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# Experimental Setup to Verify the Analogy Between Visible Light and Microwaves

Josué del Valle-Hernández*, J. Felix López Rocha**, Adrian Pérez-Benavidez***, José Alfredo Gasca González**, Emmanuel Lira Hernández*, Carlos Alberto Trujillo-Castellanos**** and Mauricio Valtierra Domínguez****
* (Dept. of Divison of Postgraduate Studies and Investigation, Tecnológico Nacional de México, Campus León
Email: josue.delvalle@leon.tecnm.mx
** (Dept. of Basic Sciences, Tecnológico Nacional de México, Campus León
*** (Dept. of Metrology and Quality control, Instituto Politécnico Nacional, Campus León
**** (Dept. of Metal-Mechanical, Tecnológico Nacional de México, Campus León

## Abstract:

Visible light and microwaves exhibit analogous behavior. This publication aims to verify this analogy by determining the wavelength of a microwave emitter using the following methods: double slit (Young's experiment), standing waves, and the Michelson interferometer. These methods are highly useful tools with numerous applications, one of which is to determine the wavelength of unknown sources. The methodology for calculating the wavelength using each technique is detailed in the subsequent sections of this document.

*Keywords* — **Microwaves, Young's Interferometer, Michelson interferometer.**

## I. INTRODUCTION

When two or more optical waves occupy the same region at the same time, the resulting wave is the sum of all individual waves. However, the total intensity of all waves is not simply the sum of their individual intensities due to the phenomenon of interference. An interferometer is an optical instrument that splits a wave into two parts and then recombines them on a plane to produce interference.

One of the most well-known interferometers is Young's interferometer, which consists of two slits. In this setup, the wavefront is divided into two parts, and the resulting interference is observed on a distant screen. Fig. 1 illustrates a schematic representation of this instrument.

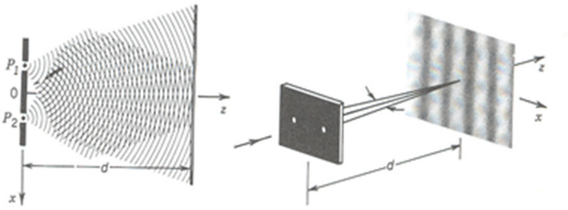

Fig. 1. Young's Interferometer setup.

In the observation plane, interference fringes are formed. The frequency of these fringes follows a sinusoidal pattern, while their intensity is governed by a Sinc function. For constructive interference to occur and for interference fringes to be observed, the optical path difference must be a multiple of the wavelength. The double-slit interferometer is particularly useful for determining the wavelength of a light source, especially if it is monochromatic, provided the distance between the observation screen and the slits, as well as the separation between the slits, is known. It can also be used to measure the separation of two slits if the wavelength and the screen distance are known.

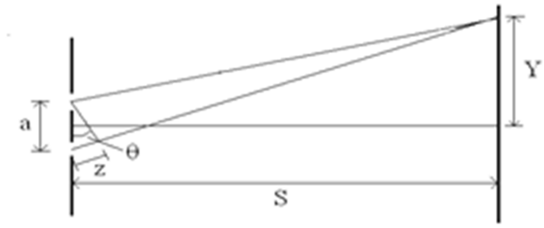

Fig. 2. Schematic diagram of the interference pattern formation caused by the outgoing interference from each slit.

With this arrangement $z = n\lambda$ , $z$ must be a multiple of the wavelength for constructive interference to occur and for interference fringes to be observed. Additionally, we know that:

$$asen\theta = z = n\lambda \tag{1}$$

For a minimum at P, the two rays must differ in phase by an odd multiple of $\pi$, that means:

$$asen\theta = \left(n+\tfrac{1}{2}\right)\lambda \; n = 0,1,2,\ldots \tag{2}$$

## STANDING WAVES

In optics, it is possible to produce standing waves when a light beam reflects off a mirror. In cases where the mirror's reflection is not perfect, as often occurs, the resulting wave will include a traveling wave component superimposed on the standing wave. This results in a net energy transfer, contrasting with a pure standing wave where no energy transfer occurs. The wave functions of standing waves formed by the superposition of two waves are:

$$E(x,t) = -2E_{max}sen(kx)\cos(\omega t) \tag{3}$$

Standing waves are not propagating waves but rather distinct vibration modes of a string, a membrane, air in a tube, or similar systems. Let us now consider a string of length $L$ fixed at both ends. The string has a set of normal modes of vibration, each with a characteristic frequency. First, if we assume that these points remain fixed, the ends of the string must be nodes.

