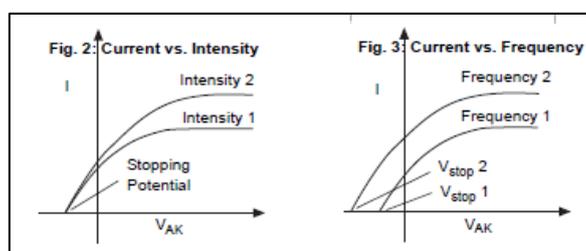
Principle of the Experiment

When incident light shines on the cathode (K), photoelectrons can be emitted and transferred to the anode (A). This constitutes a photocurrent. By changing the voltage between the anode and cathode, and measuring the photocurrent, you can determine the characteristic current-voltage curves of the photoelectric tube.



The basic facts of the photoelectric effect experiments are as follows:

- For a given frequency (color) of light, if the voltage between the cathode and anode, V_{AK} , is equal to the stopping potential, V , the photocurrent is zero.
- When the voltage between the cathode and anode is greater than the stopping voltage, the photocurrent will increase quickly and eventually reach saturation. The saturated current is proportional to the intensity of the incident light. See Figure 2.
- Light of different frequencies (colors) have different stopping potentials. See Figure 3
- The slope of a plot of stopping potential versus frequency is the value of the ratio, h/e . See Figure 1.
- The photoelectric effect is almost instantaneous. Once the light shines on the cathode, photoelectrons will be emitted in less than a nanosecond.



Part I – Measuring Current-Voltage Characteristics 1 Measuring Current-Voltage Characteristics of Spectral Lines - Constant Frequency, Different Intensity

This section outlines the instructions for measuring and comparing the current versus voltage characteristics of one spectral line at three different light intensities.

Preparation for Measurement

1. Cover the window of the Mercury Light Source enclosure with the Mercury Lamp Cap. Cover the window of the Photodiode enclosure with the Photodiode Cap.

2. Adjust the distance between the Mercury Light Source enclosure and Photodiode enclosure so that the general spacing is between 30.0 cm to 40.0 cm. NOTE: The recommended distance is 35.0 cm.
3. On the Mercury Lamp Power Supply, press the button to turn on MERCURY LAMP. On the Tunable DC (Constant Voltage) Power Supply and DC Current Amplifier, push in the POWER button to the ON position.
4. Allow the light source and the apparatus to warm up for 10 minutes.
5. On the DC (Constant Voltage) Power Supply, set the Voltage Range switch to - **4.5V – 30 V**.
On the DC Current Amplifier, turn the CURRENT RANGES switch to **10⁻¹¹ A**. (If 10⁻¹¹A is not large enough, please turn the CURRENT RANGES Switch to 10⁻¹⁰A.)
6. Push in the SIGNAL button to the “in” position for CALIBRATION.
7. Adjust the CURRENT RANGES knob until the ammeter shows that the current is zero.
8. Press the SIGNAL button so it moves to the “out” position for MEASURE.

Measurement - Constant Frequency, Different Intensities

2 mm Aperture

1. Gently pull the aperture dial away from the Photodiode Enclosure and rotate the dial so that the 2 mm aperture is aligned with the white line. Then rotate the filter wheel until the 436 nm filter is aligned with the white line. Finally remove the cover cap.
2. Uncover the window of the Mercury Light Source. Spectral lines of 436 nm wavelength will shine on the cathode in the phototube.
3. Adjust the **-4.5V– 30V VOLTAGE ADJUST** knob until the current on the ammeter is zero.
Record the voltage and current in Table 1.
4. Increase the voltage by a small amount (for example, 2 V). Record the new voltage and current in Table 1.
5. Continue to increase the voltage by the same small increment. Record the new voltage and current each time in Table 1. Stop when you reach the end of the VOLTAGE range.

4 mm Aperture

1. Cover the windows of the Mercury Light Source Enclosure and the Photodiode Enclosure.
2. Gently pull the aperture dial and rotate it so that the 4 mm aperture is aligned with the white line. Then rotate the filter
3. Uncover the window of the Mercury Light Source. Spectral lines of 436 nm will shine on the cathode in the Photodiode Enclosure.
4. Adjust the **-4.5V– 30V VOLTAGE ADJUST** knob so that the current display is zero. Record the voltage and current in Table 1.
5. Increase the voltage by a small amount (e.g. 2 V) and record the new voltage and current in Table 1. Continue to increase the voltage by the same small increment and record the new voltage and current each time in Table 1. Stop when you reach the end of the VOLTAGE range.

8 mm Aperture

1. Cover the windows of the Mercury Light Source Enclosure and the Photodiode Enclosure.
2. Gently pull the aperture dial and rotate it so that the 8 mm aperture is aligned with the white line. Then rotate the filter wheel until the 436 nm filter is aligned with the white line. Finally remove the cover cap.
3. Uncover the window of the Mercury Light Source. Spectral lines of 436 nm will shine on the cathode in the Photodiode enclosure.
4. Adjust the **-4.5V– 30V VOLTAGE ADJUST** knob so that the current display is zero. Record the voltage and current in Table 1.
5. Increase the voltage by a small amount (e.g. 2 V) and record the new voltage and current in Table 1. Continue to increase the voltage by the same small increment and record the new voltage and current each time in Table 4. Stop when you reach the end of the VOLTAGE range.
6. Turn off the MERCURY LAMP power switch and the POWER switch on the other pieces of equipment. Rotate the filter wheel until the 0 nm filter is aligned with the white line. Cover the windows of the Mercury Light Source Enclosure and Photodiode Enclosure.

Table 1: Current and Voltage of Spectral Lines

$\lambda = 436 \text{ nm}$ 2 mm dia.	V (V)													
	I ($\times 10^{-11} \text{ A}$)													
$\lambda = 436 \text{ nm}$ 4 mm dia.	V (V)													
	I ($\times 10^{-11} \text{ A}$)													
$\lambda = 436 \text{ nm}$ 8 mm dia.	V (V)													
	I ($\times 10^{-11} \text{ A}$)													

Analysis

1. Plot the graphs of Current (y-axis) versus Voltage (x-axis) for the one spectral line, 436 nm, at the three different intensities.

Questions

1. How do the curves of current versus voltage for the one spectral line at three different intensities compare? In other words, how are the curves similar to each other?
2. How do the curves of current versus voltage for the one spectral line at three different intensities contrast? In other words, how do the curves differ from each other?

Part II – Measuring Current-Voltage Characteristics 2

Measuring Current-Voltage Characteristics of Spectral Lines -

Different Frequencies, Constant Intensity

This section outlines the instructions for measuring and comparing the current versus voltage characteristics of three spectral lines, 365 nm, 405 nm, and 436 nm, but with the same light intensity.

Preparation for Measurement

1. Cover the window of the Mercury Light Source enclosure with the Mercury Lamp Cap. Cover the window of the Photodiode enclosure with the Photodiode Cap.

2. Adjust the distance between the Mercury Light Source enclosure and Photodiode enclosure so that the general spacing is between 30.0 cm to 40.0 cm. NOTE: The recommended distance is 35.0 cm.
3. On the Mercury Lamp Power Supply, press the button to turn on MERCURY LAMP. On the Tunable DC (Constant Voltage) Power Supply and DC Current Amplifier, push in the POWER button to the ON position.
4. Allow the light source and the apparatus to warm up for 10 minutes.
5. On the DC (Constant Voltage) Power Supply, set the Voltage Range switch to -4.5V – 30 V. On the DC Current Amplifier, turn the CURRENT RANGES switch to 10^{-11} A. (If 10^{-11} A is not large enough, please turn the CURRENT RANGES Switch to 10^{-10} A.)
6. Push in the SIGNAL button to the “in” position for CALIBRATION.
7. Adjust the CURRENT RANGES knob until the ammeter shows that the current is zero.
8. Press the SIGNAL button so it moves to the “out” position for MEASURE.

Measurement - Different Frequencies, Constant Intensity

365 nm Wavelength

1. Gently pull the aperture dial and rotate it so that the 4 mm aperture is aligned with the white line. Then rotate the filter wheel until the 365 nm filter is aligned with the white line. Finally remove the cover cap.
2. Uncover the window of the Mercury Light Source Enclosure. Spectral lines of 365 nm will shine on the cathode in the Photodiode Enclosure.
3. Adjust the -4.5V– 30V VOLTAGE ADJUST knob so that the current display is zero. Record the voltage and current in Table 2.
4. Increase the voltage by a small amount (for example, 2 V). Record the new voltage and current in Table 2.
5. Continue to increase the voltage by the same small increment. Record the new voltage and current each time in Table 2. Stop when you reach the end of the VOLTAGE range.

405 nm Wavelength

1. Cover the window of the Mercury Light Source Enclosure.
2. Rotate the filter wheel until the 405 nm filter is aligned with the white line.
3. Uncover the window of the Mercury Light Source enclosure. Spectral lines of 405 nm will shine on the cathode in the Photodiode Enclosure.
4. Adjust the -4.5V– 30V VOLTAGE ADJUST knob so that the current display is zero. Record the voltage and current in Table 2.
5. Increase the voltage by a small amount (e.g. 2 V) and record the new voltage and current in Table 2.
6. Continue to increase the voltage by the same small increment and record the new voltage and current each time in Table 2. Stop when you reach the end of the VOLTAGE range.

436 nm Wavelength

1. Cover the window of the Mercury Light Source Enclosure.
2. Rotate the filter wheel until the 436 nm filter is aligned with the white line.
3. Uncover the window of the Mercury Light Source Enclosure. Spectral lines of 436 nm will shine on the cathode in the Photodiode enclosure.

4. Adjust the **-4.5V– 30V VOLTAGE ADJUST** knob so that the current display is zero. Record the voltage and current in Table 2.
5. Increase the voltage by a small amount (e.g. 2 V) and record the new voltage and current in Table 2.
6. Continue to increase the voltage by the same small increment and record the new voltage and current each time in Table 2. Stop when you reach the end of the **VOLTAGE** range.
7. Turn off the **MERCURY LAMP** power switch and the **POWER** switch on the other pieces of equipment. Rotate the filter wheel until the 0 nm filter is aligned with the white line. Cover the windows of the Mercury Light Source Enclosure and Photodiode Enclosure.

Table 2: Current and Voltage of Spectral Lines

$\lambda = 365 \text{ nm}$ 4 mm dia.	V (V)												
	I ($\times 10^{-11} \text{ A}$)												
$\lambda = 405 \text{ nm}$ 4 mm dia.	V (V)												
	I ($\times 10^{-11} \text{ A}$)												
$\lambda = 436 \text{ nm}$ 4 mm dia.	V (V)												
	I ($\times 10^{-11} \text{ A}$)												

Analysis

1. Plot the graphs of Current (y-axis) versus Voltage (x-axis) for the three spectral lines, 365 nm, 405 nm, and 436 nm, at the one intensity.

Questions

1. How do the curves of current versus voltage for the three spectral lines at a constant intensity compare? In other words, how are the curves similar to each other?
2. How do the curves of current versus voltage for the three spectral lines at a constant intensity contrast? In other words, how do the curves differ from each other?

Name

TITLE OF EXPERIMENT

**THE PHOTOELECTRIC EFFECT:
EXPERIMENT No 3**

MODERN PHYSICS LAB

PHYS 393 COURSEWORK

REPORTING SHEET

PART A: SCIENTIFIC KNOWLEDGE AND PLANNING [30 MARKS]

Aim:

Methodology - Draw your set up, explaining the use of the different components you will use to achieve your aim

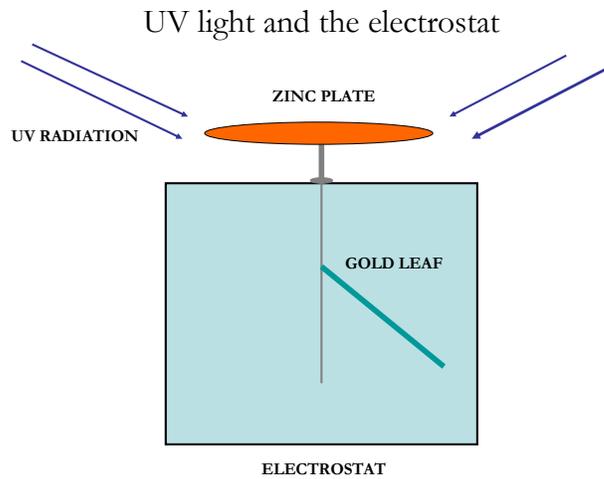
4

<p>What is meant by photoelectric emission? What is a photon? Discuss its rest mass.</p>	<p>3</p>
<p>The photoelectric effect supports a particle theory of light, but not a wave theory of light. State (3) features of the photoelectric effect, which support the particle theory of light, but not support the wave theory of light. For each feature explain why it supports the particle theory and not the wave theory.</p>	<p>7</p>

<p>(i) State Einstein's photoelectric equation and explain the meaning of each term. (ii) Plot the maximum kinetic energy against frequency</p>	4
<p>(i) What would happen to the stopping voltage and the current if the intensity of light a) decreased and b) increased for a specific wavelength and why? (ii) If the intensity of incident light is fixed, what would happen to the stopping voltage if its wavelength changed?</p> <p>In each case provide a graph corresponding to your answer.</p>	4

A freshly cleaned zinc plate is connected to a charged gold-leaf electroscope. Describe and explain what happens to the leaf of the electroscope when the plate is exposed to ultraviolet radiation if the initial charge on the electroscope is
a) positive b) negative

4



Which factors you suggest should be controlled in order to make sure that your results are accurate and reliable?

4

PART B: OBTAINING EVIDENCE	
<p>Your data. Use the correct units and convert appropriately.</p>	

PART C: ANALYSING AND CONSIDERING YOUR EVIDENCE	
Graph (use graph paper)	
Calculations	
My evidence leads to the following result.	
Compare your results with theoretical values.	

PART D: EVALUATION [10 MARKS]	
What was good or bad about the experiment you did was ...	2
Some ways you could improve the experiment were...	2
You had the following anomalies.	2
The explanation for your anomalies was	2
You believe my evidence is reliable/unreliable for the following reasons.	2

EXPERIMENT

The X-ray Experiment

METHODOLOGY:

Theoretical Background.:

Wilhelm Röntgen discovered x-rays in 1895, and in 1901 he was awarded the very first Nobel Prize in physics for this discovery. X-Rays are invisible, highly penetrating electromagnetic radiation of a much shorter wavelength (higher frequency) than visible light. The wavelength range for X rays is from about 10^{-8} m to about 10^{-11} m,

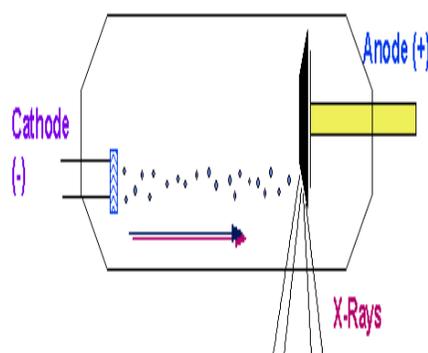


Fig.1

X rays are produced in a highly evacuated glass bulb, called an X-ray tube, see fig.1, that contains essentially two electrodes—an anode made of platinum, tungsten, or another heavy metal of high melting point, and a cathode. When a high voltage is applied between the electrodes, streams of electrons (cathode rays) are accelerated from the cathode to the anode and produce X rays as they strike the anode. Two different processes give the rise to radiation of X-ray wavelength. In one process radiation is emitted by the high-speed electrons themselves as they are slowed or even stopped in passing near the positively charged nuclei of the anode material. This radiation is often called *brehmsstrahlung* [braking radiation]. If an electron passes *very close* to a nucleus it can be accelerated so much that it gives out all its energy in one quantum. Therefore this is the biggest quantum (shortest wavelength) x ray emitted, see fig.2. The minimum wavelength therefore depends on the accelerating voltage. If the accelerating voltage U is increased the minimum wavelength of the radiation decreases.

$$\lambda_{\min} \sim 1/U \dots\dots\dots(1)$$

(where $\lambda_{\min} = c / \nu_{\max}$)

$$E_{\max} = h\nu_{\max} \dots\dots\dots(2)$$

X ray has maximum energy when its kinetic energy | $E = e U$

$$\nu_{\max} = e U / h \dots\dots\dots(3)$$

$$\text{and } \lambda_{\min} = hc / e U \dots\dots\dots(4) \quad (\text{Duane - Hunt relation})$$

where the proportionality constant $A = hc/e$, can be used to find Planck's constant.

