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Departement: material Sciences

Pedagogical handout

Title
Practical Works:
Spectroscopy wave physics

Practical works for third-year fundamental physics students

2023/2024

Preamble

Introduction to Physical Optical Spectroscopy

Optical spectroscopy is a branch of physics that studies the interaction between light and matter. It makes it possible to analyze the properties of light emitted, absorbed or scattered by different substances. This discipline finds applications in many fields such as astrophysics, chemistry, biology and medicine.

Light Diffraction Phenomena

Diffraction is a phenomenon that occurs when light encounters an obstacle or opening whose dimensions are comparable to the wavelength of light. This phenomenon can be observed when light passes through a narrow slit or when it encounters a sharp edge. Diffraction is explained by the Huygens-Fresnel principle, which states that each point in a propagating light wave behaves as a point source of new spherical waves.

Examples of diffraction:

• Young slits: When light passes through two nearby slits, it diffracts and light waves from the two slits interfere with each other, creating an interference fringe pattern on a screen behind the slits.

• Diffraction gratings: Made up of numerous parallel slits, diffraction gratings are used to disperse light into its different spectral components.

Light Wave Interference

Interference is a phenomenon that occurs when two or more light waves overlap, leading to spatial and temporal variation in light intensity. Interference can be constructive (increase in intensity) or destructive (decrease in intensity), depending on the phase difference between the waves.

Applications and examples:

• Michelson interferometer: Used to measure distances with great precision, this device divides a light beam into two beams which follow different paths before recombining, producing interference fringes.

• Thin films: Interference produced by thin films, such as soap bubbles or oil films, creates colored patterns due to variations in layer thickness and phase differences of reflected waves.

For historical reasons, we still distinguish diffraction from interference, but these two behaviours result from the wave nature of the same phenomenon: electromagnetic aspect of light. These sets of experiments allow us to study the main diffraction phenomena by a slit or a hole, as well as some interference phenomena such as Young's slits, gratings, etc.

Polarization of Light

The polarization of light refers to the direction in which oscillations of the electric field of light occur. In unpolarized light, oscillations occur in all directions perpendicular to the direction of propagation. Light can be polarized by reflection, diffusion, or using polarizing filters.

Polarization types:

Linear: Oscillations occur in one direction only.

• Circular: The oscillations of the electric field describe a circle as they move.

• Elliptical: A generalization of circular polarization where the oscillations describe an ellipse.

Applications:

• Polarized sunglasses: Reduce glare by blocking reflected light components.

• Polarizing microscopes: Used to observe samples that change the polarization of light, which is useful in mineralogy and biology.

Finally physical optical spectroscopy encompasses a variety of phenomena related to the interaction of light with matter. Diffraction, interference and polarization are fundamental concepts for understanding and exploiting the properties of light for various scientific and technological applications. These phenomena play a crucial role in many instruments and techniques used to analyze the structure and properties of materials.

Disclaimer

1 - Each manipulation must be carefully prepared in advance, in particular by theoretical references, so that you know what you are supposed to be observing and studying to observe and study before entering the laboratory. Students must consult their course and the practical work handout in order to assimilate the theoretical aspect of the manipulation and its equation.

2 - Once in the practical room, the student must be able to answer orally to three important questions:

- The objective of the experiment,
- The variables to be measured and the variables to be determined,
- The theoretical aspect introduced to explain or exploit the experimental results.

3 - At the end of each practical session, each pair of students must submit a report report presenting the results properly. The judgement will be made not only not only on the precision and accuracy of the results, but also on the relevance of the comments and the clarity and neatness of the presentation of the report.

4 – Be carful :

- Never direct laser beams into the eye.
- Avoid touching optical surfaces (slits in lenses, diapositives, ...).

Error Sources:

We can consider several sources of error, such as the accuracy of the slit size and the measurement of the central fringe.

PW.I: Light Polarization

I. 1. Introduction

The polarization of electromagnetic waves, studied in wave physics and optics, refers to the specific orientation of electric and magnetic oscillations relative to the direction of wave propagation. A polarized wave exhibits oscillations aligned in specific planes, whereas an unpolarized wave exhibits oscillations in all planes perpendicular to its direction of propagation. Polarization can be induced by various mechanisms such as polarizing filters or birefringent materials.

Understanding polarization is crucial in fields such as optical device design, optical communication, and imaging. This enables the development of innovative optical technologies and deepens our understanding of the wave nature of light and electromagnetic waves.

Overall, polarization in optics is a property of electromagnetic waves, particularly visible light. In the context of optics and communication systems, polarization describes the orientation of the electric field vector relative to the direction of the light wave.

I. 2. Type of polarization

The term "type of polarization" refers to the specific way in which the electric field of an electromagnetic wave vibrates or oscillates.

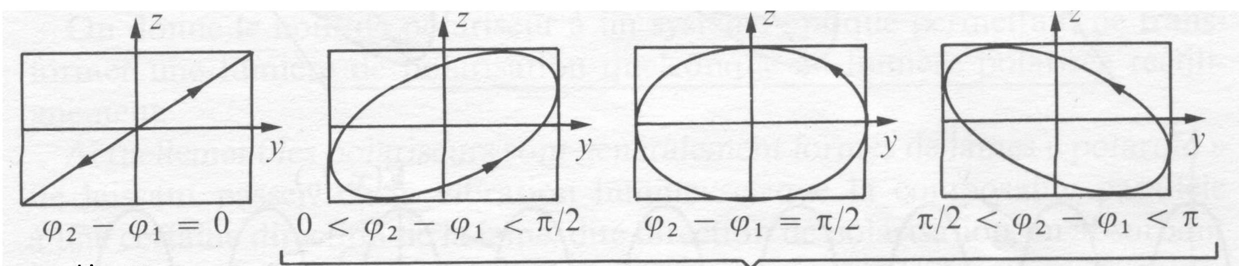
There are different types of polarization, including linear polarization, circular polarization, and elliptical polarization [1-3]. Each type has specific characteristics in terms of the orientation and behavior of the electric field vector, and they are important considerations in various applications such as photography, telecommunications, and optics [4-5].

Here is the electric field (modelization) of a mono-plane electromagnetic wave:

$$\begin{cases} E_x = E_{0x}\cos(\omega t) \\ E_y = E_{0y}\cos(\omega t + \varphi) \\ E_z = 0 \end{cases} \qquad \text{(I.1)}$$

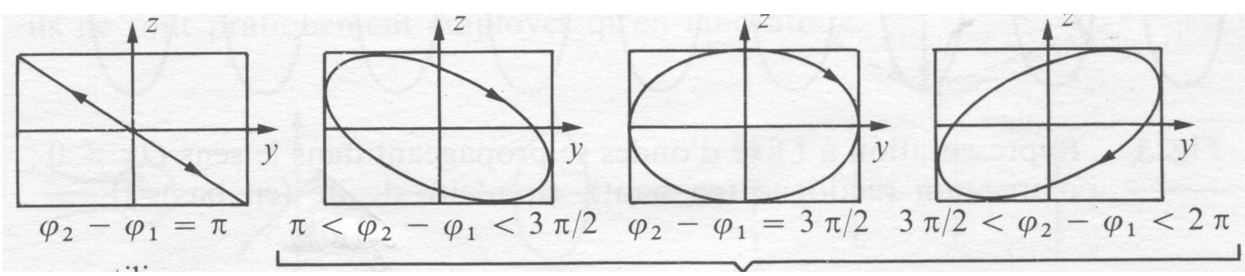
Table (1): Polarization types

Linear	elliptical	circular	random
$\frac{E_x}{E_y} = \frac{E_{0x}}{E_{0y}} = Cte$ $\rho = 0$ $\frac{E_x}{E_y} = -\frac{E_{0x}}{E_{0y}} = Cte$ $\rho = \pi$	$E_x, E_y = Cte$ $\left(\frac{E_x}{E_{ox}}\right)^2 + \left(\frac{E_y}{E_{0y}}\right)^2 = 1$ $\rho = \pm\frac{\pi}{2}$ $\rho = \pm\frac{3\pi}{2}$	Elliptical with : $E_{0x} = E_{0y} = R$ ${E_{0x}}^2 = {E_{0y}}^2 = R^2$ $\rho = \pm\frac{\pi}{2}$ ou $\rho = \pm\frac{3\pi}{2}$	E_{0x}, E_{0y}, ρ Are independent and vary