The first mode of vibration occurs when the string's length is equal to half a wavelength:

$$L = \frac{\lambda}{2} \qquad\qquad n = 0,1,2,\ldots \tag{4}$$

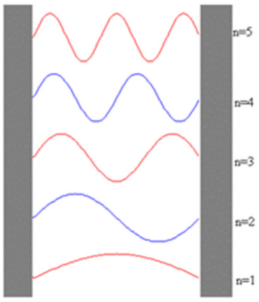

Fig. 3 Different vibration modes, $\boldsymbol{v_n = nv_1}$, Harmonics n=2,3,4, ….

For the second mode of vibration, where there is a node at the center, the length of the string corresponds to one wavelength, $L = \lambda$, n = 2 (Fig. 3). For the third mode, $L = {}^{3\lambda}/_{2}$, and so on. In general, nodes will form on a string of length "$L$" when the wavelength $\lambda$ of the wave satisfies the following conditions:

$$\lambda_n = \frac{2L}{n} \quad con \quad n = 1,2,3,\ldots \tag{5}$$

## MICHELSON INTERFEROMETER

The Michelson interferometer is another example of amplitude-division interference. It is one of the most well-known and useful devices for measuring distances with high precision and was originally designed to measure the speed of light. The configuration of this interferometer is shown in Fig. 4. A light source emits a wave that is divided in amplitude by the beam splitter D. One part of the wave travels toward mirror $E_1$, while the other part travels toward mirror $E_2$. The two beams reflected by $E_1$ and $E_2$ return to the beam splitter. At this point, part of the wave from $E_2$ passes through the splitter toward the detector, while part of the wave from $E_1$ is deflected by the splitter toward the detector as well. Consequently, the waves combine and interfere, provided that the optical path difference is not greater than the coherence length of the light source being analyzed.

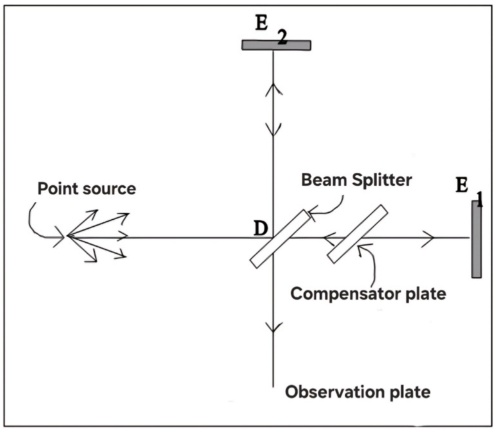

Fig. 4. Diagram of the Michelson Interferometer.

The wavelength can be calculated using the distance $d$ traveled by the mirror, the number of fringes $n$ that appear or disappear over that distance, and the following relationship:

$$\lambda = \frac{2d}{n} \tag{6}$$

## II. EXPERIMENTAL DEVELOPMENT

First, all the elements and materials required to set up the experiment were gathered. The materials provided for this practice included a microwave kit consisting of:

- An emitter.
- A receiver.
- A goniometer.
- Reflective sheets.
- Four double electroformed slits.
- A USAF test card transparency.

The objective of this practice is to determine the wavelength of a microwave emitter using the previously mentioned methods.

### DOUBLE-SLIT EXPERIMENT

To perform the double-slit experiment, the setup shown in Fig. 5 was assembled. One important consideration was ensuring that both the emitter and receiver were aligned with respect to the polarization of the microwave signal. It is worth noting that microwaves and light share analogous behavior; therefore, the emitter and detector were aligned and activated according to the polarization of the light.