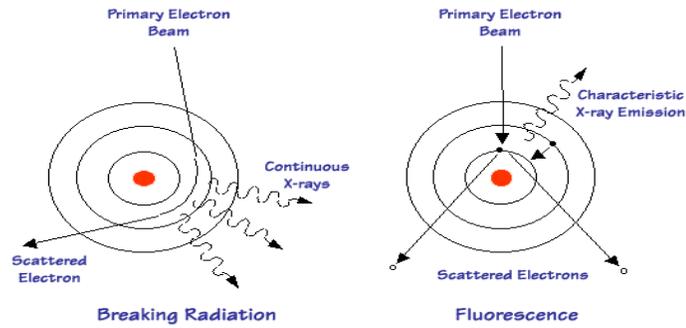


Fig.2

In a second process radiation is emitted by the electrons of the anode atoms when incoming electrons from the cathode knock electrons near the nuclei out of orbit and they are replaced by other electrons from outer orbits. The spectrum of the wavelength given off with any particular anode material thus consists of a continuous range of wavelength (the curved) emitted in the first process and superimposed on it a number of sharp peaks of intensity corresponding to discrete wavelength at which X rays are emitted in the second process. The sharp peaks constitute the X-ray line spectrum for the anode material and will differ for different materials.see fig.3.

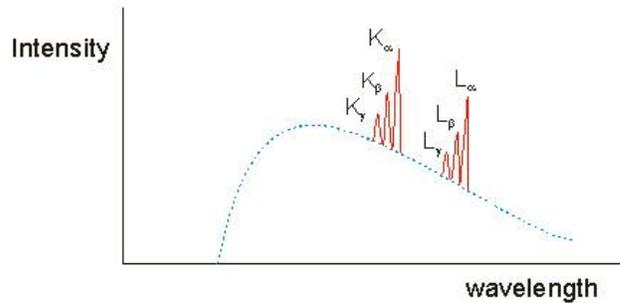


Fig.3

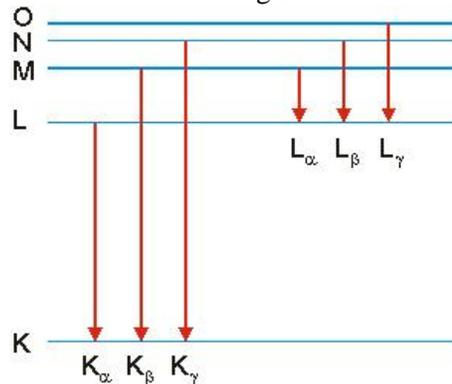


Fig.4

These "lines" in the spectrum are named after the energy level to which an electron falls, When a monochromatic X-ray beam with wavelength λ is projected onto a crystal diffraction occurs only when the distance traveled by the rays reflected from successive planes differs by a complete number n of wavelengths.

$$n\lambda = 2d \sin \theta, n = 1,2,3,.. \text{ (Bragg's law)} \dots\dots\dots(5)$$

Bragg's law allow us to calculate details about the crystal structure and to determine the wavelength of x-ray incident upon the crystal.see Fig.5.

When X-rays passthrough matter they lose energy both by scattering and by absorption. In the absorption process an X-ray photon is absorbed by the atom, and the excess energy is transferred to an electron, which is expelled from the inner shell e.g the k-shell of the atom leaving the atom ionized. This can occur when the quantum energy is greater than the binding energy E_k of the shell, See Fig.4. The transmission of the material increase abruptly as the function of the wavelength $T = R / R_0$ where R is intensity rate behind attenuator and R_0 is the intensity in front attenuator Moseley measured the k-absorption edge for various elements

$$(1/\lambda_k)^{1/2} = R^{1/2} (Z - \sigma_k) \dots \dots \dots (6)$$

where R :Rydberg constant , Z :atomic number , σ_k : screening coefficient of the k - shell

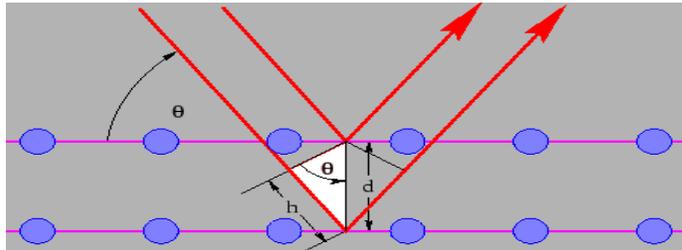


Fig.5

Safety notes:

The x-ray apparatus fulfills all regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW 807/97 Rö). The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1 μ Sv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation inspect it for damage and to make sure that the high voltage is shut off when the sliding doors are opened.
- Keep the x-ray apparatus secure from access by unauthorized persons. Do not allow the anode of the x-ray tube Mo to overheat.
- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning. The goniometer is positioned solely by electric stepper motors.
- Do not block the target arm and sensor arm of the goniometer and do not use force to move them.

Part1: Bragg reflection: diffraction of x-rays at a monocrystal

AIM:

- To investigate Bragg reflection at an NaCl monocrystal using the characteristic x-ray radiation of molybdenum.
- To determine the wavelength for the characteristic K_α and K_β x-ray radiation of molybdenum.
- To confirm Bragg’s law of reflection.
- To verify the wave nature of x-rays.

Setup:

Setting up the Bragg configuration:

Fig. 5 shows some important details of the experiment setup.

Specifically, you need to carry out the following steps

- Attach the goniometer to the guide rods (d) in such a way that the distance s_1 between the slit diaphragm of the collimator and the target arm is approx. 5 cm.

- Adjust the sensor seat (b) until the distance s_2 between the target arm and the slit diaphragm of the sensor is approx. 6.

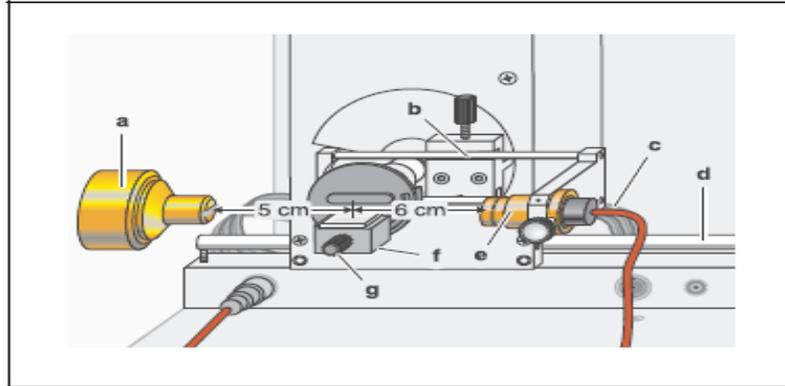


Fig.6 Experiment setup in Bragg configuration

Notes:

NaCl crystals are hygroscopic and fragile. Store the crystals in a dry place. Avoid mechanical stresses on the crystal; handle the crystal by the short faces only. If the counting rate is too low, you can reduce the distance s_2 between the target and the sensor somewhat. However, this distance must not be too small, as otherwise the angular resolution of the goniometer is no longer great enough to separate the characteristic k_α and k_β lines.

Carrying out the experiment:

- Start the program “X-ray Apparatus”, check to make sure that the x-ray apparatus is properly connected and delete any existing measurement data by clicking the button  or pressing F4.
- Set the x-ray high voltage $U = 35.0$ kV, emission current $I = 1.00$ mA, measuring time per angular step $\Delta t = 10$ s and angular step width $\Delta\beta = 0.1^\circ$.
- Press the COUPLED key on the device to enable 2θ coupling of the target and sensor; set the lower limit value of the target angle to 2° and the upper limit to 25° .
- Press the SCAN key to start the measurement and data transmission to the PC.
- When the measurement is finished, save the measurement series to a file under a suitable name using the button  or F2.

Evaluation

- Access the evaluation functions of the software “X-ray Apparatus” by clicking the right-hand mouse button and select the command “Calculate Peak Center”.
- Using the left mouse button, mark the “entire width” of the peaks; if desired, insert the calculated peak center β and the peak width σ in the diagram with $\text{Alt} + T$ and note the center as the glancing angle in the measurement table (see tables 1 and 2).
- Save your measurements and evaluations to a suitably named file with the button  or by pressing F2.
- Using the glancing angle θ and the lattice plane spacing $d = 282.01$ pm, calculate the wavelength λ using Bragg’s law of reflection (5) (see tables 1 and 2).
- Find the mean values for the individual diffraction orders of the measured wavelengths (see table 3).

n	$\theta(k_\alpha)$	$\lambda(k_\alpha)/\text{pm}$
1		
2		
3		

Table 1: Measured glancing angles of the Mo k_α line and the calculated wavelengths λ for the first through third diffraction orders.

n	V(k _β)	λ(k _β)/pm
1		
2		
3		

Table 2: Measured glancing angles of the Mo K_β line and the calculated wavelengths λ for the first through third diffraction orders.

	λ(k _α)/ pm	λ(k _β)/pm
Mean value		
Literature value		

Table 3: Mean value and literature value for the characteristic Wavelength λ.

Part2: Duane-Hunt relation and determination of Planck's constant

AIM:

- To determine the limit wavelength λ_{\min} of the bremsstrahlung continuum as a function of the high voltage U of the x-ray tube.
- To confirmed the Duane-Hunt relation.
- To determine Planck's constant $h = 6.626 \times 10^{-34}$ Js.

Setup: the same as in part 1

Carrying out the experiment:

- Start the software “X-ray Apparatus”, check to make sure that the apparatus is connected correctly, and clear any existing measurement data using the F4 key.
- Set the tube high voltage U = 22 kV, the emission current I = 1.00 mA, the measuring time per angular step $\Delta t = 30$ s and the angular step width $\Delta\beta = 0.1^\circ$.
- Press the COUPLED key to activate 2θ coupling of target and sensor and set the lower limit of the target angle to 5.2° and the upper limit to 6.2° .
- Start measurement and data transfer to the PC by pressing the SCAN key.
- Additionally record measurement series with the tube high voltages U= 24 kV, 26 kV, 28 kV, 30 kV, 32 kV, 34 kV and 35 kV; to save measuring time, use the parameters from table 4 for each series.

U/KV	I/mA	Δt/s	β _{min} /grd	β _{max} /grd	Δβ /grd
22	1.00	30	5.2	6.2	0.1
24	1.00	30	5.0	6.2	0.1
26	1.00	20	4.5	6.2	0.1
28	1.00	20	3.8	6.0	0.1
30	1.00	10	3.2	6.0	0.1
32	1.00	10	2.5	6.0	0.1
34	1.00	10	2.5	6.0	0.1
35	1.00	10	2.5	6.0	0.1

Tab. 4: Recommended parameters for recording the measurement series

- To show the wavelength-dependency, open the “Settings” dialog with the button  or F5 and enter the lattice plane spacing for NaCl.
- When you have finished measuring, save the measurement series under an appropriate name by pressing the button  or the F2 key.

Evaluation

Determining the limit wavelength λ_{\min} as a function of the tube high voltage U:

For each recorded diffraction spectrum:

- In the diagram, click the right mouse button to access the evaluation functions of the software “X-ray Apparatus” and select the command “Best-fit Straight Line”.

- Mark the curve range to which you want to fit a straight line to determine the limit wavelength λ_{\min} using the left mouse button.
- Save the evaluations under a suitable name using the pressing F2.

Confirming the Duane-Hunt relation and determining Planck's constant

- For further evaluation of the limit wavelengths λ_{\min} determined in this experiment, click on the register “Planck”.
- Position the pointer over the diagram, click the right mouse button, fit a straight line through the origin to the curve $\lambda_{\min} = f(1/U)$ and read the slope A (pm kv) from the bottom left corner of the evaluation window .

Part3: Moseley's law and determination of the Rydberg constant

AIM:

- Measuring the K-absorption edges in the transmission spectra of Zr, Mo, Ag and In.
- Verifying Moseley's law.
- Determining the Rydberg constant.

Setup:

The same as in part 1 but the following step will change :

- By moving the sensor holder (b), set the distance s2 between the target arm and the slit diaphragm of the sensor seat to approx. 5 cm in Fig. 7.

Note: do your calibration after this step.

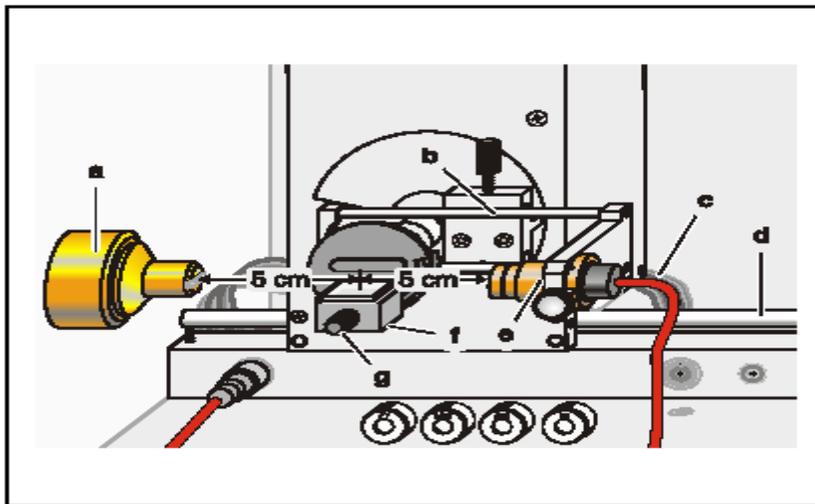


Fig. 7 Experiment setup for measuring the K-absorption edges.

Carrying out the experiment

- Start the software “X-ray Apparatus”, check to make sure that the apparatus is connected correctly, and clear any existing measurement data using the button  or the F4 key.
- Set the tube high voltage $U = 35.0$ kV, the emission current $I = 1.00$ mA and the angular step width $\Delta\beta = 0.1^\circ$.
- Press the COUPLED key to activate 2θ coupling of target and sensor and set the lower limit of the target angle to 3.7° and the upper limit to 7.5° .
- Set the measuring time per angular step to $\Delta t = 5$ s.
- Start measurement and data transfer to the PC by pressing the SCAN key.
- When the scan is finished, mount the zirconium foil on sensor seat (e) of the goniometer and start a new measurement by pressing the SCAN key.
- Replace the Zr foil with the Mo, Ag and In foils one after another and conduct further measurements.

- When you have finished measuring, save the measurement series under an appropriate name by pressing the Button  or the F2 key.
- To display the measurement data as a function of the wavelength λ , open the “Settings” dialog with the Button  or F5, and in the tab “Crystal”, click on the button “Enter NaCl”.

Evaluation:

- Click on the “Transmission” tab in the software “X-ray Apparatus” to generate the transmission spectra from the diffraction spectra.
- In the diagram, click the right mouse button to access the evaluation functions of the software “X-ray Apparatus” and select the command “Draw K-Edges”.
- Mark the range of each K-edge in the transmission spectra using the left mouse button.
- Click on the tab “Moseley” and enter the atomic numbers of the respective foils (Zr: 40, Mo: 42, Ag: 47 and In: 49) in the column Z .
- Place the mouse pointer over the diagram, click the right mouse button and select the evaluation command “Best-fit Straight Line”; then hold down the left mouse button to mark the range in the diagram to which you want to fit the line. Read off the result for the Rydberg constant R and the screening coefficient σ_K in the bottom left corner of the window.

Results:

	R	σ_K
The graphical evaluation		
Literature values	$R=1.097373 \cdot 10^7 \text{ m}^{-1}$	3.6

Name:

TITLE OF EXPERIMENT:

THE X-RAY EXPERIMENT No 10

**MODERN PHYSICS LAB
PHYS 393 COURSEWORK
REPORTING SHEET**

PART A: SCIENTIFIC KNOWLEDGE AND PLANNING

Aim:

Methodology- Draw your set up ,explaining the use of the different components you will use to achieve your aim

Why we use a heavy element as a target, why we choose tungsten?

5

<p>Distinguish between continuous & characteristic X rays. What is Bremsstrahlung radiation?</p> <p>Establish a relation between minimum wavelength and accelerating potential.</p>	ξ
<p>State & explain Moseley's law. How can Moseley's law be explained on the basis of Bohr's theory?</p>	ξ

State Bragg's equation .