Linear

Left elliptical

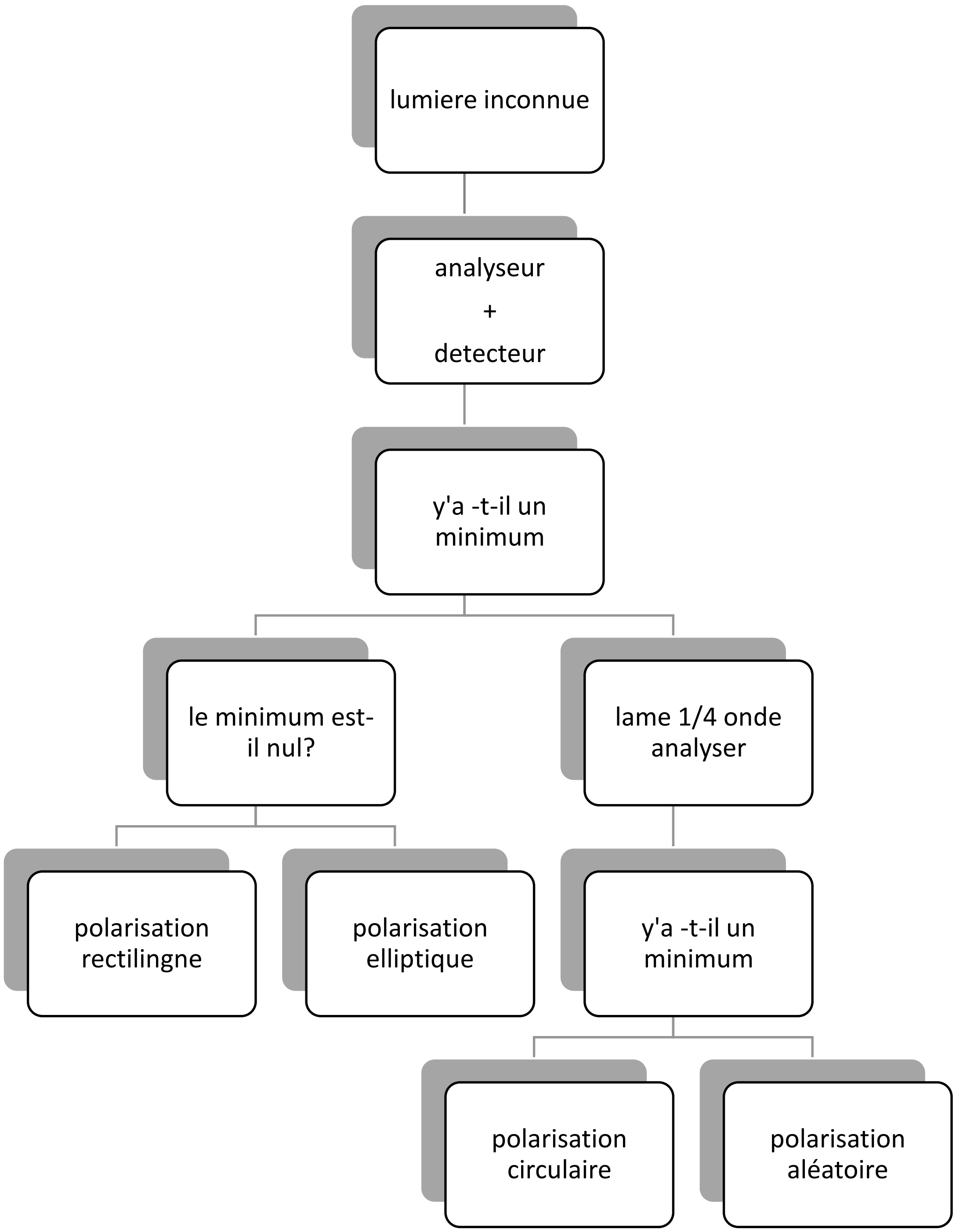


Linear

Right elliptical

Figure.1: represnted differents type of polarization

Comment déterminer une polarisation inconnue ?



I. 3. Objective:

The objective of this experience is to experimentally study the polarization of a light beam and to observe how it changes when passing through a polarizer. The goal is to verify Malus's law.

A second objective which we have to realize is the action of quarter-wave plate (λ/4) and half-wave plate (λ/2).

I. 4. Malus's Law:

Malus's Law, named after the French physicist Étienne-Louis Malus, describes the intensity of polarized light transmitted through an optical polarizer. The law is particularly relevant when analyzing the behavior of light waves as they pass through a polarizing filter.

Mathematically, Malus's Law is expressed as:

$$I = I_0 cos^2\theta \qquad (I.\ 2)$$

Where:

I: transmitted brightness

I_0: incident brightness (**θ** =0)

θ: angle of polarization of light - polarization axis.

This law expresses that the transmitted intensity I depends on the angle between the two axes.

It means that when polarized light passes through a polarizer, it allows more or less intensity to pass through depending on the angle between the polarization direction of the light and the polarization axis of the polarizer. Malus's law describes this phenomenon.

I. 5. Used equipment:

- Optical bench
- Adjustable riders
- Light source
- Polarizer
- Analyzer
- Photodiode
- Digital multimeter
- Screen
- In this experiment, we also need a quarter-wave plate and another half-wave plate to observe the change in polarization of light.

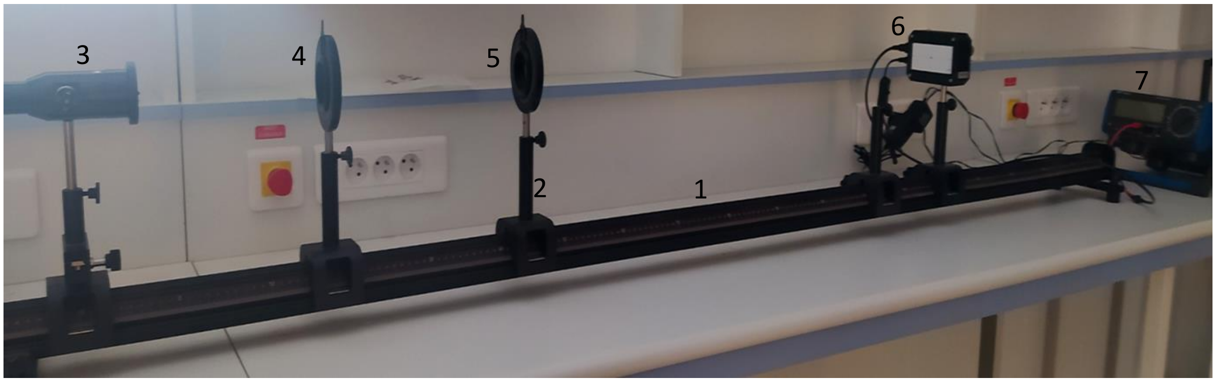


Fig. 2: Light plarization, 1- Optical bench, 2-Adjustable riders, 3-Light source, 4-Polarizer, 5-Analyzer, 6-Photodiode, 7-Digital multimeter.

I. 6. 1st Experiment:

To ensure that the light from our source is not polarized, we perform this first experiment with only one analyzer.

We rotate the axis of the analyzer.