To perform this operation, the emitter was positioned and secured. The receiver was then mounted as shown in the figure and rotated until reaching a position with maximum intensity. It was observed that maximum intensity occurred when the emitter's horn was perpendicular to the receiver's horn.

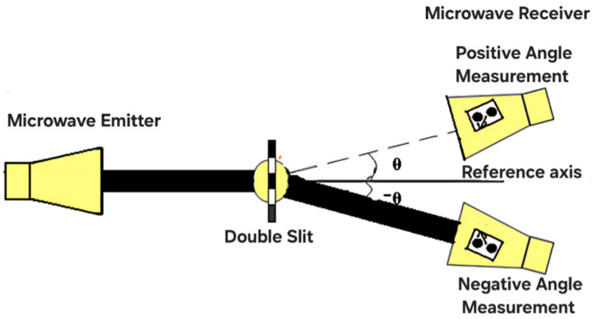

Fig. 5. Experimental setup of the double-slit for a microwave signal.

Starting from a reference axis at 0°, measurements were taken by sweeping the positive part of $\theta$ at 1-degree intervals, followed by the negative part of $\theta$. This resulted in a total measurement range of 72°.

During the measurements, care was taken to remove any objects that could interfere with the emission or detection of microwaves, ensuring reliable readings. Additionally, the receiver's placement facilitated data collection without obstructing the microwave trajectory.

For the double-slit formation, three reflective sheets were used, spaced 3 cm apart and magnetically secured to a special mount included in the microwave kit.

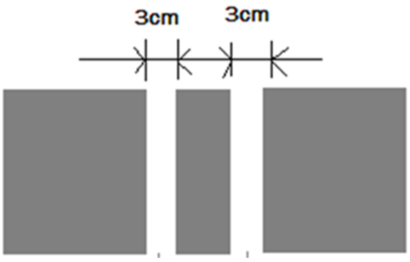

Fig. 6. Diagram of the reflective sheets used to form the double slit.

With the collected data, a graph was generated to show the variation of intensity concerning the receiver's angular position. This graph displayed maxima and minima, which were used along with equations (1) and (2) to calculate the wavelength.

## STANDING WAVES

The method used to calculate the wavelength of our emitted signal involves aligning a microwave emitter with a reflective sheet, which serves as an analog to a mirror when reflecting light. This setup is illustrated in Fig. 7. A point detector is then placed between the emitter and the mirror, allowing the signal's intensity (amplitude in mA) to be observed on the receiver, as the point detector is connected to it.

To vary the intensity and identify the maxima and minima of the function, the point detector is initially positioned at a specific distance. The detector is then gradually moved, and readings are taken at various points to collect sufficient data for graphing the resulting function. The wavelength can be calculated knowing that the distance between consecutive maxima corresponds to ${}^{\lambda}/_{2}$.

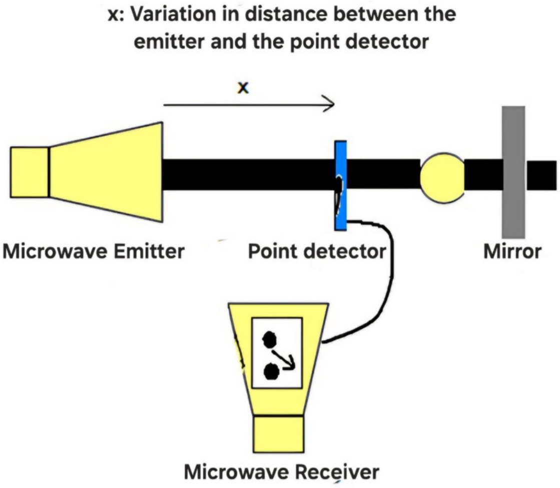

Fig. 7. Schematic diagram of the experimental setup for standing waves in microwaves.

## MICHELSON INTERFEROMETER

Another method to calculate the wavelength is through the Michelson interferometer. For this purpose, the experimental setup shown in Fig. 8 was assembled.