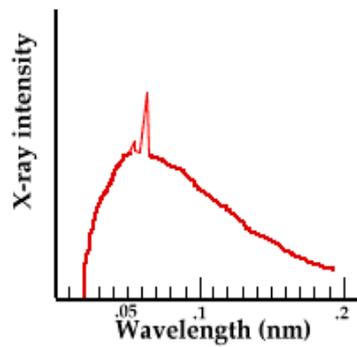
ξ

Bragg's equation will have no solution if :

- 1) $\lambda > 2d$
- 2) $\lambda < 2d$
- 3) $\lambda < d$
- 4) $\lambda = d$

Using the figure below what is the wavelength of the K_{α} X-ray line and what is the voltage on the X-ray tube?

ξ



Can we use diffraction grating instead of the crystal in this experiment (explain) ??	۲
What are the properties of X-rays ?	۴
Which factor you suggest should be controlled in order to make sure that your results are accurate and reliable?	۳

EXPERIMENT 5

THE ZEEMAN EFFECT

AIM:

This experiment demonstrates the splitting of the spectral lines in the presence of a constant magnetic field. The ratio e/m is experimentally calculated and compared with the theoretical value.

APPARATUS:

Fabry Perot interferometer, electromagnet, millimeter, Teslameter

METHODOLOGY:

Pieter Zeeman noted within the field of experimental spectroscopy that a constant magnetic field imposed on an atomic discharge tube produced a splitting of the spectral lines. This effect is due to the extra energy possessed by the atomic electrons due to the external \mathbf{B} field, and obviously its interaction due to both orbital and spin angular momentum of the atom must be taken into account.

However one can experiment with particular atomic gases, where the total spin is zero. In such a case the external magnetic field will exert a torque on a magnetic dipole and the magnetic potential energy will increase from E_o to $E = E_o + U$ where:

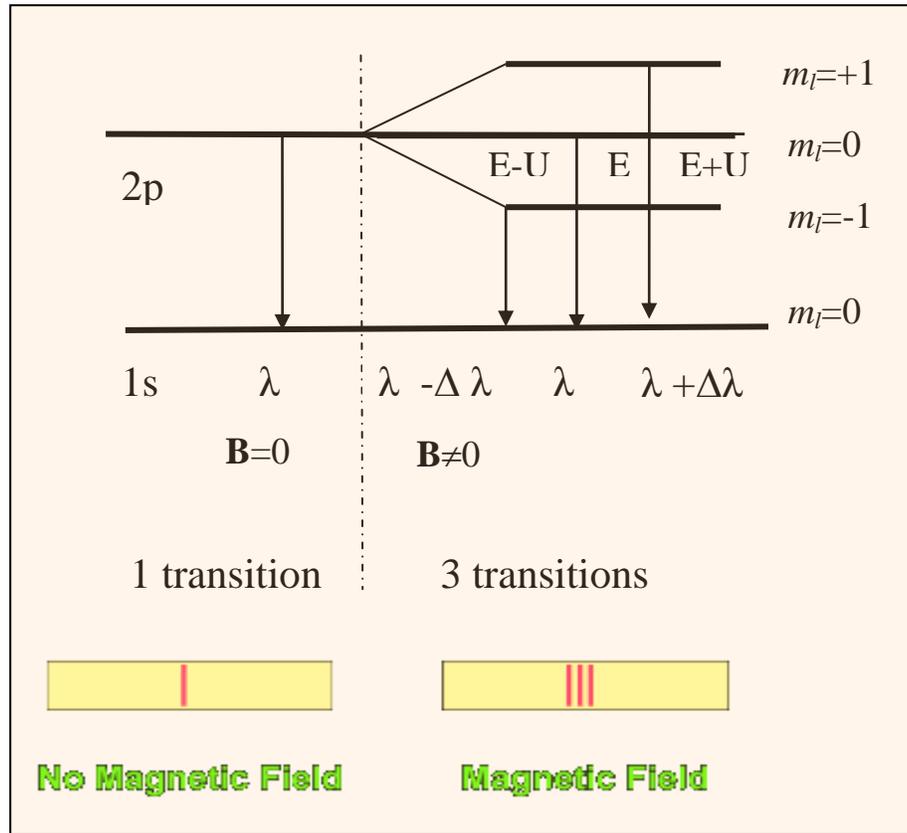
$$U = m_l \mu_B B \quad (5.1)$$

$\mu_B = 9.274 \times 10^{-24} \text{ J/T}$ is the Bohr magneton.

The change in wavelength would thus be:

$$E = \frac{hc}{\lambda} \Rightarrow dE = -\frac{hc}{\lambda^2} d\lambda \quad \text{or} \quad \Delta\lambda = \frac{\lambda^2}{hc} \Delta E \quad (5.2)$$

Figure 5.1 The normal Zeeman effect in Hydrogen. Looking at the 1s to 2p transition. (Total Spin=0)



In the absence of the constant magnetic field, the hydrogen energies depend only upon the principal quantum number n and the emissions occur at a **single (1) wavelength**. As we can see that is not the case when a magnetic field is applied. The emissions occur at **three (3) wavelengths**.

We note that the only possible transitions are governed by the light polarization rules in Table 5.1

Table 5.1: Possible polarisations

$\Delta m_l = 0$	Linearly Polarised Light	
$\Delta m_l = 1$	Circularly Polarised Light	
$\Delta m_l = -1$	Circularly Polarised Light	

Table 5.2. The rules governing the quantum numbers (n, l, m_l)

$n = 1, 2, 3, \dots$
$m_l = 0, \pm 1, \pm 2, \dots, \pm l$
$l = 0, 1, 2, \dots, n - 1$

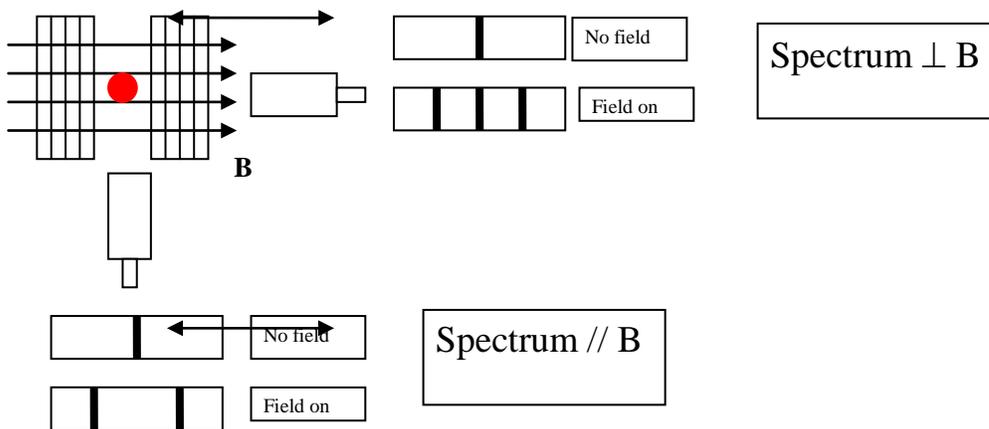
The number of split levels in the magnetic field is $2 * l + 1$.

Table 5.3 The angular momentum states

l	0	1	2	3	4	5	6
	s	p	d	f	d	h	i

Atomic physicists use the abbreviation "s" for a level with $l=0$, "p" for $l=1$, and "d" for $l=2$, and so on. It is also common to precede this designation with the integer principle quantum number n . Thus, the designation "2p" means a level that has $n=2$ and $l=1$. In the preceding example the lowest level is an "s" level, so it has $l=0$ and $2l + 1 = 1$, so it isn't split in the magnetic field, while the first excited state has $l = 1$ ("p" level), so it is split into $2l + 1 = 3$ levels by the magnetic field.

Figure 5.2 Using your experimental apparatus note that the direction of viewing changes the effect seen.



PROCEDURE:

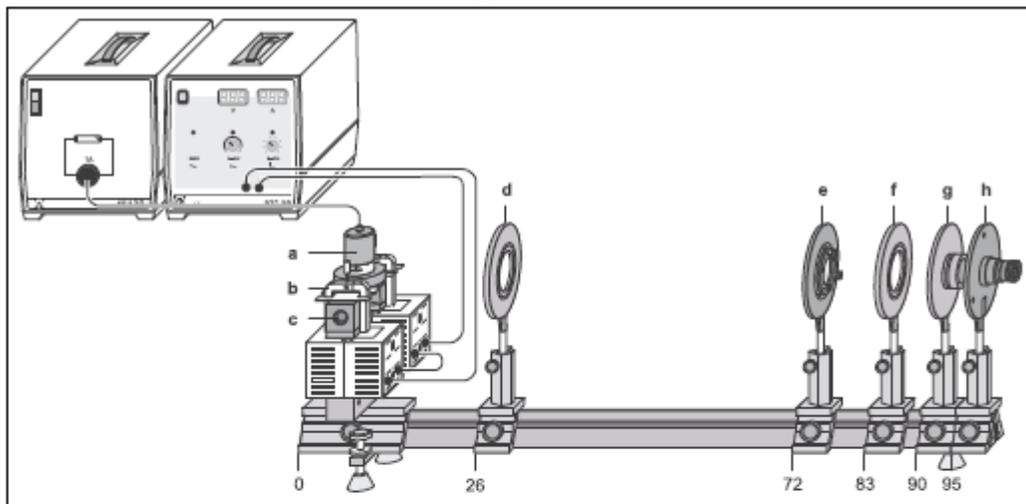
Electrical connection:

1. Connect the coils of the electromagnet in series and then to the high current power supply.
2. Connect the B sensor S to the Universal measuring instrument.
3. Connect the cadmium lamp to the universal choke.
4. Connect the VideoCom to the computer.

Adjusting the observing optics:

1. Mount the optical components according to Fig. 5.3.
2. After switching on the universal choke wait 5 min until the light emission is sufficiently strong.

Figure 5.3



Experimental setup for observing the *Zeeman* effect in transverse configuration. The position of the left edge of the optics riders is given in cm.

- a Cadmium lamp with holding plate
- b Clamps
- c Pole pieces
- d Positive lens, $f = 150$ mm (Condenser lens)
- e *Fabry-Perot* etalon
- f Positive lens, $f = 150$ mm (imaging lens)
- g Interference filter in holder
- h VideoCom (it is helpful to use an ocular for adjustment)

VideoCom:

1. It is possible to optimize the exposure time so that the peaks have an intensity of approximately 50 %.
2. To ensure that the CCD is in the focal plane of the imaging lens, move the imaging lens along the optical axis until the peaks of the observed curve are sharply imaged and show the maximum intensity. The center of the ring system must then be imaged on the CCD line. For this, you can either move VideoCom perpendicular to the optical axis or tilt the etalon slightly using the adjusting screws. You have found the center of the ring system when further adjustment does not cause any more peaks to emerge and the two central peaks (left and right intersections of the innermost rings) are the maximum distance apart.
3. Move the condenser lens until you obtain the most uniform possible illumination of the entire CCD line, so that the maxima in the middle are nearly at the same intensity (see Fig. 5.4).
4. For angular calibration of the VideoCom, the focal length of the imaging lens is specified (here $f = 150 \text{ mm}$). To shift the zero point, determine the angles of the two central peaks using the function “Calculate Peak Center” and enter the negative mean value of the two peak centers manually. This sets the center of the ring system to 0° on the angular scale.

a) Measuring the magnetic field

1. Hold the tangential probe vertically in the center of the pole pieces, while the cadmium lamp is not mounted.
2. Starting from 0A to 5A, increase the current in steps of 0.5A through the coils and measure the magnetic field in dependency of the current.

b) Measuring the splitting of the cadmium line

1. Cautiously insert the cadmium lamp between the pole pieces without changing the distance of the pole pieces. Start the software “VideoComInt” and adjust the observing optics.
2. The intensity of the peak should be around 50 %.
3. The table “Zeeman” is provided for evaluation; switch to this table by clicking on the corresponding tab. This table contains columns for the magnetic field B, the angle α_1 of the non-displaced line (p-component), the angle α_2 of the displaced line ($\sigma+$ or $\sigma-$) and the corresponding wavelength and energy shifts. These last two values are calculated automatically after entry of α_1 and α_2 using:

$$\frac{\Delta\lambda}{\lambda} = \frac{\cos\beta_2}{\cos\beta_1} - 1 \text{ with } \frac{\sin\alpha}{\sin\beta} = n = 1.46 \text{ for the etalon and}$$

$$\Delta E \approx \frac{-\Delta\lambda}{\lambda} \cdot E = -h c \cdot \frac{\Delta\lambda}{\lambda^2} \text{ with } \lambda = 643.8 \text{ nm for the Cd line.}$$

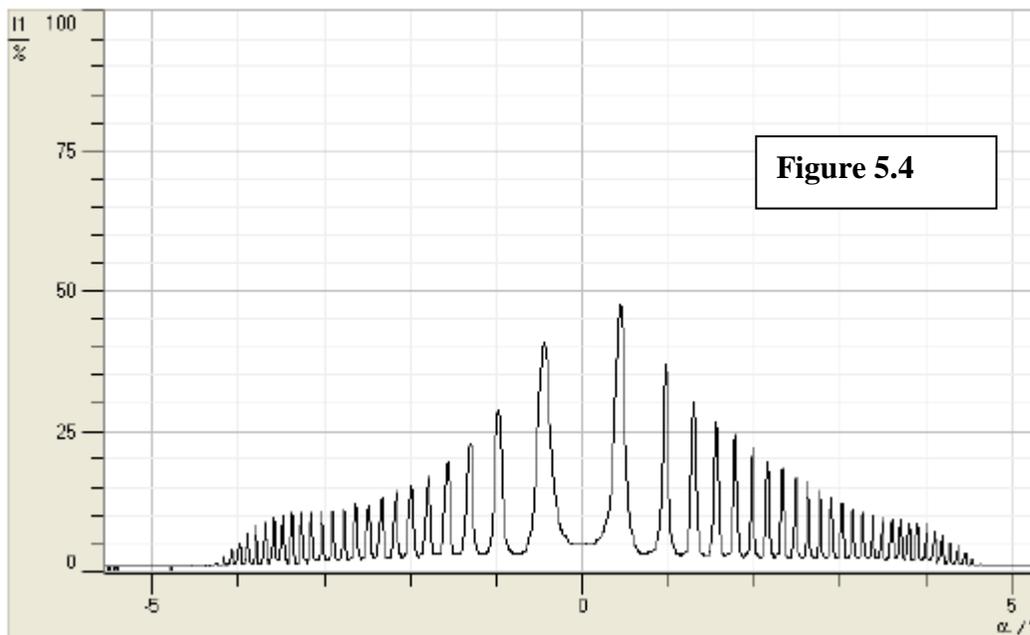
4. Start the evaluation by marking a peak (p) with “Calculate Peak Center”.
5. Transfer this value to the “Zeeman” table by dragging it from the status line to column α_1 of the table (drag and drop).
6. To determine the origin in the diagram, drag the value to column α_2 as well.
7. Enter the value 0 in column B (non-displaced ring without magnetic field).
8. Examine the ring as it is split in the magnetic field (σ^+ or σ^-).
9. Determine the displaced angle α_2 using “Calculate Peak Center” and drag it to column α_2 in the “Zeeman” table. The non-displaced angle α_1 remains unchanged (you can e.g. import it from a previous measurement using drag and drop), and the magnetic flux density is entered.
10. Using these values, the software calculates the percentage shift in wavelength and the energy split. Additionally, the corresponding point is plotted in the diagram. (To confirm the effect for other rings at equal flux densities or for repetition with different flux densities, it is necessary to examine peaks with identical components (σ^+ or σ^-) each time.)
11. To get the gradients of the line splitting fit straight lines through the measured points and find the slope.
12. Find the average of the absolute values of the two slopes. This value represents the Bohr's magneton μ_B .
13. Find e/m using

$$\frac{e}{m} = \frac{4\pi\mu_B}{h} \text{ where } h = 6.626 \times 10^{-34} \text{ J.s.} \quad (5.3)$$

14. Compare your result to the literature value:

$$\frac{e}{m} = 1.759 \times 10^{11} \text{ C/kg}$$

Figure 5.4



Name

TITLE OF EXPERIMENT

THE ZEEMAN EFFECT: EXPERIMENT No 5

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PHYS 393 COURSEWORK

REPORTING SHEET

PART A: SCIENTIFIC KNOWLEDGE AND PLANNING [30 MARKS]

Aim:

Methodology - Draw your set up, explaining the use of the different components you will use to achieve your aim

5

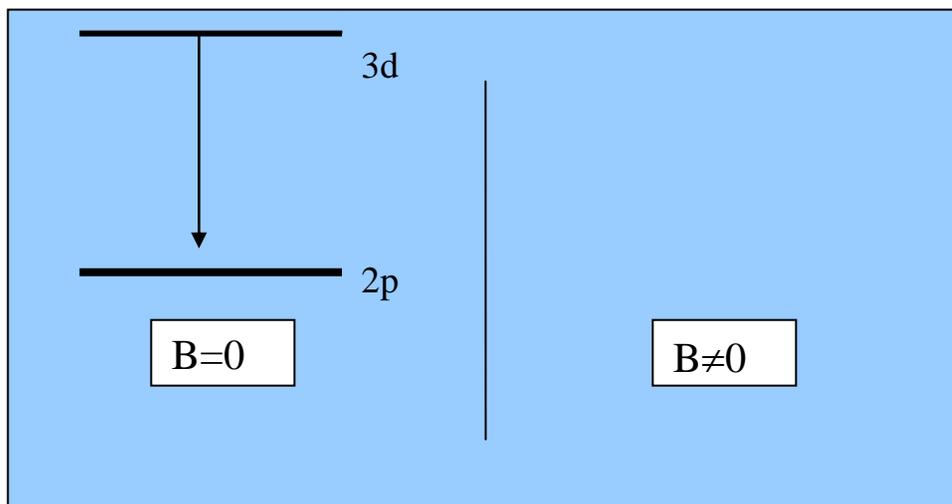
What do you predict according to quantum theory to observe on the telescope?