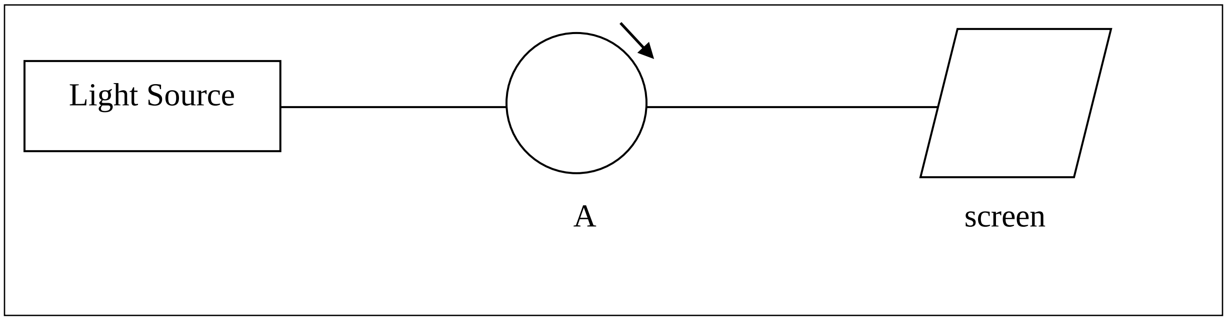


Figure 3: Ensure that the light is not polarized

Question: What do you notice on the screen?

• The intensity of the light changes.

• The intensity of the light does not change.

Explain.

I. 7. 2nd Experiment:

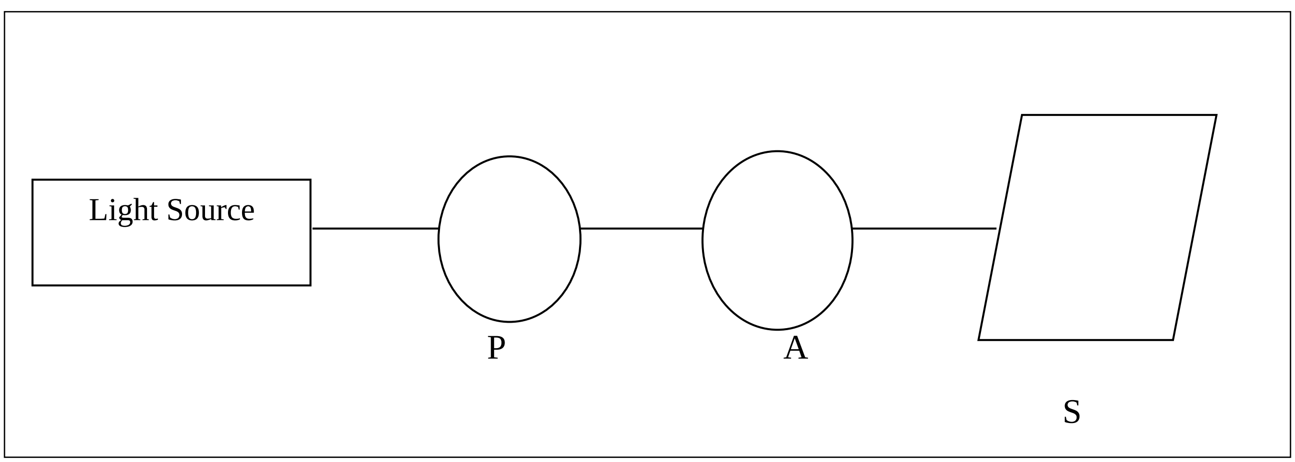


Figure 4: Polarization of the light

In a second experiment, we will use a Polarizer to polarize the light and an Analyzer to analyze it at the output of the Polarizer. The polarization axis of the Polarizer indicates the polarization direction, such that the light from the source, when it passes through the Polarizer, will be polarized in the direction of the axis (for example, vertically).

Question: What do you observe? Compare with the first experiment and explain.

I. 7. a. Change in angle and observations:

As the angle increases, the intensity decreases until I = 0 when cos(θ) = 0.

Fill in the table below:

Angle α(P-A)	$\boldsymbol{cos^2\alpha}$	**$I_{experimental}$**	**$I_{theoretical}$**
0			
15			
30			
45			
60			
90			
120			
135			
150			
165			
180			
195			
210			
225			
240			
270			
300			
315			
330			
360			

Questions:

- Find the intensity I_0.
- Plot the graph $I_{exp} = f(\theta)$.

- Plot the graphs $I_{exp} = f(\cos^2\theta)$ and $I_{th} = f(\cos^2\theta)$.

Compare and draw conclusions with a mention of light polarization examples in daily life.

I. 7. b. The Effect of a Quarter-Wave Plate

We will now demonstrate how to transform linear polarization into circular polarization. To achieve this, we linearly polarized a laser using a polarizer. We will then place a quarter-wave plate at a 45° angle to the neutral lines, where the neutral lines are positioned at 45° from the direction of the incident polarization. By turning the analyzer, we can verify that the intensity remains constant, indicating isotropic polarization. However, it is not certain whether this is circular polarization or possibly random polarization.

To prove that it is circular polarization, we will introduce a second quarter-wave plate between the first quarter-wave plate and the analyzer. This means placing it between the initial quarter-wave plate and the analyzer. A quarter-wave plate transforms circular polarization into elliptical polarization, regardless of the orientations of the neutral lines for this transformation, we rotate the analyzer until extinction is achieved witch is a clear sign that we have converted circular polarization into linear polarization, confirming that the wave was indeed circularly polarized.

I. 7. c. The Effect of a Half-Wave Plate

Let's now examine the effect of a half-wave plate on circular polarization. We take a quarter-wave plate at a 45° angle. Earlier, we observed that it produced circular polarization. We then pass this circular wave through a half-wave plate, rotate the analyzer, and visually confirm that we indeed have isotropic circular or random polarization. Reintroducing a quarter-wave plate between the analyzer and the half-wave plate in any orientation, we will seek to achieve extinction. We can observe that extinction is attainable, indicating that the half-wave plate transforms circular polarization into another circular state. This circular state is then further transformed back into linear polarization using the quarter-wave plate.

I. 8. Conclusion

The laboratory session on light polarization provided valuable insights into the fundamental role of polarization in optics. Through practical experiments, we observed how polarizing filters selectively transmit or block light waves based on their orientation, demonstrating the practical applications of polarization in optical devices. Additionally, we explored the phenomenon of birefringence in certain materials, where the polarization state of light is altered depending on its propagation direction. This phenomenon has significant implications in fields like mineralogy for identifying crystalline structures.

Overall, the session deepened our understanding of the wave nature of light and its polarization characteristics, emphasizing its relevance in both theoretical and practical aspects of optics. By mastering these concepts, we are better equipped to analyze and manipulate light for various scientific and technological applications, contributing to advancements in optics and related fields.

I. 9. Light Polarization in nature [6]:

The polarization of light can also be observed in various natural phenomena. Here are some notable examples:

- **Blue Sky:** The light from the blue sky is partially polarized due to the scattering of sunlight by molecules in the atmosphere, a phenomenon known as Rayleigh scattering. Light scattered perpendicularly to the sun is strongly polarized.
- **Reflection from surfaces:** When light reflects off non-metallic surfaces, such as water, glass, or roads, it becomes partially polarized. The polarization is maximum at a specific angle of reflection known as Brewster’s angle.
- **Rainbow:** In addition to refraction and reflection, the light forming rainbows is partially polarized. Polarized sunglasses can help observe this polarization by making certain parts of the rainbow more visible or reducing glare.
- **Clouds and solar halos:** Solar halos and iridescent clouds can show polarization effects. Ice crystals in clouds and halos can polarize light, a phenomenon often observable with polarizing filter.
- **Insects and animals:** Some insect species, such as bees, can detect polarized light. They use this ability to navigate based on the polarized light pattern in the sky, even on the cloudy days.

These examples show that the polarization of light is a common natural phenomenon, observable in various contexts, and provides valuable information about the properties of light and the materials in the interacts with.

References:

[1] E. Collett, "Field Guide to Polarization." SPIE Press, 2005.

[2] Dennis H. Goldstein, "Polarized Light, Third Edition." CRC Press, 2017.