Similar to the previous method, calculating the emission signal's wavelength requires obtaining the intensity variation. This is achieved by moving one mirror from an initial point to a final point. Finally, using Eq. 4, the desired wavelength is determined.

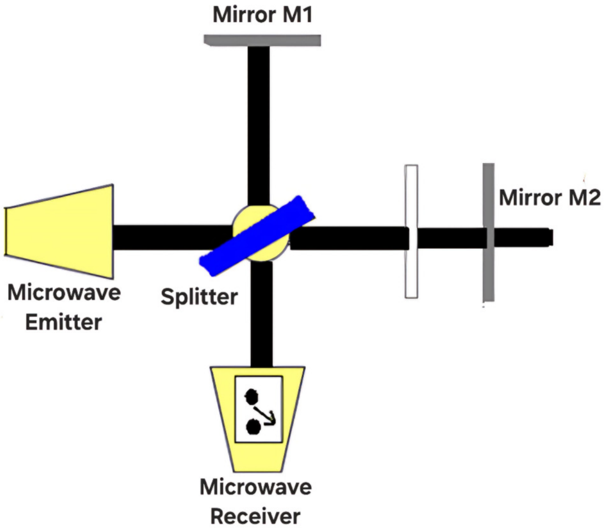

Fig. 8. Schematic diagram of a Michelson interferometer for microwaves.

## III. RESULTS

### DOUBLE SLIT

The data obtained from the measurements are presented in the following table:

| Angle° | I (mA) | Angle° | I (mA) | Angle° | I (mA) |
|---|---|---|---|---|---|
| -35 | 1,8 | -9 | 0,6 | 17 | 3,9 |
| -34 | 1,5 | -8 | 0,6 | 18 | 4,8 |
| -33 | 1,2 | -7 | 0,75 | 19 | 5,4 |
| -32 | 1,05 | -6 | 1,2 | 20 | -- |
| -31 | 0,9 | -5 | 2,4 | 21 | 5,1 |
| -30 | 0,6 | -4 | 3,3 | 22 | 4,8 |
| -29 | 0,9 | -3 | 4,5 | 23 | 4,8 |
| -28 | 1,2 | -2 | 5,4 | 24 | 4,8 |
| -27 | 1,5 | -1 | 6,3 | 25 | 4,5 |
| -26 | 1,8 | 0 | 6,6 | 26 | 4,2 |
| -25 | 2,4 | 1 | 6,3 | 27 | 3,3 |
| -24 | 2,7 | 2 | 6,15 | 28 | 3 |
| -23 | 3,45 | 3 | 5,7 | 29 | 2,1 |
| -22 | 3,6 | 4 | 5,1 | 30 | 1,95 |
| -21 | 4,8 | 5 | 4,2 | 31 | 1,2 |
| -20 | 5,4 | 6 | 3,3 | 32 | 0,9 |
| -19 | 5,7 | 7 | 2,1 | 33 | 0,75 |
| -18 | 5,4 | 8 | 1,2 | 34 | 0,9 |
| -17 | 4,8 | 9 | 0,6 | 35 | 0,9 |
| -16 | 4,2 | 10 | 0,3 | 36 | 0,9 |
| -15 | 3,9 | 11 | 0,45 | 37 | 1,2 |
| -14 | 3,6 | 12 | 0,6 | | |
| -13 | 3,3 | 13 | 0,9 | | |
| -12 | 2,7 | 14 | 1,2 | | |
| -11 | 1,8 | 15 | 2,1 | | |
| -10 | 1,2 | 16 | 2,7 | | |

Table 1. Measurements taken from the double-slit experimental setup.

Subsequently, the data from the table were plotted, resulting in a sinc function modulated by a cosine function. This represents the interference and diffraction pattern caused by the double slit, as shown in Fig. 9. The graph displays the variation of amplitude (mA) as a function of the angular position of the receiver (see Fig. 5).