6

Because... (Explain how do the (3) spectral lines occur using an example)

In the absence of a constant magnetic field there is only wavelength associated with the transition from $n=3d$ to $n=2p$. Complete the figure below in the case that a magnetic field B is applied. How will the spectral lines split and what will be the possible transitions? *Hint:* Follow the polarisation rules.

5



In which case do the (3) spectral lines reduce to (2) in the presence of a constant magnetic field?	4
What is meant by the anomalous Zeeman effect?	4
What values do you predict to get for e/m ?	3
Which factors you suggest should be controlled in order to make sure that your results are accurate and reliable?	3

PART B: OBTAINING EVIDENCE	
<p>Your data. Use the correct units and convert appropriately.</p>	

PART C: ANALYSING AND CONSIDERING YOUR EVIDENCE	
Graph (use graph paper)	
Calculations	
My evidence leads to the following result.	
Compare your results with theoretical values.	

PART D: EVALUATION [10 MARKS]	
What was good or bad about the experiment you did was ...	2
Some ways you could improve the experiment were...	2
You had the following anomalies.	2
The explanation for your anomalies was	2
You believe my evidence is reliable/unreliable for the following reasons.	2

EXPERIMENT 6

Introduction to Interferometry

THE MICHELSON-MORLEY AND FABRY-PEROT INTERFEROMETERS

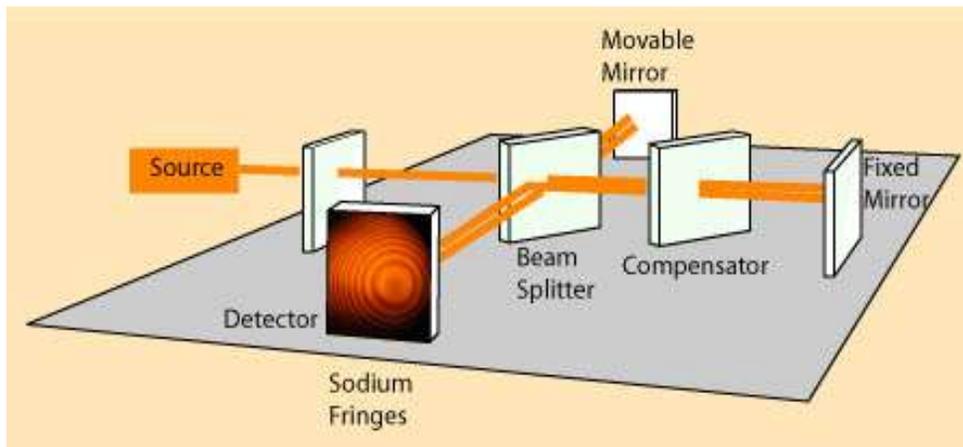
AIM: Calculating the wavelength λ of an unknown light source

APPARATUS: 0.6328 μm for a standard helium-neon laser, Laser Bench Adjustable Mirror, Movable Mirror, Beam Splitter, Compensator Plate, Viewing Screen, Lens, 18 mm Focal Length, base of Michelson and Morley interferometer.

METHODOLOGY:

The Michelson and Morley interferometer is primarily used to measure wavelengths of unknown monochromatic light sources. The method lies in firing the light sample as illustrated in Figure 6.1 and observing the resultant fringe pattern. While it is being observed, the movable mirror is adjusted backwards. That is until a fringe pattern change of exactly one is observed. This means that the mirror has been moved one-quarter of its wavelength; this is because the path length of the light has changed one-half of its wavelength (because it goes both to and from the mirror) and this change in path length shifts the interference pattern by precisely one fringe.

A schematic representation of the Michelson and Morley interferometer using a sodium light source



Precise distance measurements can be made with the Michelson interferometer by moving the mirror and counting the interference fringes which move by a reference point. The distance d associated with m fringes is

$$2d = 2(L_f - L_m) = m\lambda \quad (6.1)$$

Part1: The Michelson Mode

PROCEDURE:

STEP A: Setup and Operation

Laser Alignment:

Adjust your laser so that the beam is approximately 4 cm above the table top. Then align the beam as in steps 4 and 5, below.

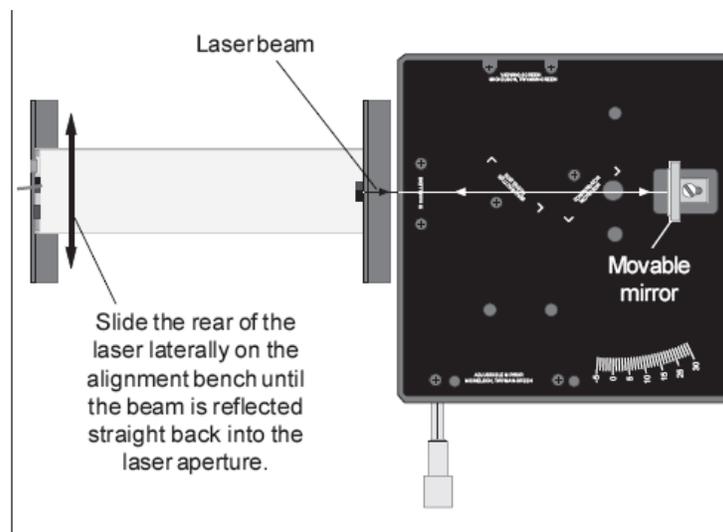


Figure 6.1. Aligning the Laser

Michelson Mode:

1. Align the laser and interferometer base as previously described. The laser beam should be approximately parallel with the top of the base, should strike the center of the movable mirror, and should be reflected directly back into the laser aperture.
2. Mount the adjustable mirror on the interferometer base. Position one component holder in front of the laser. see figure 6.2.

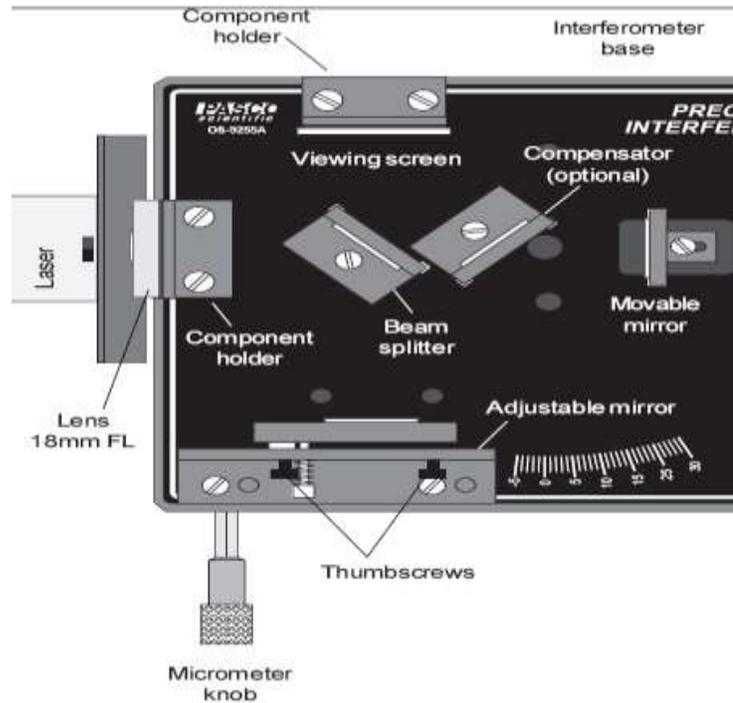


Figure 6.2. Michelson Mode Setup

3. Position the beam-splitter at a 45 degree angle to the laser beam, within the crop marks, so that the beam is reflected to the fixed mirror. so that the reflected beam hits the fixed mirror near its center.
4. There should now be two sets of bright dots on the viewing screen or wall ; one set comes from the fixed mirror and the other comes from the movable mirror. Adjust the angle of the beam-splitter again until the two sets of dots are as close together as possible.
5. Using the thumbscrews on the back of the adjustable mirror, adjust the mirror's tilt until the two sets of dots on the viewing screen coincide.
6. The compensator is not needed for producing interference fringes when using a laser light source. why?
7. Attach the 18 mm FL lens to the magnetic backing of the component holder in front of the laser, as shown ,and adjust its position until the diverging beam is centered on the beam-splitter. You should now see circular fringes on the viewing screen. If not, carefully adjust the tilt of the adjustable mirror until the fringes appear.

StepB:

1. Align the laser and interferometer in the Michelson mode, so an interference pattern is clearly visible on your wall.
2. Rotate the micrometer knob slowly counterclockwise. Count the fringes as they pass your reference mark. Continue until some predetermined number of fringes have passed your mark (count *at least* 20 fringes). Record the final reading of the micrometer dial x in the table 1.
3. Repeat the operation previous several times until you complete table 1.

NOTE: Knowing that each small division on the micrometer knob corresponds to one μm (10^{-6} meters) of mirror movement find d_0 the ratio of path difference (twice the distance of mirror movement) to Δx . due to $d_0 = .1$.

n	Number of fringes	X(mm)
1	0	
2	20	
3	40	
.	.	
.	180	

Table.1

5. Draw a graph of X as a function of m, and find the slope $=\lambda/2d_0$, then find wavelength of laser, where $d_0=.1$, and compare by the real $\lambda=633\text{nm}$.

Part2: The Fabry-Perot Mode

PROCEDURE:

STEP A: Setup and Operation

1. Mount the adjustable mirror where indicated on the interferometer base and one component holder in front of the movable mirror. See Figure 6.3.

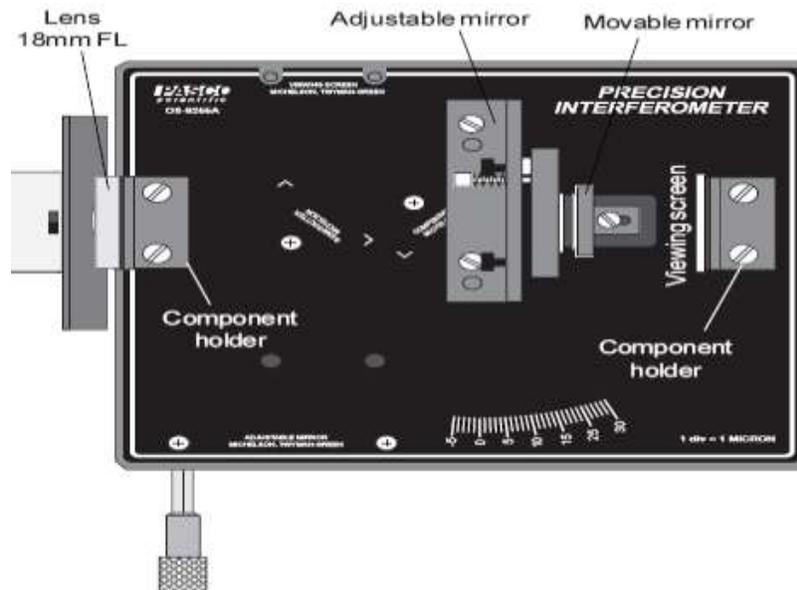


Figure 6.3. Fabry-Perot Mode Setup

2. Place the other component holder behind the movable mirror. You should see several images of the laser beam on wall.
3. Using the thumbscrews, adjust the tilt of the adjustable mirror until there is only one bright dot on the wall.
4. Now mount the 18 mm FL lens on the front component holder. A clear sharp interference pattern should be visible on wall.

STEP B: Procedure for Wavelength by using the Fabry-Perot Mode:

1. Repeat step 1 and 2 as in the first part. Record x in table 2.
2. Record d_m , the distance that the movable mirror moved toward the beam-splitter according to your readings of the micrometer knob using $d_m = d_0 * \Delta x$, where $d_0 = 0.1$.

n	Number of fringes	x (mm)	$\Delta x = (x_{n+1} - x_n)$ (mm)	$d_m = d_0 * \Delta x$ (mm)	$\lambda = 2d_m/20$
1	0				
2	20				
3	40				
.	.				
.	180				

Table 2

3. For each trial, calculate the wavelength independently for that data. The same formula applies, then average your results and compare by the real $\lambda = 633\text{nm}$.

Name

TITLE OF EXPERIMENT

**INTRODUCTION TO INTERFEROMETRY: The
Michelson and Morley/Fabry Perot Experiments**

MODERN PHYSICS LAB

PHYS 393 COURSEWORK

REPORTING SHEET

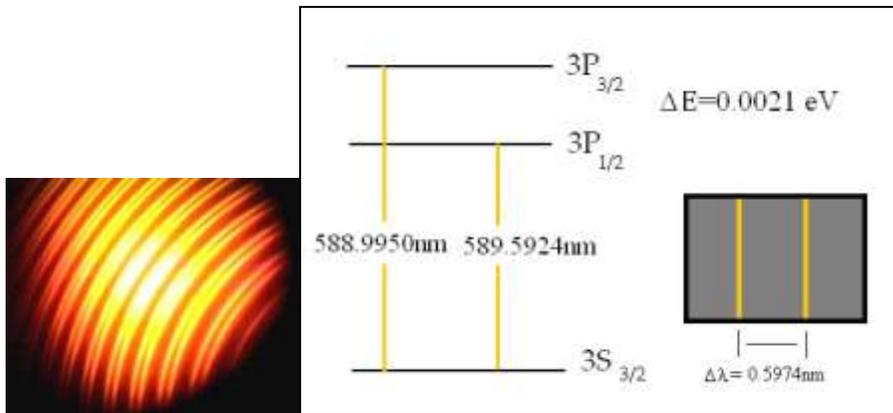
PART A: SCIENTIFIC KNOWLEDGE AND PLANNING	
Aim:	
Methodology- Draw your set up ,explaining the use of the different components you will use to achieve your aim- both for part A and B <u>What is interferometry? and why scientist use it?</u>	5

<p>What was the idea of the ether? and why did scientists in the 19th century introduced it?</p> <hr/> <p>What was the first experiment to show that there is no ether?</p> <ol style="list-style-type: none">1. The Fabry Perot Experiment2. Young's Double Slit experiment3. Milikan's oil drop experiment4. The Michelson and Morley experiment5. Both 1 and 4 <p>Explain briefly, why in conclusion there was no ether based on the principles of interferometry.</p> <hr/>	8
<p>If one fires electrons through a double slit, what pattern would they observe on the screen behind the slit? And why is that?</p>	6

If now a camera is placed at the slit, would the pattern change? Explain.

Using a Fabry Perot Interferometer one can observe the so called Sodium D-Lines.

6



Explain the origin of the double lines. How is such a doublet formed? Discuss it within the theory of spin orbit coupling.

<p>Discuss the basics of interferometers in astronomy.</p>	<p>3</p>
<p>Which factor you suggest should be controlled in order to make sure that your results are accurate and reliable?</p>	<p>2</p>

PART B: OBTAINING EVIDENCE	
<p>Your data. Use the correct units and convert appropriately.</p>	

PART C: ANALYSING AND CONSIDERING YOUR EVIDENCE	
Graph (use graph paper)	
Calculations	
My evidence leads to the following result.	
Compare your results with theoretical values.	