[3] R. M. A. Azzam, and N. M. Bashara. "Ellipsometry and Polarized Light." Elsevier Science, 1977.

[4] Bahaa E. A. Saleh, and Malvin Carl Teich, " Fundamentals of Photonics ", Wiley, 1991.

[5] Craig F. Bohren, and Donald R. Huffman. "Absorption and Scattering of Light by Small Particles." Wiley-VCH, 1998.

[6] S. Houard, “Optique une approche expérimentale et pratique”, De Boeck, 2011.

LIGHT POLARIZATION IN NATURE

Rainbow

Solar halos

PW. II : Light diffraction

II. 1. Introduction and description:

The phenomenon of diffraction occurs when light encounters an obstacle in its path with dimensions on the order of its wavelength. It results in the appearance of fringes in the regions of geometric waves.

The phenomenon of light diffraction refers to the bending or spreading of light waves as they encounter an obstacle or aperture. It is a characteristic behavior of waves when they encounter an obstruction or opening that is comparable in size to the wavelength of the incident light. Light diffraction can be observed when light waves encounter edges, slits, or obstacles in their path, leading to interference patterns and the bending of light in various directions [1-3].

II. 2. Imported terms of light diffraction include: [4-6]

- **Wave Nature of Light:** Diffraction is a phenomenon that results from the wave nature of light. When light encounters an obstacle or aperture, it behaves as a wave, diffracting and producing a pattern of alternating bright and dark regions.
- **Interference Patterns:** The diffracted light waves interfere with each other, leading to the formation of interference patterns. These patterns can be observed as a series of alternating bright and dark fringes.
- **Single-Slit Diffraction:** When light passes through a single narrow slit, it produces a diffraction pattern characterized by a central bright maximum (central maximum) and a series of secondary maxima and minima on either side.
- **Double-Slit Diffraction:** In the case of double-slit diffraction, when light passes through two closely spaced slits, it results in an interference pattern with multiple bright and dark fringes. This pattern is similar to that seen in double-slit interference.
- **Diffraction Gratings:** Periodic structures with multiple slits, known as diffraction gratings, can produce complex diffraction patterns with numerous orders of bright and dark fringes.

II. 3. Applications: Diffraction plays a crucial role in various scientific and technological applications, such as in the design of optical instruments, the analysis of crystal structures using X-ray diffraction, and in the creation of holograms.

Understanding the phenomenon of light diffraction has contributed significantly to our knowledge of wave optics and has practical implications in fields ranging from physics to engineering [3-6].

II. 4. Objectives of the experiment:

- Observation of diffraction phenomena.
- Investigate the factors or parameters influencing the diffraction pattern:
  - Determine the width of the narrow slit used while keeping the wavelength of the laser constant and varying the distance F-E (slit-screen).
  - Determine the wavelength of a laser while keeping the width of the slit constant and varying the distance D.

II. 5. Diffraction Law:

The width "**L**" of the central spot can be given by the following relation **(II. 1).**

$$L = 2\lambda D/a \qquad \text{(II. 1)}$$

By setting up the diffraction experiment (Figure. II. 1) on the screen, we will observe bright fringes created by different zones (Figure. II. 2).

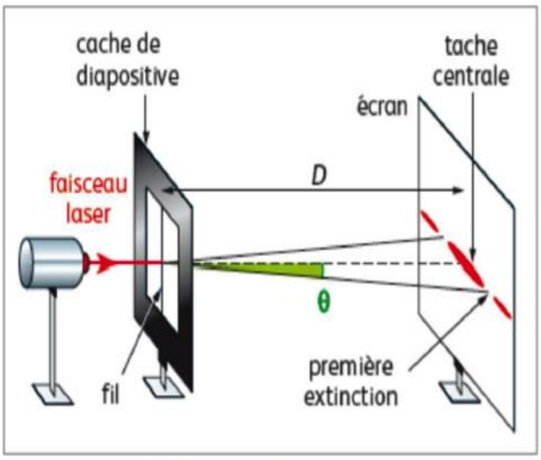


Fig. II. 1: Experimental device

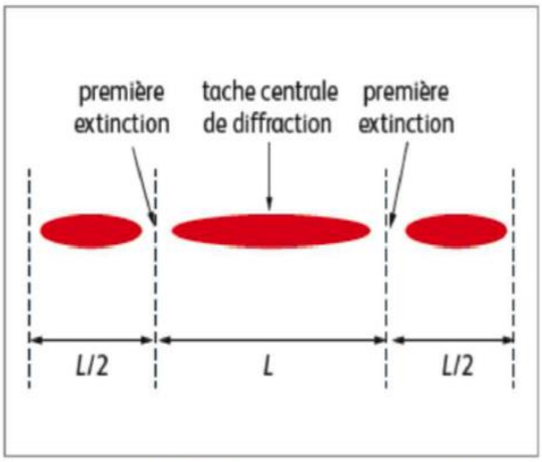


Fig. II. 2: Diffraction figure obtained with a wire of width a

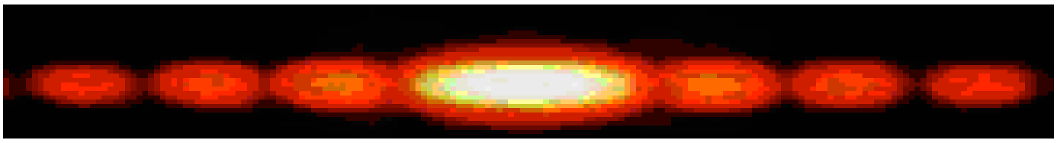


Fig. II. 3: Reel photo of
diffraction phenomena

When :

λ is the wavelength of the laser source, **a** is the width of the used slit, and **D** is the distance between the slit and the observation screen.

II. 6. Other diffracting obstacles

The shape of the diffracting obstacle has an influence on the appearance of the diffraction pattern obtained with a square (Figure II. 4) or circular (Figure II. 5) aperture, we have [6]:

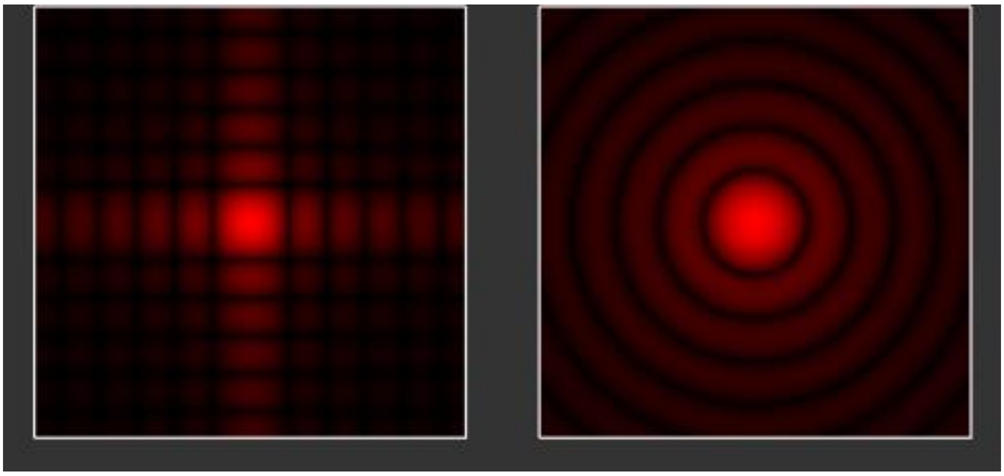


Fig. II. 4: Diffraction through a rectangular aperture

Fig. II. 5: Diffraction through a circular aperture

II. 7. Equipment Used:

- Laser (with known wavelength λ)
- 1 Red laser diode 650nm 1mW
- 1Green laser diode 532nm 1mW
- 1 Blue laser diode 450nm 1mW
- Prismatic bench (2m)
- 3 standard prismatic riders of witch, one vertical and one lateral.
- White Screen.
- Slit with an unknown width "a."
- Wire or hair.
- Millimeter paper.

II. 8. Experimental Work:

➢ Observation of Diffraction Phenomena:

- Observe the appearance of a laser beam on a screen without any obstacles.
- Observe the appearance of a laser beam on a screen with an obstacle (slit).

Note: Different types of obstacles (holes, slits, wires, hair) and different dimensions can be used.

➢ Record your observations.

Based on your observations on the screen, does the diffraction pattern depend on the shape of the encountered obstacle and its dimensions?

Since the width of the slit used is unknown, we will use a laser with a wavelength **λ = 650 nm**, measure the distance between the screen and the slit (D), and measure the width "L" of the central spot. Measure "L" and deduce the value of the slit width "a": **$a = 2\lambda D/L$**

Now that "a" is known, we can vary some parameters:

- **1st experiment**: fixed D at 50cm and vary the wavelength λ

λ (nm)	450	532	650
L(mm)			

- Plot L = f (λ), and discuss.
- Deduce the slope and compare it with the theoretical value (2D/a).

- **2nd experiment:** wavelength λ is fixed at 650 nm and vary the distance D

D (cm)	50	100	150	180
L (mm)				

- Plot L = f (D), and discuss.
- Deduce the slope and compare it with the theoretical value (2D/a).

- **3d Experiment**:

We have a laser with an unknown wavelength λ, propose an experiment to determine it, carry it out, and draw conclusions.

References:

[1] Max Born, Emil Wolf and A. B Bhatia, “Principles of Optics”, Cambridge University Press, 1999.

[2] Grant R. Fowles, "Introduction to Modern Optics", 1989.

[3] Eugene Hecht, "Optics", Adelphi University, 2017.

[4] Bahaa E. A. Saleh, and Malvin Carl Teich, "Fundamentals of Photonics." Wiley, 1991.

[5] F. Graham Smith, "Optics and Photonics: An Introduction", Wiley, 2007.

[6] J. M. Cowley, "Diffraction Physics", Elsevier, 1995.

INTERFERENCE AND DIFFRACTION PHENOMENON IN NATURE

Iridescent clouds

Opal colors

PW. III: Young's Slits Interference

III. 1. Introduction

Light interference occurs when two coherent light waves meet and overlap, creating regions of increased light intensity (constructive interference) and reduced light intensity (destructive interference). The conditions to observe these interferences are that the sources must be coherent (having a constant phase difference) and generally monochromatic (having a single wavelength) [1-3].

- **Constructive interference:** This occurs when the peaks of the two waves overlap, which amplifies the light. This happens when the path difference between the two waves is an integer multiple of the wavelength ($n\lambda$).
- **Destructive interference:** This occurs when the peak of one wave coincides with the trough of the other, which reduces the light intensity. This happens when the path difference is an odd multiple of half the wavelength ($(2n+1)\ \lambda/2$) [4, 5].

Fig. III. 1: figure of interference

III. 2. Young’s slits:

The Young's double-slit experiment demonstrates that under usual conditions, two different light sources do not produce interference. It was at the very beginning of the 19th century that Young first observed optical interference by constructing a device (interferometer) that splits and then superimposes light from a single source [6].

Young’s double-slits experiment is crucial because it provides clear evidence of the wave nature of light, showing that light can interfere with itself. This demonstration was a major step towards the development of the wave theory of light, and later, the quantum theory of light [7].

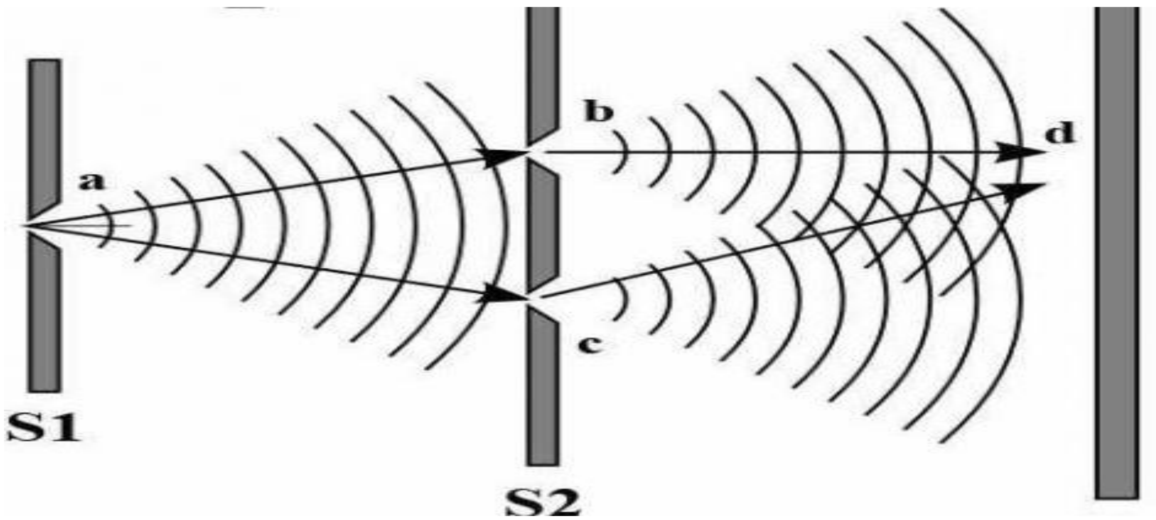


Fig. III. 2: Young’s double slits experimental

III. 3. Objective:

In this experiment, we will study the phenomenon of interference that is observed through a double slit known as Young's slits, using a monochromatic wave emitted by a laser.

We observe bright fringes separated by dark regions. The distance between two consecutive bright fringes is called the interfringe and is denoted as 'i'. Also we have to deduce the relationship between the parameters 'i,' and the other parameters.

III. 4. Used equipment:

- Optical bench
- Diode laser with two sources at λ=650nm and λ=532nm
- Millimeter paper
- Young's double-slit tokens with slit separations of 0.2, 0.3, and 0.4mm.

III. 5. Experimental work:

➢ In the first stage, we will observe the influence of the distance between the slits and the screen, denoted as 'D,' on the fringe spacing 'i'.

- Carry out the following assembly: two slits separated by 0.2mm and a distance of 50cm to the screen. Place a red laser with λ=650nm behind the slits.
- Then measure 10 fringe spacings.
- Repeat the same study with D=100cm and 150 cm and once again measure 10 fringes spacings,

λ=650nm, a=0.2mm			
Distance slits-screen (cm)	50	100	150
Interfrange i (mm)			

- Give your observations on the obtained values of “i”with different values of the distance D.

  ➢ In the second stage, we will study the influence of the wavelength on 'i.'
- We use Young's slits separated by 0.2mm and a distance of 150cm.
- Initially, we use a green laser with λ=532nm, and then a red laser with λ=650nm.
- what do you observe on the value of the fringe spacing variation with the red laser?
- what does it mean or indicate?

D=150cm, a=0.2mm		
λ (nm)	650	532
i(mm)		
$\frac{\lambda}{i}$		

- How is 'i' (fringe spacing)vary with variation of λ (wavelength)?

  - Finally, we will study the influence of the separation between the slits, denoted as 'a,' on the value of 'i,' the fringe spacing. We use a red laser with λ = 650nm, and the distance D is fixed at 1.50m. Firstly, we have a=0.2mm, a=0.3mm, and a=0.4mm.

summarize the results in the following table:

D=160cm , λ=650nm			
Ecartement « a » (mm)	0.2	0.3	0.4
Interfrange « i » (mm)			
Rapport $\frac{i}{1/a} = i * a$			

- What do you notice about the results obtained?
- How is the relationship between “a” and “i”?

- Give a summer for this experiment and then deduce the relationship between the parameters 'i,' 'λ,' 'a,' and 'D'.