PART D: EVALUATION [10 MARKS]	
What was good or bad about the experiment you did was ...	2
Some ways you could improve the experiment were...	2
You had the following anomalies.	2
The explanation for your anomalies was	2
You believe my evidence is reliable/unreliable for the following reasons.	2

Experiment 7

The Microwave experiment

Aim:

This experiment uses microwaves in order to demonstrate the formation of standing waves, verifying the wavelength λ of the microwaves as well as diffraction from double slit and investigate the phenomenon of polarization.

Part 1: Standing Waves - Measuring Wavelengths

Apparatus:

Transmitter – Goniometer– Receiver

Introduction

When two electromagnetic waves meet in space, they superpose. therefore, the total electric field at any point is the sum of the electric fields created by both waves at that point. If the two waves travel at the same frequency but in opposite direction they form a standing wave. Nodes appear where the fields of the two waves cancel and antinodes where the superposed field oscillates between a maximum and a minimum. The distance between nodes in the standing wave pattern is just $1/2$ the wavelength (λ) of the two waves.

Method

1. Set up the equipment as shown in Figure 7.1. Adjust the Receiver controls to get a full-scale meter reading with the Transmitter and Receiver as close together as possible. Slowly move the Receiver along the Goniometer arm, away from the Transmitter. *How does this motion effect the meter reading?* The microwave horns are not perfect collectors of microwave radiation. Instead, they act as partial reflectors, so that the radiation from the Transmitter reflects back and forth between the Transmitter and Reflector horns, diminishing in amplitude at each pass. However, if the distance between the Transmitter and Receiver diodes is equal to $n\lambda/2$, (where n is an integer and λ is the wavelength of the radiation) then all the multiply-reflected waves entering the Receiver horn will be

in phase with the primary transmitted wave. When this occurs, the meter reading will be a maximum. (The distance between adjacent positions in order to see a maximum is therefore $\lambda/2$.)

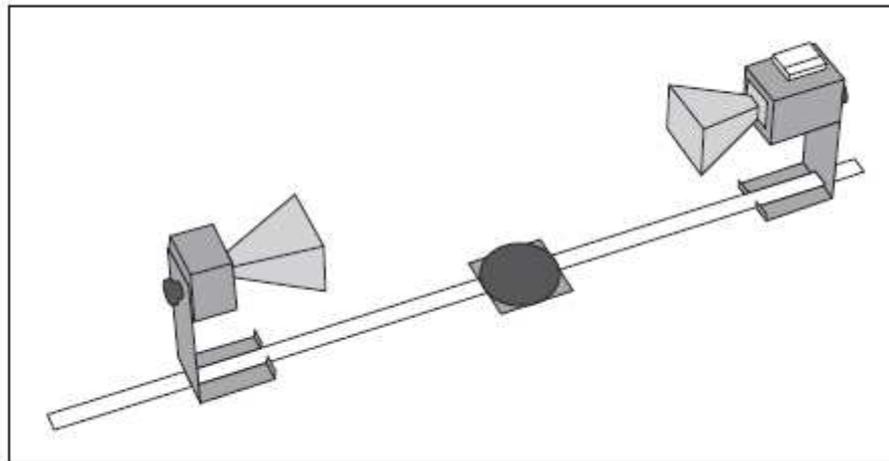


Figure 7.1: Equipment Setup

2. Slide the Receiver one or two centimeters along the Goniometer arm to obtain a minimum meter reading. Record the Receiver position along the metric scale of the Goniometer arm.
Initial Receiver Position =
3. Slide the Receiver to obtain a second minimum.
Final Receiver Position =
4. Repeat your measurements for 3 successive minima and find the average.

You can use table 7.1.

Initial Receiver Position (R_1)	Final Receiver Position (R_2)	$L = R_2 - R_1$
		$L_{avg.} =$

Table 7.1

5. Use the data you have collected to calculate the wavelength of the microwave radiation.
 6. Calculate the frequency of the microwave signal.
 7. Compare your result with the theoretical value.
-

Part 2: Polarization

Apparatus:

Transmitter – Receiver – Goniometer.

Introduction

The microwave radiation from the Transmitter is linearly polarized along the Transmitter diode axis (i.e., as the radiation propagates through space, its electric field remains aligned with the axis of the diode). If the Transmitter diode were aligned vertically, the electric field of the transmitted wave would be vertically polarized, as shown in Figure 7.3. If the detector diode were at an angle θ to the Transmitter diode, as shown in Figure 7.4, it would only detect the component of the incident electric field that was aligned along its axis. In this experiment you will investigate the phenomenon of polarization.

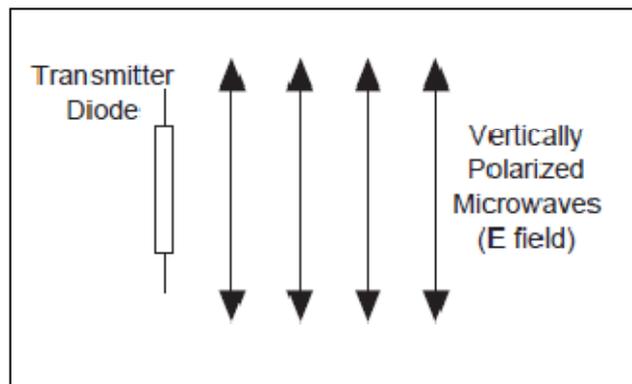


Figure 7.3: Vertical Polarization

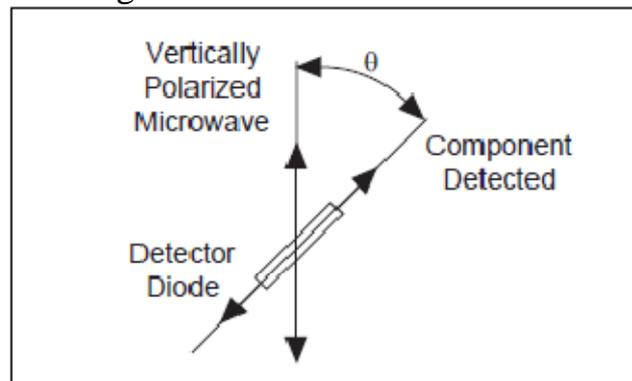


Figure 7.4: Detecting Polarized Radiation

Method

- 1- Arrange the equipment as shown in Figure 7.1 and adjust the Receiver controls for nearly full-scale meter deflection.
- 2- Loosen the hand screw on the back of the Receiver and rotate the Receiver in increments of ten degrees. At each rotational position, record the meter reading in table 7.2.
- 3- Note what happens to the meter readings if you continue to rotate the Receiver beyond 180-degrees?

- 4- Calculate M using $M=M_0\cos\theta$ where θ is the angle between the detector and Transmitter diodes and M_0 is the meter reading when $\theta = 0$.
- 5- Graph your data from step 2 of the experiment. On the same graph, plot the relationship $M_0\cos\theta$. Compare the two graphs.

Angle of receiver	Meter reading M	$M=M_0\cos\theta$	Angle of receiver	Meter reading M	$M=M_0\cos\theta$
0			100		
10			110		
20			120		
30			130		
40			140		
50			150		
60			160		
70			170		
80			180		
90					

Table 7.2

Part 3: Double-Slit Interference

Apparatus:

Transmitter, Receiver - Goniometer, Rotating - Component Holder- Metal Reflectors (2) - Slit Extender Arm -Slit Spacer.

Introduction

When an electromagnetic wave passes through a two-slit aperture. The wave diffracts into two waves which superpose in the space beyond the apertures. Similar to the standing wave pattern, there are points in space where maxima are formed and others where minima are formed. With a double slit aperture, the intensity of the wave beyond the aperture will vary depending on the angle of detection. For two thin slits separated by a distance d , maxima will be found at angles such that $d \sin\theta = n\lambda$. (Where θ = the angle of detection, λ = the wavelength of the incident radiation, and n is any integer) (See Figure 7.5).

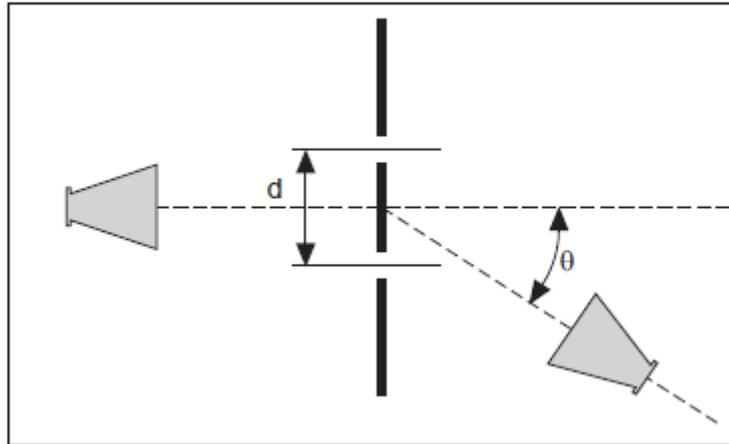


Figure 7.5 Double-Slit Interference

Method

- 1- Arrange the equipment as shown in Figure 7.6 Use the Slit Extender Arm, two Reflectors, and Slit Spacer to construct the double slit. (We recommend a slit width of about 1.5 cm.) Be precise with the alignment of the slit and make the setup as symmetrical as possible.
- 2- Adjust the Transmitter and Receiver for vertical polarization (0°) and adjust the Receiver controls to give a full-scale reading at the lowest possible amplification.
- 3- Set the Goniometer arm so the Receiver directly faces the Transmitter. Adjust the Receiver controls to obtain a meter reading of 1.0. Now set the angle θ to each of the values shown in table 7.3. At each setting record the meter reading in the table.
- 4- Plot your data.

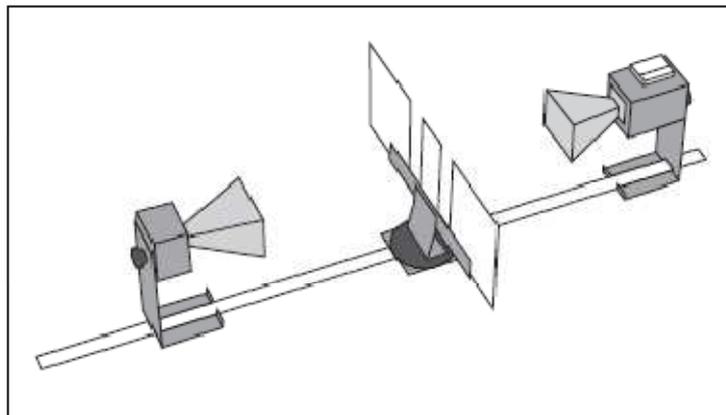


Figure 7.6 Equipment Setup

Angle	Meter Reading	Angle	Meter Reading
0°		45°	
5°		50°	
10°		55°	
15°		60°	
20°		65°	
25°		70°	
30°		75°	
35°		80°	
40°		85°	

Table 7.3

Equipment

Introduction

There are many advantages to studying optical phenomena at microwave frequencies. Using a 2.85 centimeter microwave wavelength transforms the scale of the experiment. Microns become centimeters and variables obscured by the small scale of traditional optics experiments are easily seen and manipulated. The PASCO scientific Model WA-9314B Basic Microwave Optics System is designed to take full advantage of these educational benefits. The Basic Microwave Optics System comes with a 2.85 centimeter wavelength microwave transmitter and a receiver with variable amplification (from 1X to 30X). All the accessory equipment needed to investigate a variety of wave phenomena is also included.

This manual describes the operation and maintenance of the microwave equipment and also gives detailed instructions for many experiments. These experiments range from quantitative investigations of reflection and refraction to microwave models of the Michelson and Fabry-Perot interferometers. For those who have either the Complete Microwave Optics System (WA-9316) or the Microwave Accessory Package (WA-9315), the manual describes experiments for investigating Bragg diffraction and Brewster's angle.

Equipment

Gunn Diode Transmitter

The Gunn Diode Microwave Transmitter provides 15 mW of coherent, linearly polarized microwave output at a wavelength of 2.85 cm. The unit consists of a Gunn diode in a 10.525 GHz resonant cavity, a microwave horn to direct the output, and an 18 cm stand to help reduce table top reflections. The Transmitter may be powered directly from a standard 115 or 220/240 VAC, 50/60 Hz outlet by using the provided power supply. Other features include an LED power-indicator light and a rotational scale that allows easy measurement of the angle of polarization.

The Gunn diode acts as a non-linear resistor that oscillates in the microwave band. The output is linearly polarized along the axis of the diode and the attached horn radiates a strong beam of microwave radiation centered along the axis of the horn.

To Operate the Microwave Transmitter

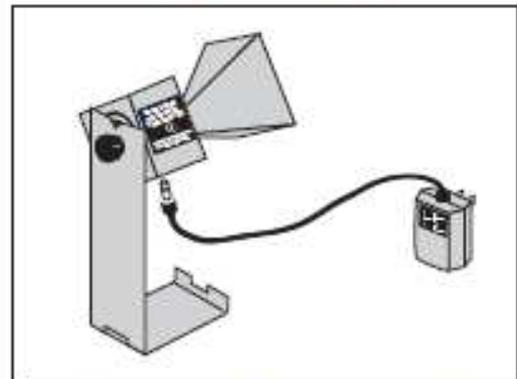
Simply plug the power supply into the jack on the Transmitter's bottom panel and plug the power supply into a standard 115 or 220/240 VAC, 50/60 Hz outlet. The LED will light indicating the unit is on.

► **CAUTION:** The output power of the Microwave Transmitter is well within standard safety levels. Nevertheless, one should never look directly into the microwave horn at close range when the Transmitter is on.

Power Supply Specifications:

9 Volt DC, 500 mA.

Miniature Phone Jack Connector (the tip is positive)

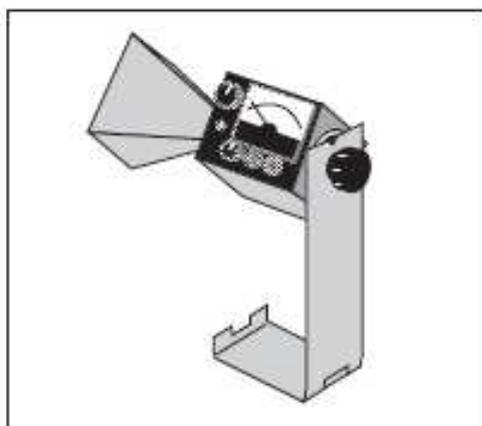


Microwave Transmitter with Power Supply

Microwave Receiver

The Microwave Receiver provides a meter reading that, for low amplitude signals, is approximately proportional to the intensity of the incident microwave signal. A microwave horn identical to that of the Transmitter's collects the microwave signal and channels it to a Schottky diode in a 10.525 GHz resonant cavity. The diode responds only to the component of a microwave signal that is polarized along the diode axis, producing a DC voltage that varies with the magnitude of the microwave signal.

Special features of the Receiver include four amplification ranges—from one to thirty—with a variable sensitivity knob that allows fine tuning of the amplification in each range. For convenience in class demonstrations, banana plug connectors provide for an output signal via hookup to a projection meter (such as PASCO Model ES-9065 Projection Meter or SE-9617 DC Voltmeter). This output can also be used for close examination of the signal using an oscilloscope. The receiver is battery powered and has an LED battery indicator; if the LED lights when you turn on the Receiver, the battery is working. As with the Transmitter, an 18 cm high mount minimizes table top reflections, and a rotational scale allows convenient measurements of polarization angle.



Microwave Receiver

The female audio connector on the side of the Receiver is for an optional Microwave Detector Probe (PASCO Model WA-9319). The probe works the same as the Receiver except it has no horn or resonant cavity. The Probe is particularly convenient for examining wave patterns in which the horn could get in the way, such as the standing wave pattern described in Experiment 3 of this manual.

►NOTE: The detector diodes in the Receiver (and the Probe) are non-linear devices. This non-linearity will provide no problem in most experiments. It is important however, to realize that the meter reading is not directly proportional to either the electric field (E) or the intensity (I) of the incident microwave. Instead, it generally reflects some intermediate value.

To Operate The Microwave Receiver:

►NOTE: Before using the Receiver, you will need to install the two 9-volt transistor batteries—they are included with the system. See the instructions in the Maintenance section at the end of this manual.

- ① Turn the INTENSITY selection switch from OFF to 30X, the lowest amplification level. The battery indicator LED should light, indicating that the battery is okay. If it does not, replace the battery following the procedures in the Maintenance section of this manual.

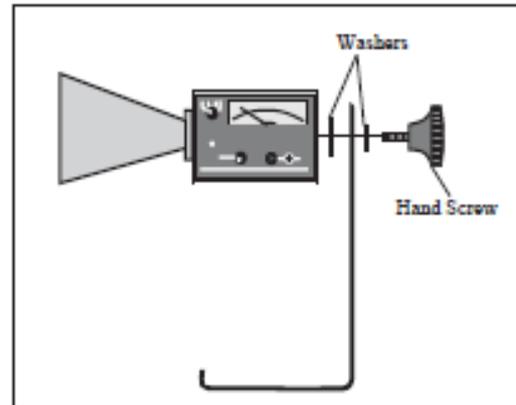
►NOTE: The INTENSITY selection settings (30X, 10X, 3X, 1X) are the values you must multiply the meter reading by to normalize your measurements. 30X, for example, means that you must multiply the meter reading by 30 to get the same value you would measure for the same signal with the INTENSITY selection set to 1X. Of course, this is true only if you do not change the position of the VARIABLE SENSITIVITY knob between measurements.

- ② Point the microwave horn toward the incident microwave signal. Unless polarization effects are under investigation, adjust the polarization angles of the Transmitter and Receiver to the same orientation (e.g., both horns vertically, or both horns horizontally).
- ③ Adjust the VARIABLE SENSITIVITY knob to attain a meter reading near midscale. If no deflection of the meter occurs, increase the amplification by turning the INTENSITY selection switch clockwise. Remember, always multiply your meter reading by the appropriate INTENSITY selection (30X, 10X, 3X, or 1X) if you want to make a quantitative comparison of measurements taken at different INTENSITY settings.

Initial Setup

To attach the microwave Transmitter and Receiver to their respective stands prior to performing experiments, proceed as follows:

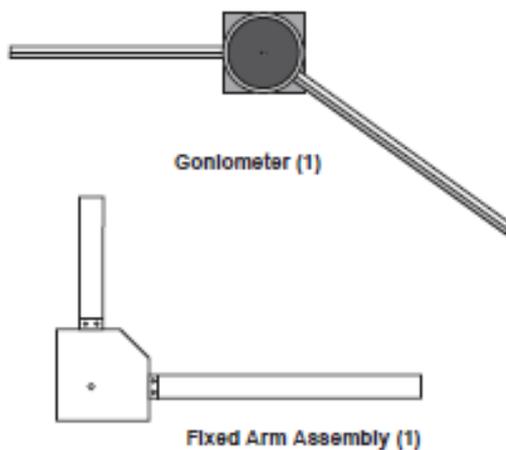
- ① Remove the black hand screw from the back panel of both the Transmitter and the Receiver.
- ② Attach both units to the stands as shown below. Observe the location of the washers.
- ③ To adjust the polarization angle of the Transmitter or Receiver, loosen the hand screw, rotate the unit, and tighten the hand screw at the desired orientation. Notice the rotational scale on the back of each unit for measuring the angle of polarization. Be aware, however, that since the Transmitter and Receiver face each other in most experiments it is important to match their polarization angle. If you rotate one unit to an angle of 10-degrees, you must rotate the other to -10-degrees (350-degrees) to achieve the proper polar alignment.



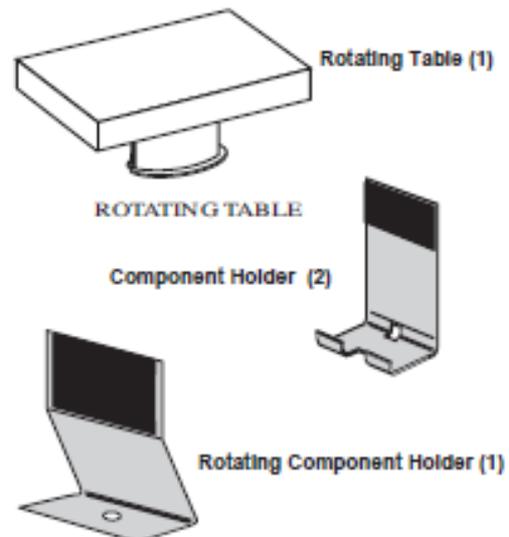
Attaching the Transmitter and Receiver Stands

Accessory Equipment

Accessory equipment for the Basic Microwave Optics System includes:



PASCO
SCIENTIFIC

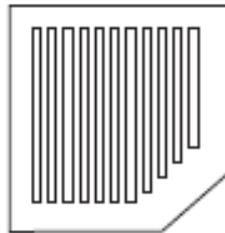




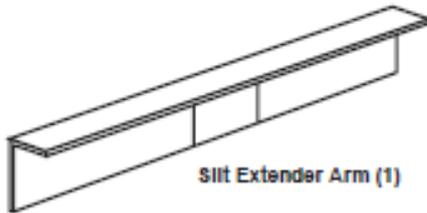
Metal Reflector (2)



Partial Reflector (2)



Polarizers (2)



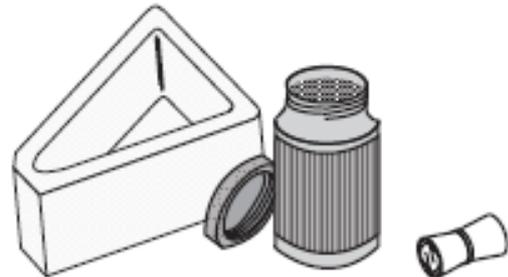
Slit Extender Arm (1)



Narrow Slit Spacer (1)



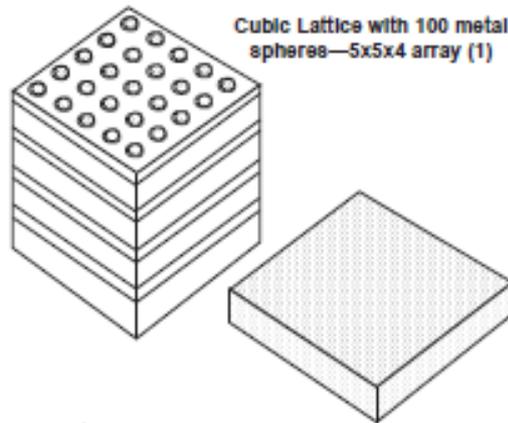
Wide Slit Spacer (1)



Ethafoam Prism Mold w/
Styrene Pellets (1)

Tubular
Plastic Bags (4)

The WA-9315 Microwave Accessory Package (which is part of the Complete Microwave Optics System Model WA-9316) includes the following:



Cubic Lattice with 100 metal
spheres—5x5x4 array (1)

Polyethylene Panel (1)

The following components, compatible with the WA-9314B Basic Microwave Optics System, are available from PASCO scientific:

Model WA-9319 Microwave Detector Probe plugs directly into the Microwave Receiver. The probe is essential for experiments in which the horn of the Receiver might otherwise interfere with the wave pattern being measured.

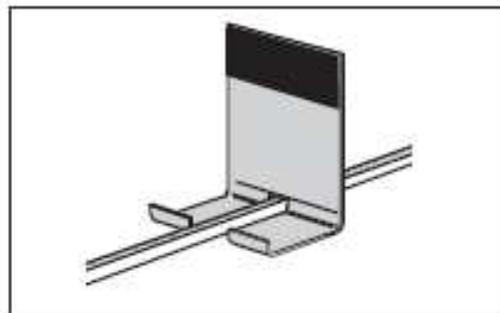
Model WA-9318 Microwave Modulation Kit includes a modulator and microphone. With this kit, you can use your Transmitter and Receiver as a microwave communications system.

Assembling Equipment for Experiments

The arms of the Goniometer slide through the holes in the Component Holders as shown. Make sure the magnetic strip on the bottom of the arm grips the base of the carriage. To adjust the position of the holders, just slide them along the Goniometer arms. Attach the mounting stands of the microwave Transmitter and Receiver to the arms of the Goniometer in the same manner.

For most experiments it is advantageous to attach the Transmitter to the long arm of the Goniometer and the Receiver to the shorter, rotatable arm. This maintains a fixed relationship between the microwave beam and components mounted on the long arm (or on the degree plate) of the Goniometer. In turn the Receiver moves easily to sample the output.

Reflectors, Partial Reflectors, Polarizers, Slit Spacers, and the Slit Extender Arm all attach magnetically to the Component Holders. The metric scale along the Goniometer arms and the degree plate at the junction of the arms allow easy measurement of component placement. When rotating the rotatable arm, hold the degree plate firmly to the table so that it does not move.



Mounting the Component Holder

► IMPORTANT NOTES:

1. **CAUTION**—Under some circumstances, microwaves can interfere with electronic medical devices. *If you use a pacemaker, or other electronic medical device, check with your doctor or the manufacturer to be certain that low power microwaves at a frequency of 10.525 GHz will not interfere with its operation.*
2. Always mount the apparatus on a **CLEAN, SMOOTH** table. Before setting up the equipment, brush off any material—*particularly metal chips*—that might have adhered to the magnetic strips on the bottom of the Goniometer arms.

Name

TITLE OF EXPERIMENT
THE MICROWAVE EXPERIMENT

MODERN PHYSICS LAB
PHYS 396 COURSEWORK
REPORTING SHEET

PART B: OBTAINING EVIDENCE

Your data. Use the correct units and convert appropriately.

PART C: ANALYSING AND CONSIDERING YOUR EVIDENCE	
Graph (use graph paper)	
Calculations	
My evidence leads to the following result.	
Compare your results with theoretical values.	

PART D: EVALUATION [10 MARKS]	
What was good or bad about the experiment you did was ...	2
Some ways you could improve the experiment were...	2
You had the following anomalies	2
The explanation for your anomalies was	2
You believe my evidence is reliable/unreliable for the following reasons.	2

EXPERIMENT 8

THE FARADAY EFFECT

AIM:

- a) Verifying the proportionality between the rotation ϕ of the polarisation plane and the magnetic field B
- b) Demonstration the decrease of the Verdet's constant V with increasing wavelength λ .

APPARATUS:

1 Flint glass square with holder, 1 U-core with a pair of pole pieces, 1 Halogen lamp, 4 Filters, 1 Lens, 2 Polarisation filters, 1 Translucent screen, 1 Optical bench, 1 Teslometer, 1 Variable extra low-voltage transformer.

METHODOLOGY:

In 1845 Michael Faraday described the interaction between light and a magnetic field in optically transparent dielectric materials, including liquids. He concluded that such an interaction would result to a rotation of the plane of polarization of the light that would be proportional to the intensity of the component of the magnetic field in the direction of the beam of light.

This observation can be explained by imaging linearly polarised light as the coherent superposition of two opposite circularly polarised components σ_+ and σ_- .

In atomic physics the magnetic field influences the motion of the electrons in the atom. The magnetic field causes the oscillating charges to carry out an additional precession movement. The precession frequency is called the Larmor frequency, i.e.:

$$\omega_L = \frac{e}{m} B \quad (8.1)$$

where e and m are the charge and mass of the oscillating particles, and B the magnetic flux density.

The components σ_+ and σ_- of the polarised light have different frequencies relative to the charges performing the precession movement. One component has the frequency

$\omega + \omega_L$ and the other component has the frequency $\omega - \omega_L$. The refractive indices n_+, n_- and the phase velocities v_+, v_- differ, which is equivalent to optical activity.

Upon emergence from the medium, the rays can be considered to re-combine, however they suffer a phase shift of $\Delta\theta = 2\pi L (n^+ - n^-)/\lambda$, resulting in a rotation of the angle of linear polarization by ϕ . This process is shown explicitly in Figure 8.1.

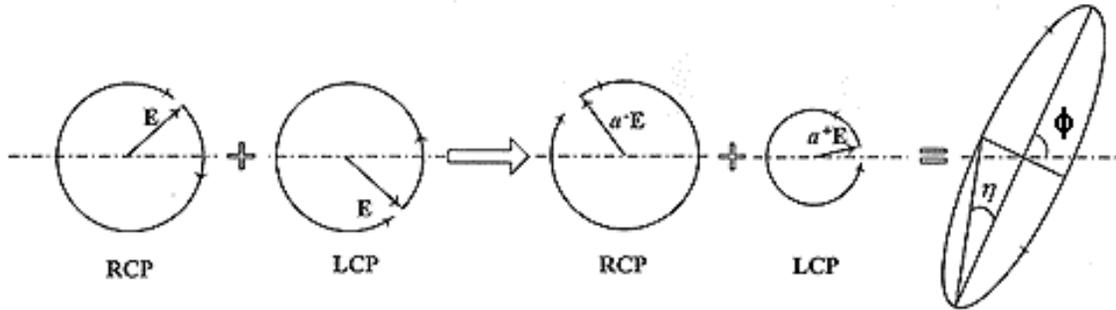


Figure 8. 1 A linearly-polarized beam of light may be considered as the superposition of equal amounts of right- and left-circularly polarized beams. In going through a perpendicularly magnetized slab of material at normal incidence, the two components of circular polarization experience different (complex) refractive indices and, therefore, each emerges from the medium with a different phase and amplitude. The amplitudes of the emergent beams may be denoted by a^+ and a^- , and their phase difference by $\Delta\phi$. The superposition of the emergent circular polarization states yields elliptical polarization. The angle of rotation of the major axis of the ellipse from the horizontal direction (which is the direction of the incident linear polarization) is given by $\phi = \frac{1}{2}\Delta\theta$, and the ellipticity η is given by $\tan \eta = (a^+ - a^-)/(a^+ + a^-)$.

The relation between the angle of rotation of the polarization and the magnetic field in a diamagnetic material is:

$$\phi = VBL \quad (8.2)$$

where

ϕ is the angle of rotation (in radians)

B is the magnetic flux density in the direction of propagation (in teslas)

L is the length of the path (in metres) where the light and magnetic field interact

is the Verdet constant for the material. This empirical proportionality constant (in units of radians per tesla per metre) varies with wavelength and temperature.

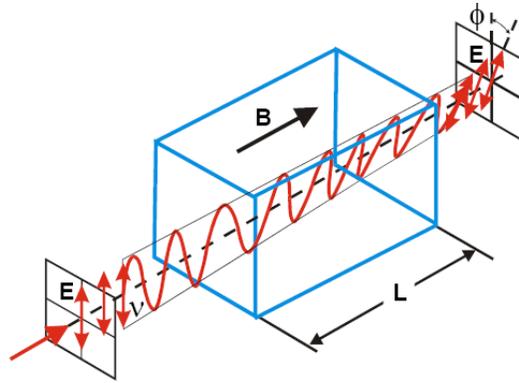


Figure 8.2 A schematic representation of the Faraday effect: B magnetic flux density parallel to the propagation direction of the polarised light. E: Electric field, L: length of isotropic material

A positive Verdet constant corresponds to L-rotation (anticlockwise) when the direction of propagation is parallel to the magnetic field and to R-rotation (clockwise) when the direction of propagation is anti-parallel. Thus, if a ray of light is passed through a material and reflected back through it, the rotation doubles. Finally note that Verdet's constant is inverse proportional to the wavelength of light λ , i.e.:

$$V = -\frac{e}{2mc^2} \frac{1.8 \times 10^{-14}}{\lambda^2} m^2 \quad (8.2)$$

PROCEDURE:

Setup

- In this experiment a thread cross is attached to the analyzer and projected onto the translucent screen so that the angle of rotation $\Delta\phi$ can be determined precisely.
- Equip one of the polarizing filters with a thread cross like depicted in Fig.(8.3) Make sure, that the cross is exactly at right angles and placed exactly in the center of the analyzer. Use the analyzer protractor scale to align it. The best material for this is silk thread.
- Arrange the halogen lamp on the optical bench according to Fig.(8.4). Mount the picture slider with heat insulation filter on the condenser.