III. 6. Interference and diffraction in nature [8]:

There are many natural phenomena in which interference and diffraction of light can be observed. Here are just a few examples:

- **Rainbows:** Rainbows are the result of the refraction, reflection and diffraction of sunlight by water droplets in the atmosphere. Although mainly a phenomenon of refraction and reflection, rainbows also show interference between the different colors of light.
- **Butterfly wings and bird feathers:** The brilliant, shimmering colors of some butterfly's wings and bird feathers, such as those of the peacock, are due to microscopic structures that cause light to interfere. These structures cause constructive and destructive interference, amplifying certain colors and attenuating others.
- **Soap bubbles and oil films:** Soap bubbles and oil films produce iridescent colors due to the interference of light reflected from the front and back surfaces of the thin film. Variations in film thickness cause constructive and destructive interference at different wavelengths, creating color patterns.
- **Iridescent clouds:** Clouds sometimes appear iridescent around the Sun or Moon. This is due to the diffraction of light by small water droplets or ice crystals in the clouds.
- **Opal colors:** Opals have brilliant, ever-changing colors due to the diffraction and interference of light on the regular arrays of small silica spheres contained within the stone.
- **Lunar halo:** A lunar halo is a luminous ring around the Moon, often visible in cold weather when ice crystals are present in the atmosphere. Halos are caused by the refraction, reflection and diffraction of lunar light by hexagonal ice crystals.

References:

[1] Max Born, Emil Wolf and A. B Bhatia, "Principles of Optics", Cambridge University Press, 1999.

[2] Grant R. Fowles, "Introduction to Modern Optics", 1989.

[3] Eugene Hecht, "Optics", Adelphi University, 2017.

[4] Bahaa E. A. Saleh, and Malvin Carl Teich, "Fundamentals of Photonics." Wiley, 1991.

[5] F. Graham Smith, "Optics and Photonics: An Introduction", Wiley, 2007.

[6] J. M. Cowley, "Diffraction Physics", Elsevier, 1995.

[7] Ajoy Ghatak, "Optic", McGraw-Hill Education; 1st edition, March 23, 2009.

[8] S. Houard, "Optique une approche expérimentale et pratique", De Boeck, 2011.

PW. IV. Michelson interferometer

IV. 1. Objectives

IV. 1. 1 General objectives

The general aim of this practical exercise is to explore the phenomena of light interference using the Michelson interferometer. This instrument enables wavelengths to be measured with great precision, the properties of light to be analysed and variations in the refractive index to be determined. Objectives include:

- Understanding the principles of interferometry.

- Learn how to use a Michelson interferometer for various applications.

- Make accurate measurements of wavelengths and wavelength deviations.

IV. 1. 2 Specific aims

- Measure the wavelength difference between the two spectral lines of the sodium doublet.

- Obtain interference fringes under different optical configurations.

- Measure the variation in the index of air as a function of pressure and deduce the index of air at atmospheric pressure.

- Analyse and interpret the results obtained with the interferometer.

IV. 2. Theory

IV. 2. 1. Principles of interferometry

Interferometry is based on the observation of interference fringes, which form when two coherent light beams are superimposed. The fringes are the result of phase differences between the light waves, making it possible to measure distances with great precision. Interferometry has many applications, ranging from metrology to fundamental physics.

Light waves produced by a coherent source, such as a laser, are superimposed to form interference fringes. These fringes can be observed and analysed to obtain information about the differences in the optical paths travelled by the beams.

IV. 2. 2 Theory of the Michelson interferometer

The Michelson interferometer uses a beam splitter to divide a light beam into two beams. These beams are reflected by two perpendicular mirrors and then recombined. The difference in optical path between the beams creates interference fringes. The conditions for constructive interference (maximum light) and destructive interference (minimum light) depend on the phase difference between the recombined beams.

The equations for Michelson interferometry are as follows:

- Constructive interference condition: $2d \cos \theta = m\lambda$

- Destructive interference condition: $2d \cos \theta = (m+0.5)\lambda$

whered is the optical path difference, θ is the angle of incidence, m is an integer, and λ is the wavelength of the beam.

IV. 2. 3. Air blade and air wedge interference

- **Air blade**

When beams pass through a blade of air, circular fringes (fringes of equal inclination) appear. Their shape and position are influenced by the thickness of the plate and the wavelength of the light. Equally inclined fringes form when light beams travel along paths of almost identical length. These fringes can be used to measure wavelength differences with great precision.

- **Air wedge**

By configuring the interferometer to form an air wedge, linear fringes are obtained. These fringes are used to measure variations in the refractive index of air as a function of pressure. Fringes of equal thickness are formed when light beams pass through a region where the thickness of the air wedge varies linearly. This makes it possible to measure small variations in distance or refractive index with great accuracy.

IV. 3. Interferometer settings

IV. 3. 1 Adjusting the parallelism of the compensating and separating plates

The parallelism of the plates is essential to obtain sharp interference fringes. This is achieved by adjusting the plate supports until the fringes are clearly visible. This is done using micrometer screws for fine adjustment. The process involves the following steps:

- **Initialisation:** Switch on the light source and direct the beam towards the interferometer.
- **Coarse adjustment:** Use adjusting screws to align the mirrors at approximately 90 degrees.
- **Observation of fringes:** Observe the interference fringes on a screen.
- **Fine adjustment:** Use micrometer screws to fine tune the alignment until the fringes are regular and uniform.

IV. 3. 2. Fine adjustment of air gap mirrors: (obtaining rings)

To obtain circular fringes (rings), the mirrors need to be precisely adjusted. A screen or camera is used to observe the fringes and small angular adjustments are made to the mirrors until the rings are clearly visible. The regularity and symmetry of the rings indicate a good adjustment. Steps include:

- **Preparation:** Check that the plates and mirrors are correctly aligned.
- **Initial observation:** Observe the interference fringes on a screen or through an eyepiece.
- **Mirror adjustment:** Use adjustment screws to adjust the mirrors until circular fringes are obtained.
- **Optimisation:** Fine-tune the mirrors to obtain well-defined, concentric rings.

IV. 3. 3. Projecting the equally inclined fringes and fine-tuning the mirrors

The equally inclined fringes are projected onto a screen for easier observation. The mirrors continue to be adjusted to refine the sharpness and symmetry of the fringes. Fine adjustments minimise optical aberrations and improve the quality of the projected fringes. The steps include:

- **Screen set-up:** Position a screen or camera to project the interference fringes.
- **Initial observation:** Observe the projected fringes and identify any adjustments required.
- **Adjusting the mirrors:** Use adjusting screws to fine-tune the mirrors until you obtain sharp, even fringes.
- **Final optimisation:** Continue to adjust the mirrors to minimise aberrations and obtain clear, accurate fringe projection.

IV. 4. Air plate

IV. 4.1. Measuring the radius of the rings

The radius of the interference rings is measured using a ruler or optical measuring device. The radius of the rings is directly related to the wavelength of the light and the thickness of the air plate. By measuring several radii and calculating their average, we can obtain an accurate value for the wavelength. The steps include:

- **Preparing to observe:** Set up a screen or camera to observe the rings.
- **Measuring the rays :** Use a graduated ruler or optical device to measure the radii of the rings.
- **Calculating wavelengths:** Use measurements to calculate the wavelength of light.
- **Analysing the results:** Compare the results obtained with the theoretical values to check the accuracy of the measurements.

IV. 4.2 Measuring the difference between the two wavelengths of the sodium doublet

The sodium doublet has two very similar wavelengths. By observing the interference fringes produced by these two wavelengths, we can measure their difference by analysing the position of the fringes. The fringes corresponding to the two wavelengths shift slightly, making it possible to calculate the wavelength difference. The steps include:

- **Preparing the experiment:** Set up the interferometer to observe the fringes of the sodium doublet.
- **Observation of the fringes:** Observe the interference fringes and identify the positions of the fringes for the two wavelengths.
- **Measuring the spacing:** Use a ruler or optical device to measure the spacing between the fringes.
- **Calculating the difference:** Use the measurements to calculate the wavelength difference between the two lines of the sodium doublet.