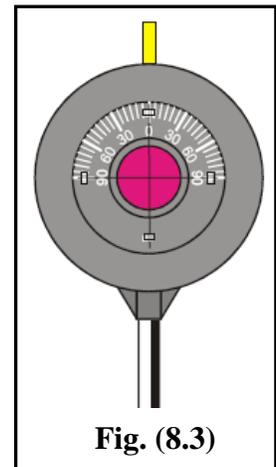
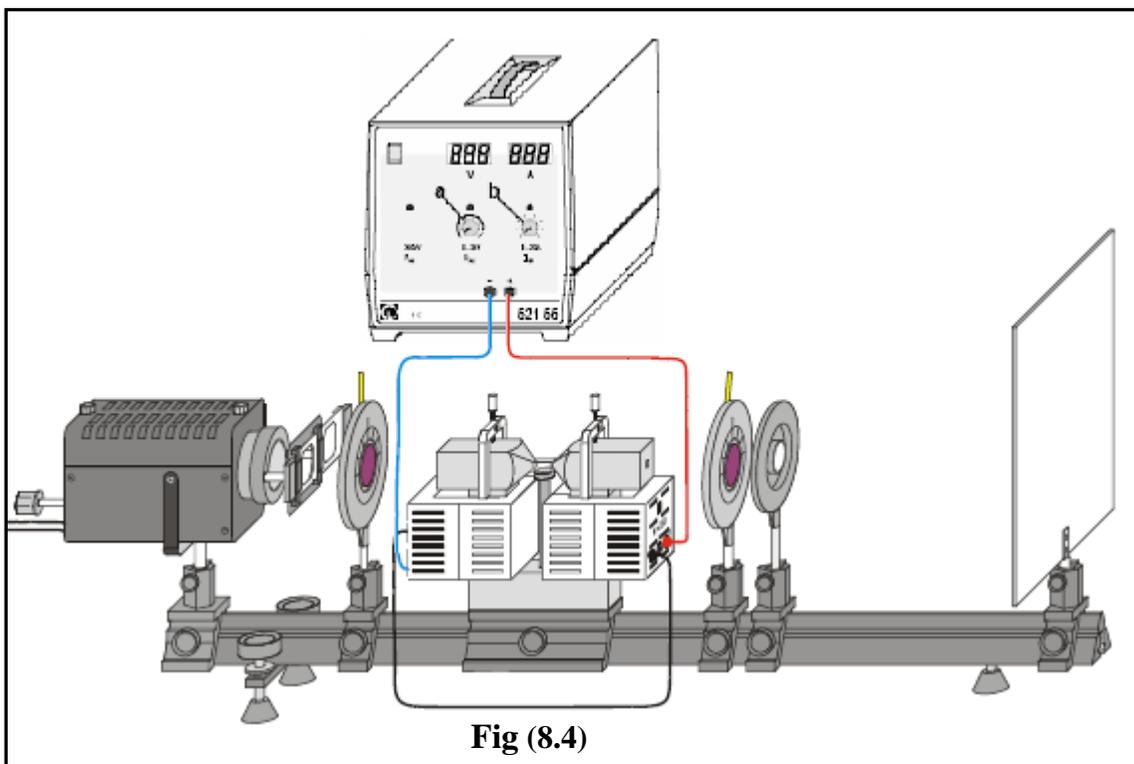


Fig. (8.3)

- Position a polarizer close the halogen lamp on the optical bench as shown in Fig.(8.4).
- Place the U-core of the demountable transformer with the two coils on the rider base with thread and fix it with the holder for the flint glass square.
- Place the bored pole pieces on the U-core in such a manner that the flint glass square can be placed on the holder as depicted in Fig.(8.4).
- Push the pole pieces right up to the flint glass square but without touching it.
- Use the clamps to fix the bored pole pieces on the U-core.
- Position the analyzer close the U-core on the optical bench as shown in Fig.(8.4).
- Position the translucent screen opposite to the analyzer.
- Place the lens $f = +50$ mm between the analyzer and the translucent screen.

Electrical setup

- Connect the coils to the power supply unit.



- Connect the halogen lamp to 12 V sockets of the power supply unit.

Optical adjustment

- Use picture slider with the heat filter for absorbing the infrared component in halogen light.
- Switch on halogen lamp.
- Align the light source and the bored pole pieces in such a manner that light – as much as possible – passes through the bores in the pole pieces (with no flint glass square on the holder).
- To project an image of the thread cross on the analyzer onto the translucent screen shift the lens towards the analyzer until a sharp image is observed.

Note: The thread cross and protractor scale should be exactly concentric.

- Insert the polarizing filter.

Carrying out the experiment

a) Calibration of the magnetic field

1. Remove the flint glass square.
2. Place the tangential B probe of the Teslameter between the pole pieces. Use the stand material to hold the magnetic probe between the bored pole pieces.
3. Record the magnetic field B as function of the current I through the coils for currents from 0 to 10 A in steps of 1 A.
4. Plot I vs. B.

b) Rotation of the polarization plane ϕ as function of the magnetic field B

1. Insert the blue-with-violet filter that has $\lambda = 450 \text{ nm}$ (468 11) in the diagram slider.
2. Align the flint glass square between the bored pole pieces.
3. Set the desired magnetic field by means of the magnet current.
4. Set the analyzer to 0° position.
5. Find the intensity minimum by turning the polarizer.

Note: For a final minimum adjustment (almost dark) the minimum light intensity can be easily checked by looking directly into the light beam behind the imaging lens. The polarizer and analyzer are set to the intensity minimum as it can be easier accessed than the intensity maximum.

6. Reverse the polarity of the magnetic field without changing the magnet current. To do so, switch off magnetic field; reverse polarity of coil current; switch on magnetic field.

Note: When the direction of the field is reversed the doubled angle of rotation 2ϕ is measured as in Fig.(8.5).

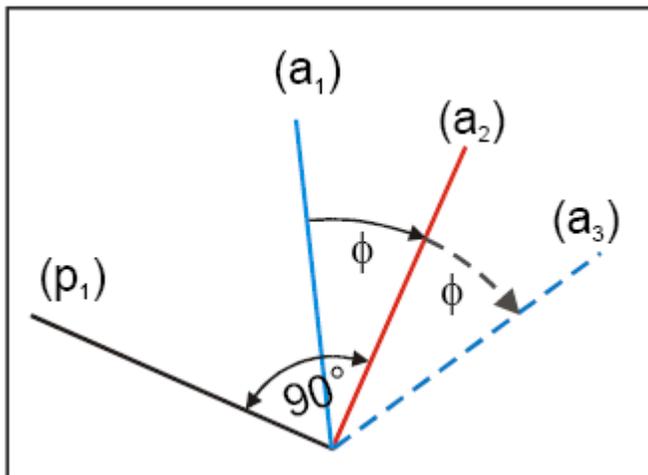


Fig.(8.5): Measuring the doubled angle of rotation 2ϕ by reversing the polarity of the magnetic field. ϕ : angle of rotation of the polarization plane

- (a₁): analyzer position at the start
- (a₂): polarization plane of the light after passing through the flint glass square in both experiments.
- (p₁) polarizer position for the first magnetic field setting.
- (a₃): analyzer position after reversing the polarity of the magnetic field.

7. Find the intensity minimum by turning the analyzer.

8. Switch off the magnetic field and find the intensity maximum by turning the polarizer.
9. Remove the color filter from the beam path to enhance the contrast of the projected thread cross.
10. Read off the thread cross position.
11. Repeat this measurement steps for various magnetic fields by varying the magnetic current from 1 A to 10 A in steps of 1 A.
12. Plot B vs. $2\Delta\varphi$. Find Verdet constant for the used wavelength.

c) Verdet's constant as function of the wavelength λ

1. Place one of the color filters (Table. 8.1) in the picture slider of the halogen lamp fitting.
2. Set the thread cross to zero.
3. Place the filter in the beam path and apply a magnetic field of 135 mT.
4. Measure the rotation of the polarization plane 2φ as described in part b).
5. Remove the color filter from the beam path before reading off the thread cross position.
6. Repeat the measurement for the other filters.
7. Plot λ^{-2} vs. Verdet constant.

Filter	Transmitted Color	λ (nm)
468 05	Yellow	570
468 09	Blue Green	515
468 11	Blue with Violet	450
468 13	Violet	440

Table. (8.1)

Safety notes

When operating the halogenlamp.

- Operate with AC voltage only (i.e. 12 V AC)
- Do not cover the ventilation slits (danger of overheating).
- Do not touch the bulb of the halogen lamp with your fingers.
- Protect the heat filter of the picture slider from shocks, dropping or similar (the fragile material can break easily).

Name

TITLE OF EXPERIMENT

THE FARADAY EFFECT: EXPERIMENT No 8

MODERN PHYSICS LAB

PHYS 393 COURSEWORK

REPORTING SHEET

PART A: SCIENTIFIC KNOWLEDGE AND PLANNING

Aim:

Method – what I am going to do in order to achieve my aim

A. List the equipment you plan to use

B. Draw your set up, explaining the use of the different components.

Explain the origin of the Faraday Effect.

Discuss the idea of Larmor precession within the above context.

What relationship you expect to get between the rotation ϕ of the polarisation plane and the magnetic field B	
What relationship you expect to get between Verdet's constant V and the wavelength λ .	
Which factors you suggest should be controlled in order to make sure that your results are accurate and reliable?	

PART B: OBTAINING EVIDENCE	
<p>Your data. Use the correct units and convert appropriately.</p>	

PART C: ANALYSING AND CONSIDERING YOUR EVIDENCE

Graph (use graph paper)

Calculations

My evidence leads to the following result.

Compare your results with theoretical values.

PART D: EVALUATION [10 MARKS]	
What was good or bad about the experiment you did was ...	2
Some ways you could improve the experiment were...	2
You had the following anomalies.	2
The explanation for your anomalies was	2
You believe my evidence is reliable/unreliable for the following reasons.	2

Related Topics

Energy quanta, quantum jumps, electron collision, excitation energy, Bohr's shell model

Principle

Electrons are accelerated in a tube filled with mercury vapour. The excitation energy of mercury is determined from the distance between the equidistant minima of the electron current in a variable opposing electric field.

Equipment

1 Franck-Hertz operating unit	09105.99
1 Franck-Hertz Hg-tube on plate	09105.10
1 Franck-Hertz oven	09105.93
1 NiCr-Ni thermocouple	13615.01
1 5-pin connecting cable, for Hg-tube	09105.30
1 Shielded BNC-cable, $l = 75$ cm	07542.11
1 RS 232 data cable	14602.00
1 Franck-Hertz software	14522.61
PC, Windows® 95 or higher	

Additional equipment:

1 Oscilloscope, 30 MHz, 2 channels	11459.95
2 Adapter, BNC-socket/4mm plug pair	07542.27
2 Screened cable, BNC, $l = 75$ cm	07542.11



Fig.1: Set-up for the Franck-Hertz experiment with PC.

Tasks

Record the countercurrent strength I in a Franck-Hertz tube as a function of the anode voltage U . Determine the excitation energy E from the positions of the current strength minima or maxima by difference formation.

Set-up and procedure

Set up the experiment as shown in Fig. 1. For details see the operating instructions of the unit 09105.99. Connect the operating unit to the computer port COM1, COM2 or to USB port (use USB to RS232 Adapter Converter 14602.10). Start the measure program and select Cobra3 Franck-Hertz experiment Gauge. The window "Frank-Hertz-experiment – measuring" (see Fig. 2) appears. The optimum parameters are different for each Hg-tube. You find the specific parameters for your device on a sheet which is enclosed in the package of the Hg-tube. Choose the parameters for U_1 , U_2 and U_H as given on that sheet and make sure that the rest is set as shown in Fig. 2. Press the continue button. Now the oven of the Franck-Hertz tube will be heated to 175 °C. Wait another 30 min before starting the measurement to make sure that the interior of the tube reaches its final temperature, too. At a particular voltage $U_1 = U_2$, which is dependent on temperature, a glow discharge between anode and cathode occur through ionisation. Meaningful measurements can therefore only be taken at voltages $U_1 < U_2$.

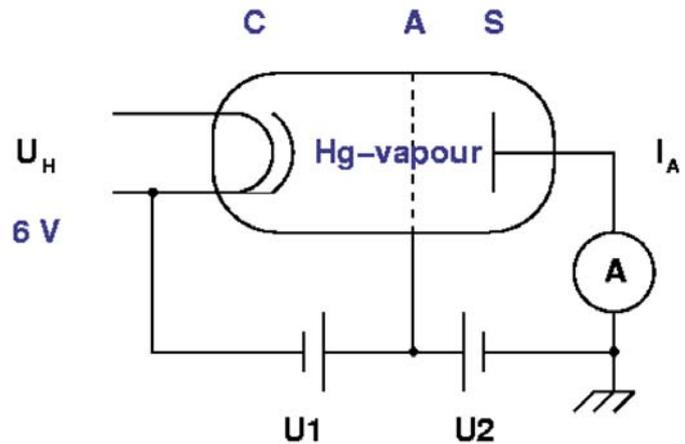


Fig. 3: Principle of the measurement.

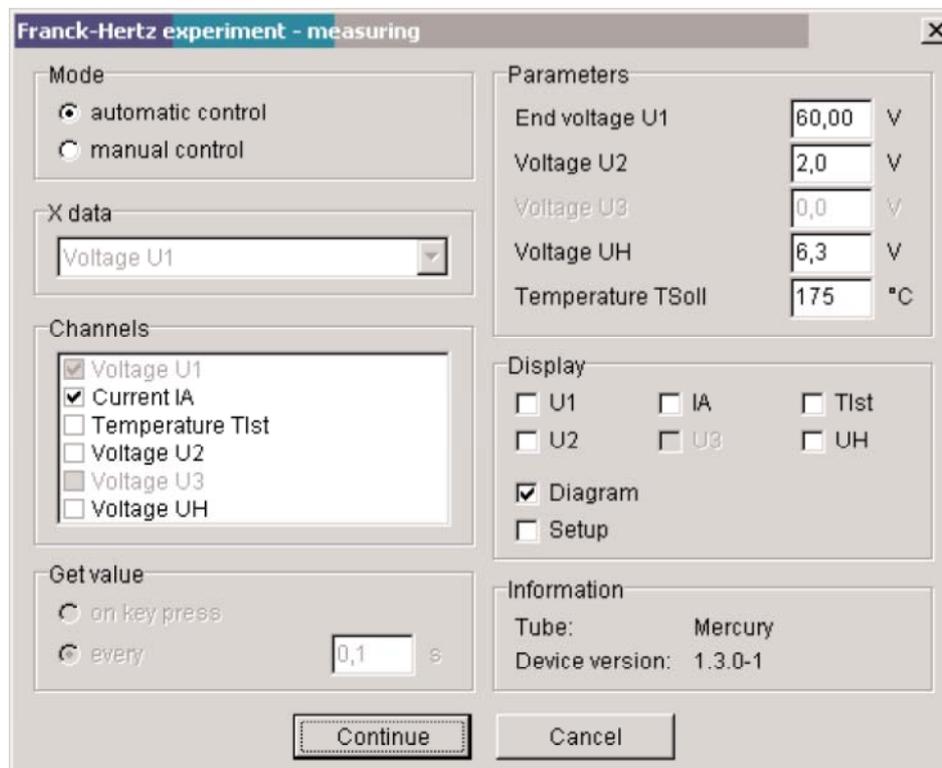


Fig. 2: Measuring parameters.

Theory and evaluation

Niels Bohr introduced the planetary model of the atom in 1913: An isolated atom consists of a positively charged nucleus about which electrons are distributed in successive orbits. He also postulated that only those orbits occur for which the angular momentum of the electron is an integral multiple of $h/2\pi$, i.e. $n \cdot h/2\pi$, where n is an integer and h is Planck's constant. Bohr's picture of electrons in discrete states with transitions among those states producing radiation whose frequency is determined by the energy differences between states can be derived from the quantum mechanics which replaced classical mechanics when dealing with structures as small as atoms. It seems reasonable from the Bohr model that just as electrons may make transitions down from allowed higher energy states to lower ones, they may be excited up into higher energy states by absorbing precisely the amount of energy representing difference between the lower and higher states. James Franck and Gustav Hertz showed that this was, indeed, the case in a series of experiments reported in 1913, the same year that Bohr presented his model. Franck and Hertz used a beam of accelerated electrons to measure the energy required to lift electrons in the ground state of a gas of mercury atoms to the first excited state.

The electrons emitted by a thermionic cathode are accelerated between cathode C and anode A in the tube filled with mercury vapour (Fig. 3) and are scattered by elastic collision with mercury atoms. From an anode voltage U_1 of 4.9 V, however, the kinetic energy of the electrons is sufficient to bring the valence electron of the mercury to the first excitation level 6^3P_1 by an inelastic collision. Because of the accompanying loss of energy, the electron can now no longer traverse the opposing field between anode A and counter electrode S: the current I is at a minimum. If we now increase the anode voltage further, the kinetic energy of the electron is again sufficient to surmount the opposing field: the current strength I increases. When $U_1 = 2 \times 4.9$ V the kinetic energy is so high that two atoms in succession can be excited by the same electron: we obtain a second minimum (Fig. 4). The graph of I/U_1 thus shows equidistant maxima and minima. These minima are not, however, very well-defined because of the initial thermal distribution of the electron velocities. The voltage U_1 between anode and cathode is represented by

$$U_1 = U + (\Phi_A - \Phi_C)$$

where U is the applied voltage, and A and C the work function voltages of the anode and cathode respectively. As the excitation energy E is determined from the voltage differences at the minima, the work function voltages are of no significance here.

According to the classical theory the energy levels to which the mercury atoms are excited could be random. According to the quantum theory, however, a definite energy level must suddenly be assigned to the atom in an elementary process. The course of the I/U_A curve was first explained on the basis of this view and thus represents a confirmation of the quantum theory.

The excited mercury atom again releases the energy it has absorbed, with the emission of a photon. When the excitation energy E is 4.9 eV, the wavelength of this photon is

$$\lambda = \frac{ch}{E} = 253 \text{ nm}$$

where $c = 2.9979 \cdot 10^8 \frac{m}{s}$ and $h = 4.136 \cdot 10^{-15} \text{ eV}$ and thus lies in the UV range.

For our evaluation we determine the voltage values of the minima. From the differences between these values we obtain the excitation energy E of the mercury atom by taking an average. By evaluating the measurements in Fig. 4 we obtained the value

$$E = (4.86 \pm 0.09) \text{ eV.}$$

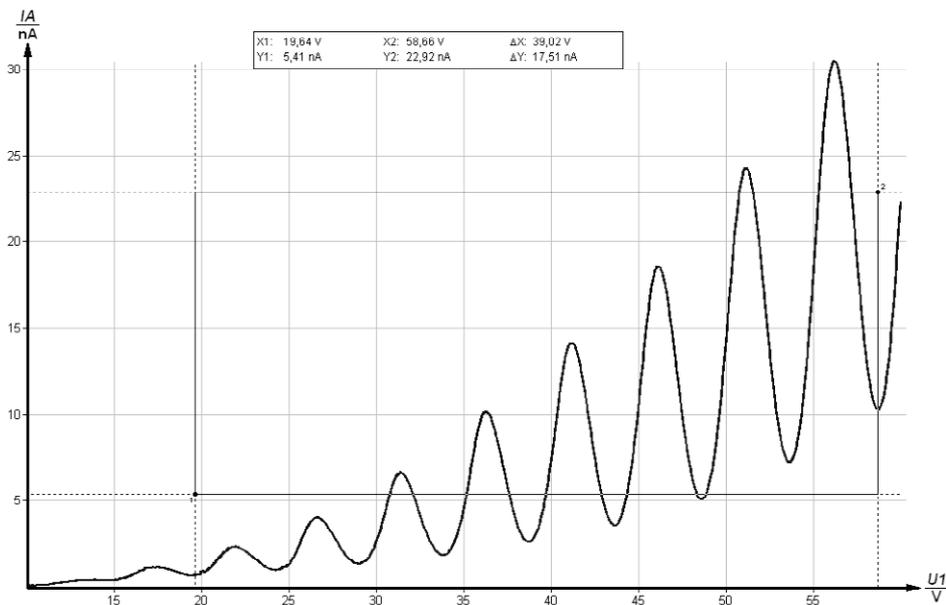


Fig. 4: Example of a Franck-Hertz curve recorded with $T = 175^{\circ}\text{C}$ and $U_2 = 2\text{ V}$.

Notes

- Generally speaking the first minima are easier to observe at low temperatures. On the other hand, we obtain a larger number of minima at higher temperatures, as the ignition voltage of the tube is raised to higher values.
- Due to oven temperature variations slightly different levels of collection current may be obtained for repeated measurements at the same acceleration voltage. However, the position of the maxima remains unaffected.
- When the bimetallic switch switches the oven on and off, there is a change of load on the AC mains, causing a small change in the set acceleration voltage. This should be noted if the switching takes place just when the curve is being recorded.
- The position of the maxima for the collection current remains unchanged when the reverse bias changes, but the position of the minima are displaced a little. The level of the mean collection current decreases with increasing reverse bias.

Related topics

Energy quanta, quantum jumps, electron collision, excitation energy, Bohr's shell model.

Principle

Electrons are accelerated in a tube filled with neon gas. The excitation energy of neon is determined from the distance between the equidistant minima of the electron current in a variable opposing electric field.

Equipment

Franck-Hertz operating unit	09105.99	1
Franck-Hertz neon-tube with housing	09105.40	1
5-pin connecting cable, for Ne tube	09105.50	1
Shielded BNC-cable, $l = 75$ cm	07542.11	1
RS 232 data cable	14602.00	1
Franck-Hertz software	14522.61	1
PC, Windows® 95 or higher		

Additional equipment:

Oscilloscope, 30 MHz, 2 channels	11459.95	1
Adapter, BNC-socket/4mm plug pair	07542.27	2
Screened cable, BNC, $l = 75$ cm	07542.11	2

Tasks

To record the countercurrent strength I in a Franck-Hertz tube as a function of the anode voltage U . To determine the excitation energy E from the positions of the current strength minima or maxima by difference formation.

Set-up and procedure

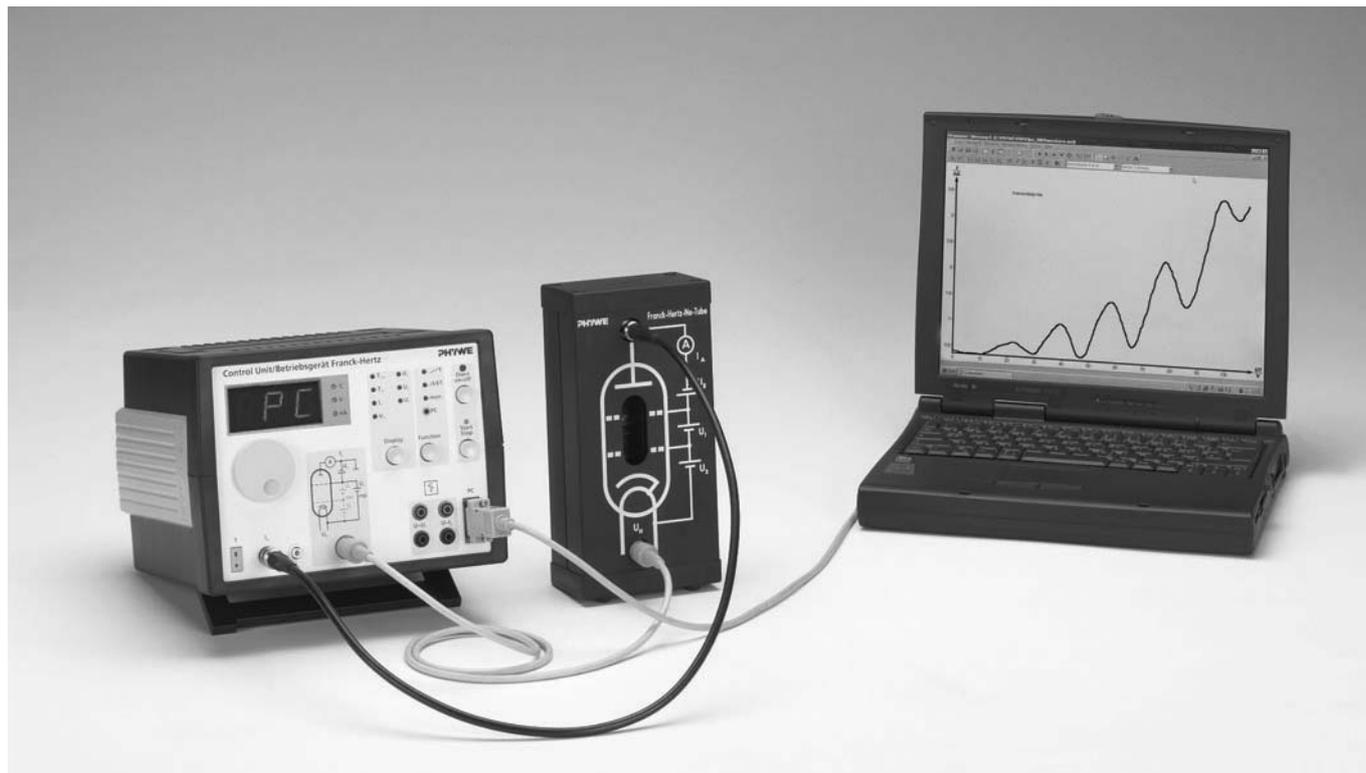
Set up the experiment as shown in Fig. 1. For details see the operating instructions of the unit 09105.99. Connect the Cobra3 Basic Unit to the computer port COM1, COM2 or to USB port (use USB to RS232 Adapter Converter 14602.10). Start the measure program and select Cobra3 Franck-Hertz experiment Gauge. Select the parameters given in Fig. 2 and press continue button.

Theory and evaluation

Niels Bohr introduced the planetary model of the atom in 1913: An isolated atom consists of a positively charged nucleus about which electrons are distributed in successive orbits. He also postulated that only those orbits occur for which the angular momentum of the electron is an integral multiple of $h/2\pi$, i.e. $n \cdot h/2\pi$, where n is an integer and h is Planck's constant.

Bohr's picture of electrons in discrete states with transitions among those states producing radiation whose frequency is determined by the energy differences between states can be derived from the quantum mechanics which replaced classical mechanics when dealing with structures as small as atoms. It seems reasonable from the Bohr model that just as electrons may make transitions down from allowed higher energy states to lower ones, they may be excited up into higher energy states by absorbing precisely the amount of energy representing difference between the lower and higher states. James Franck and Gustav Hertz showed that this was, indeed, the case in a series of experiments reported in 1913, the same year that Bohr presented his model. Franck and Hertz used a beam of accelerated electrons to measure the energy required to lift

Fig.1: Set-up for the Franck-Hertz experiment with PC.



electrons in the ground state of a gas of mercury atoms to the first excited state (see experiment 5.1.03-11). In present experiment a tube filled with neon gas is used.

These minima are not, however, very well-defined because of the initial thermal distribution of the electron velocities.

The voltage U_1 between anode and cathode is represented by

$$U_1 = U + (\phi_A - \phi_C),$$

where U is the applied voltage, and ϕ_A and ϕ_C the work function voltages of the anode and cathode respectively. As the excitation energy E is determined from the voltage differences at the minima, the work function voltages are of no significance here.

According to the classical theory the energy levels to which the mercury atoms are excited could be random. According to the quantum theory, however, a definite energy level must suddenly be assigned to the atom in an elementary process. The course of the I/U_A curve was first explained on the basis of this view and thus represents a confirmation of the quantum theory.

The excited neon atom again releases the energy it has absorbed, with the emission of a photon. When the excitation energy E is 16.8 eV, the wavelength of this photon is

$$\lambda = \frac{ch}{E} = 73.8 \text{ nm, where}$$

$$c = 2.9979 \cdot 10^8 \frac{\text{m}}{\text{s}}$$

and

$$h = 4.136 \cdot 10^{-15} \text{ eV.}$$

For our evaluation we determine the voltage values of the minima. From the differences between these values we obtain the excitation energy E of the neon atom by taking an average.

By evaluating the measurements in Fig. 4 we obtained the value

$$E = (17.4 \pm 0.7) \text{ eV.}$$

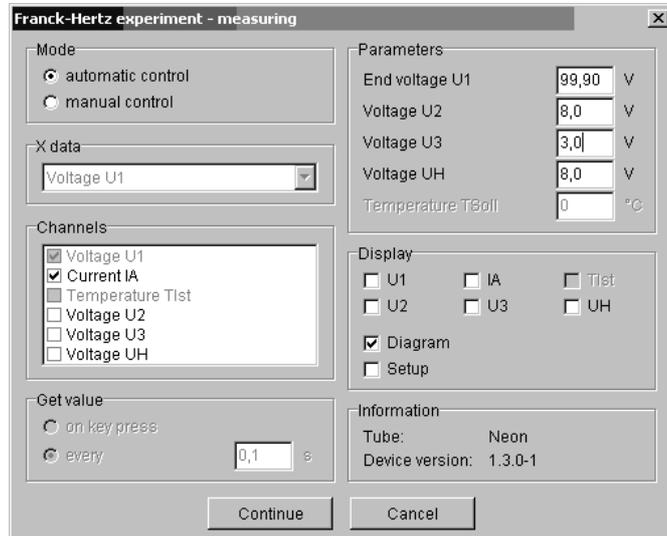


Fig. 2: Measuring parameters.

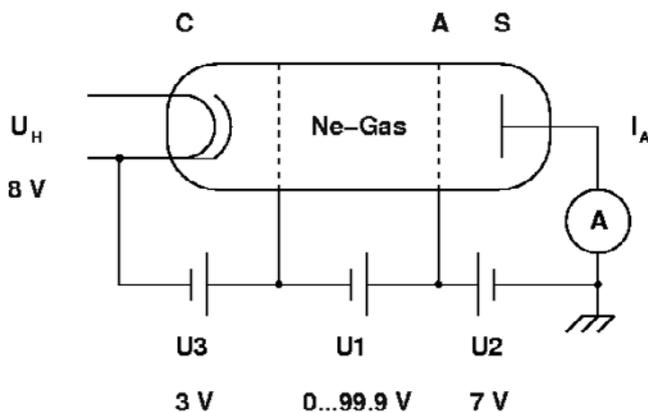


Fig. 3: Principle of the measurement.

The electrons emitted by a thermionic cathode are accelerated between cathode C and anode A in the tube filled with neon gas (Fig. 3) and are scattered by elastic collision with neon atoms.

From an anode voltage U_1 of 16,8 V, however, the kinetic energy of the electrons is sufficient to bring the valence electron of the neon to the first excitation level by an inelastic collision. Because of the accompanying loss of energy, the electron can now no longer traverse the opposing field between anode A and counter electrode S: the current I is at a minimum. If we now increase the anode voltage further, the kinetic energy of the electron is again sufficient to surmount the opposing field: the current strength I increases. When $U_1 = 2 \times 16.8 \text{ V}$ the kinetic energy is so high that two atoms in succession can be excited by the same electron: we obtain a second minimum (Fig. 4). The graph of I/U_1 thus shows equidistant maxima and minima.

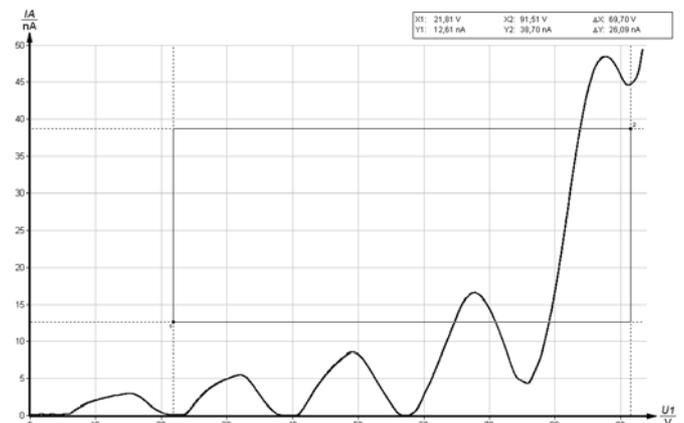


Fig. 4: Example of a Franck-Hertz curve recorded with Ne-tube.

Name

TITLE OF EXPERIMENT

**THE FRANCK-HERTZ EXPERIMENT:
EXPERIMENT No 9**

MODERN PHYSICS LAB

PHYS 393 COURSEWORK

REPORTING SHEET

PART A: SCIENTIFIC KNOWLEDGE AND PLANNING

Aim:

Method – what I am going to do in order to achieve my aim

A. List the equipment you plan to use

B. Draw your set up, explaining the use of the different components.

Explain the Bohr's model of the atom.

Discuss how the classical Franck-Hertz experiment in 1914 supports it.

<p>How do you expect the relationship between the current and voltage in the experiment would look like- plot it.</p>	
<p>Which factors you suggest should be controlled in order to make sure that your results are accurate and reliable?</p>	

PART B: OBTAINING EVIDENCE	
<p>Your data. Use the correct units and convert appropriately.</p>	

PART C: ANALYSING AND CONSIDERING YOUR EVIDENCE	
Graph (use graph paper)	
Calculations	
My evidence leads to the following result.	
Compare your results with theoretical values.	

PART D: EVALUATION [10 MARKS]	
What was good or bad about the experiment you did was ...	2
Some ways you could improve the experiment were...	2
You had the following anomalies.	2
The explanation for your anomalies was	2
You believe my evidence is reliable/unreliable for the following reasons.	2