IV. 4. 3 Measuring the spectral width of an interference filter

By inserting an interference filter into the path of the light beam, the spectral width of the filter can be measured. The interference fringes obtained with the filter inserted can be used to determine the spectral width by analysing the fringe distribution. The steps include:

- **Preparing the experiment:** Install the interference filter in the optical path of the interferometer.
- **Observation of the fringes:** Observe the interference fringes with the filter in place.
- **Analysis of the fringes:** Measure the fringe distribution to determine the spectral width of the filter.
- **Calculation of the spectral width:** Use the measurements to calculate the spectral width of the interference filter.

IV. 4. 4 Measuring wavelength or displacement

The Michelson interferometer can be used to measure unknown wavelengths or small displacements. By observing the displacement of the interference fringes, we can calculate the wavelength or distance travelled by the displaced object. This measurement is based on the fact that the displacement of the fringes is proportional to the physical displacement of the object. The steps include:

- **Preparing the experiment:** Set up the interferometer to measure an unknown wavelength or displacement.
- **Observation of the fringes:** Observe the interference fringes and note their initial position.
- **Moving the object:** Move the object or light source and observe the displacement of the fringes.
- **Calculation of wavelength or displacement:** Use the measurements of the displacement of the fringes to calculate the wavelength or distance travelled.

IV. 5. Optical Contact setting: e = 0

To obtain optimum interference fringes, it is essential to set the optical contact to $e = 0$. This means that the optical surfaces must be in perfect contact with no air space between them. This is achieved by gently adjusting the optical elements until the fringes appear clear and uniform. The steps include:

- **Preparing the optical surfaces:** Ensure that the optical surfaces are clean and free of dust.
- **Initial adjustment:** Place the optical surfaces in contact and observe the interference fringes.

- **Fine adjustment:** Use micrometer screws to adjust the surfaces until the fringes are regular and uniform.
- **Check optical contact:** Ensure that the optical contact is perfect and that the fringes are stable.

IV. 6. Air wedge

IV.6. 1 Transition from air gap to air wedge

To change from an air gap to an air wedge configuration, the mirrors and plates are adjusted to form a wedge-shaped gap. This changes the shape of the interference fringes from circular to linear. This configuration makes it possible to study variations in the refractive index of air. The steps include:

- **Preparing the experiment:** Adjust the mirrors and plates to form a wedge of air.
- **Observation of the fringes:** Observe the interference fringes and check that they are linear.
- **Fine adjustment:** Use adjustment screws to fine tune the air wedge configuration.
- **Optimising the fringes:** Continue to adjust the mirrors and plates to obtain linear and regular fringes.

IV. 6. 2 Changing the observation conditions

By changing the observation conditions, such as the distance between the mirrors and the angle of incidence of the light, it is possible to obtain different fringe configurations. These changes allow various optical properties to be explored and conditions optimised for specific measurements. The steps include:

- **Preparing the experiment:** Setting up the interferometer to allow adjustments to the observation conditions.
- **Initial observation:** Observe the interference fringes under the current conditions.
- **Changing the conditions:** Change the distance between the mirrors and the angle of incidence of the light.
- **Observation and analysis:** Observe the new fringes and analyse the changes.

IV. 6. 3 Measuring the variation of the index of air as a function of pressure

To measure the variation in the refractive index of air as a function of pressure, we use the air wedge configuration. By observing the displacement of the interference fringes as the air pressure changes, we can calculate the variation in refractive index. This measurement is important for understanding the optical properties of air at different pressures. The steps include:

- **Preparing the experiment:** Set up the interferometer in the air wedge configuration.
- **Initial observation:** Observe the interference fringes at atmospheric pressure.
- **Changing the pressure:** Change the air pressure and observe the displacement of the fringes.
- **Calculate the variation in index:** Use the measurements to calculate the variation in refractive index as a function of pressure.

V. Conclusion

V.1. Summary of results

The summary of the experimental results enables the initial objectives to be verified and the measurements made to be concluded. The main observations and values obtained for wavelengths, wavelength differences and variations in refractive index are summarised. A comparison with theoretical values and measurement uncertainties is also made. The following points are discussed:

- Results of measurements of wavelengths and wavelength differences.

- Results of air refractive index variation measurements.

- Comparison of experimental results with theoretical values.

- Analysis of sources of error and measurement uncertainties.

V.2. Discussion of experimental limitations

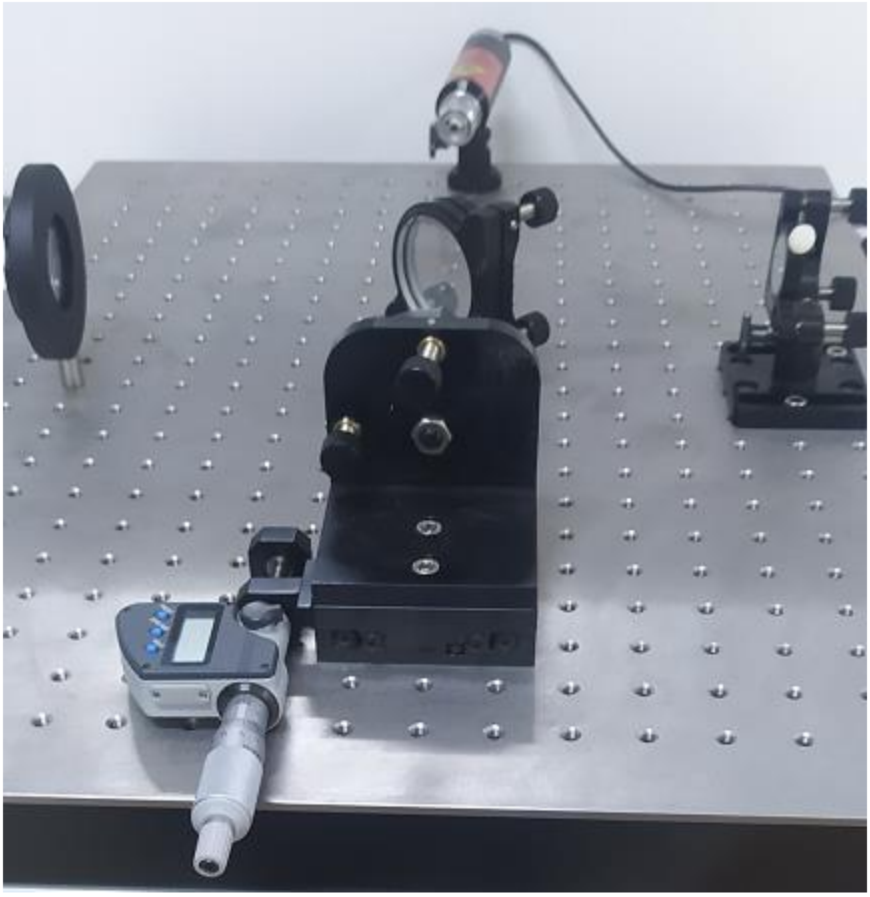
Experimental limitations include possible errors in the measurements, uncertainties due to the settings of the mirrors and plates, and theoretical approximations. It is important to discuss these aspects in order to assess the accuracy and reliability of the results. Sources of error can include imperfections in optical components, vibrations, and temperature variations. The following points are discussed:

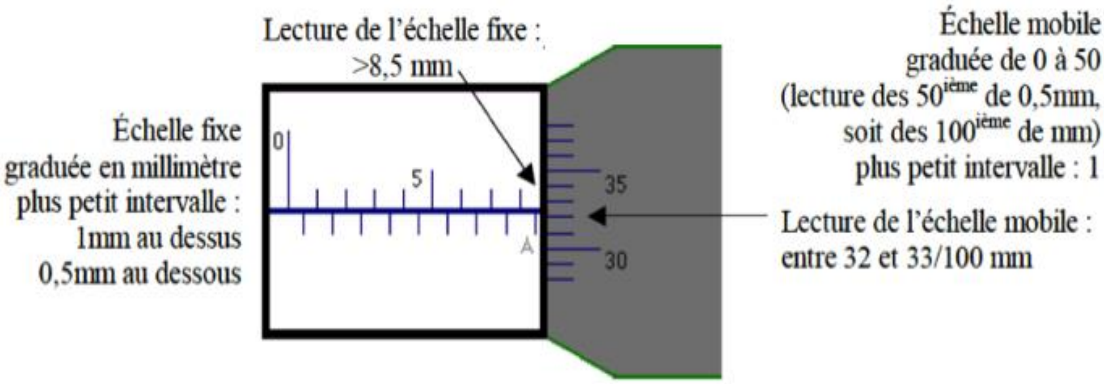
- Potential sources of error in measurements.

- Impact of optical component imperfections on results.

- Effects of vibrations and temperature variations.

- Limits of theoretical approximations used in calculations.





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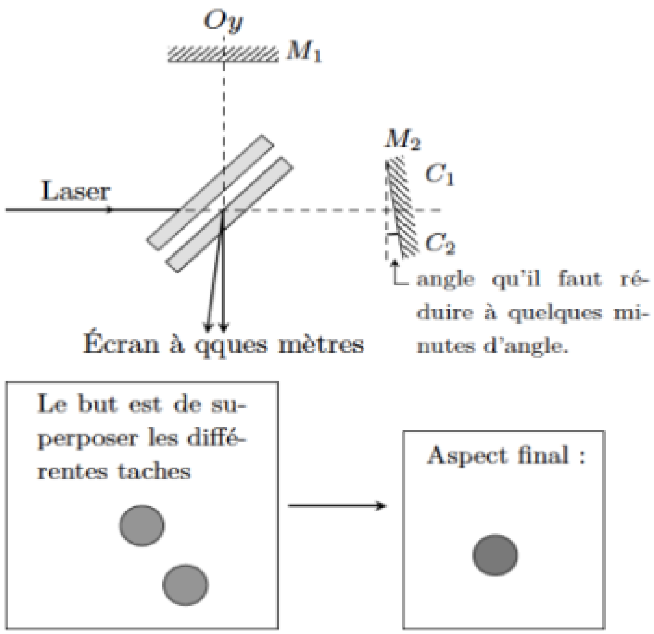

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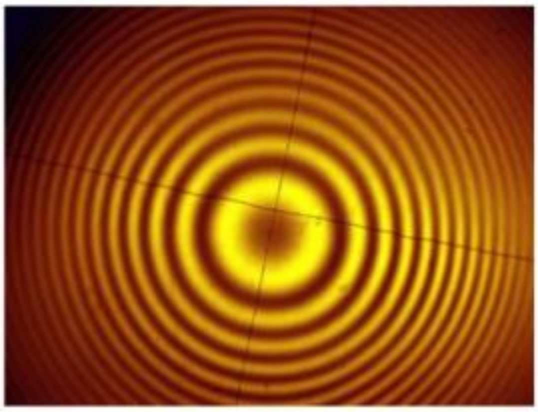

PW. V: Diffraction by a grating

V. 1. Objective:

To study the phenomenon of diffraction of light by a diffraction grating and determine the wavelength of different light sources.

V. 2. Materials required:

- Diffraction grating (transmission or reflection grating)
- Light source (laser and mercury vapour lamp)
- Collimator and slit
- Spectrometer or detector
- Projection screen

Principle of the experiment: A diffraction grating disperses light into its different spectral components as a function of wavelength. Diffraction maxima occur at specific angles, determined by the grating equation.

V. 3. Experimental procedure:

V. 3. 1. Setting up the apparatus:

- Position the light source so that the light passes through the collimator and the slit to obtain a parallel beam.
- Orient the diffraction grating perpendicular to the incident beam.

V. 3. 2. Observing the diffraction:

- Project the diffraction spectrum on the screen or use a spectrometer to observe the diffraction angles.
- Note the positions of the diffraction maxima.

V. 4. Determining the wavelength:

- Use the grating equation:

$$d\sin\theta = n\lambda \tag{V. 1}$$

Where:

d: is the distance between grating lines, θ: is the diffraction angle,

n: is the diffraction order,

λ: is the wavelength.

- Measure the diffraction angles for the different orders and calculate the wavelength of the light source.

V. 5. Spectrum analysis:

- For a mercury vapour lamp, identify the different spectral lines.
- Calculate the corresponding wavelengths and compare them with the theoretical values. Fill in the table.

Color	purple	blue	indigo	Green-blue	green	yelow	yelow	red
Wavelength								

- Plot the sin (θ) = f (λ) curve. determine the step size of the grating
- Discuss potential sources of error, such as the accuracy of angular measurements and the quality of the grating.

V. 6. Conclusion

This practical work enables you to understand and manipulate the concepts of interference and diffraction of light, using devices such as the Michelson interferometer and the diffraction grating. These experiments are fundamental for exploring the wave properties of light and their applications in the measurement of wavelengths and other optical phenomena.


PATON HAWKSLEY
600 lines / mm

General Conclusion

The practical work in wave optics spectroscopy provides a thorough exploration of the fundamental properties of light and the associated phenomena. Through experiments such as polarization, diffraction, Young's slits, diffraction gratings, and the Michelson interferometer, we have demonstrated key concepts that highlight the wave nature of light and its interaction with matter.

These experiments not only deepen our understanding of fundamental physical principles but also open perspectives for modern and innovative applications. For example, polarization is exploited in LCD screens, anti-glare glasses, and optical detection techniques. Diffraction and interference play a crucial role in the design of precision instruments such as spectrometers and in the development of technologies like optical fibers and telecommunication devices.

The Michelson interferometer, renowned for its role in detecting gravitational waves, exemplifies how the principles of physical spectroscopy can be applied to fundamental research and high-precision measurements.

Moreover, the methods and techniques covered in this practical work pave the way for advancements in interdisciplinary fields such as biophotonics for medical imaging and nanotechnology, where manipulating light on a nanometric scale revolutionizes material fabrication.

These practical activities are therefore not limited to understanding the wave phenomena of light. They serve as an introduction to scientific innovation and solving technological challenges, providing a solid foundation for addressing increasingly complex research problems and industrial applications.

Specific Applications and Perspectives

1. **Metrology and Optical Instrumentation**

   - **Specific Application**: The Michelson interferometer is used to measure lengths or position changes with nanometric precision, for example, in instrument calibration systems or scientific observatories like LIGO for detecting gravitational waves.
   - **Highlight**: Its role in advancing measurement standards and fundamental units, particularly the meter defined by the speed of light.

2. **Medical Imaging and Biophotonics**

   - **Specific Application**: Polarization phenomena are used to detect the optical properties of human tissues, such as early cancer detection through polarization imaging.
   - **Highlight**: The direct impact on human health and the growing importance of spectroscopy in medicine.

3. **Fiber Optic Telecommunications**

   - **Specific Application**: Diffraction and interference are crucial in wavelength-division multiplexers used to increase the capacity of fiber optic cables.
   - **Highlight**: The role of these principles in enabling higher data rates, supporting the growth of the Internet.

4. **Energy and Photovoltaics**

   - **Specific Application**: Diffraction gratings are used in spectrometers to analyze the efficiency of photovoltaic materials and optimize their design.
   - **Highlight**: This application links to climate urgency and the transition to renewable energy sources.

5. **Nanotechnology and Material Fabrication**

   - **Specific Application**: Diffraction and interference concepts are used in optical lithography to fabricate nanometric structures, essential in creating integrated circuits.

- **Highlight**: The importance of these techniques in modern electronics and technological advancements such as cutting-edge processors.

6. **Astrophysics and Space Exploration**

- **Specific Application**: Diffraction gratings and interferometers are used in spectrographs on telescopes to analyze starlight and detect exoplanets.
- **Highlight**: Connecting optical phenomena to the fundamental human quest for understanding the universe and discovering habitable planets.