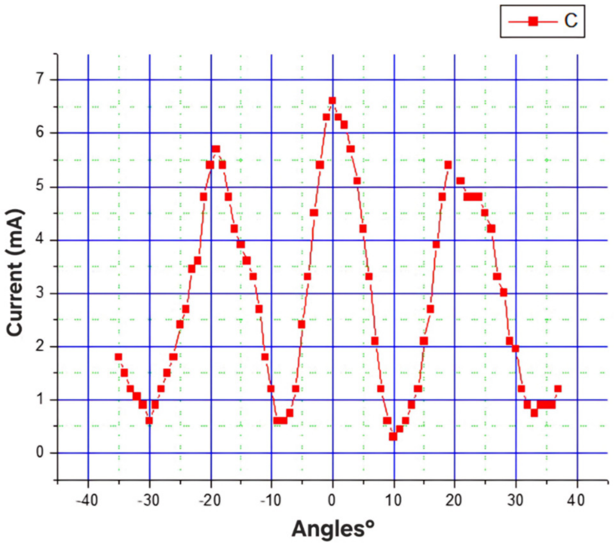

Fig. 9. Experimental graph obtained from Table 1 for the double slit.

The following table lists the calculated wavelengths corresponding to the maxima and minima of the sinc function modulated by the cosine function obtained experimentally.

Using Eqs. 1 and 2, the wavelength was calculated

| Order (n) of maxima | θ, angles | λ, cm |
|---|---|---|
| -1 | -19 | 2.93 |
| 0 | 0 | -- |
| 1 | 19 | 2.93 |
| | **Average** | **2.93** |

| Order (n) of maxima | θ, angles | λ, cm |
|---|---|---|
| -2 | -30 | 3 |
| -1 | -8 | 2.5 |
| 0 | 10 | 3.12 |
| 1 | 33 | 3.26 |
| | **Average** | **2.97** |

Averaging these results gives: $\boldsymbol{\lambda = 2.95\ cm}$.

With an error of 3.14% compared to the theoretical value indicated by the microwave emitter.

STANDING WAVES.

In this experimental setup (see Fig. 7), the data shown in the following table were obtained:

| X (cm) | I (mA) | X (cm) | I (mA) | X (cm) | I (mA) |
|---|---|---|---|---|---|
| 0,8 | 0,06 | 3,4 | 0,11 | 5,9 | 0,17 |
| 1 | 0,08 | 3,5 | 0,11 | 6 | 0,14 |
| 1,1 | 0,13 | 3,6 | 0,12 | 6,1 | 0,12 |
| 1,2 | 0,18 | 3,7 | 0,14 | 6,2 | 0,1 |
| 1,3 | 0,22 | 3,8 | 0,16 | 6,3 | 0,09 |
| 1,4 | 0,23 | 3,9 | 0,185 | 6,4 | 0,09 |
| 1,5 | 0,2 | 4 | 0,21 | 6,5 | 0,11 |
| 1,6 | 0,17 | 4,1 | 0,225 | 6,6 | 0,12 |
| 1,7 | 0,14 | 4,2 | 0,22 | 6,7 | 0,15 |
| 1,8 | 0,13 | 4,3 | 0,22 | 6,8 | 0,16 |
| 1,9 | 0,12 | 4,4 | 0,205 | 6,9 | 0,17 |
| 2 | 0,12 | 4,5 | 0,18 | 7 | 0,18 |
| 2,1 | 0,13 | 4,6 | 0,14 | 7,1 | 0,18 |
| 2,2 | 0,16 | 4,7 | 0,11 | 7,2 | 0,17 |
| 2,3 | 0,18 | 4,8 | 0,09 | 7,3 | 0,16 |
| 2,4 | 0,19 | 4,9 | 0,085 | 7,4 | 0,15 |
| 2,5 | 0,2 | 5 | 0,1 | 7,5 | 0,13 |
| 2,6 | 0,21 | 5,1 | 0,11 | 7,6 | 0,1 |
| 2,7 | 0,22 | 5,2 | 0,13 | 7,7 | 0,09 |
| 2,8 | 0,23 | 5,3 | 0,14 | 7,8 | 0,08 |
| 2,9 | 0,24 | 5,4 | 0,16 | 7,9 | 0,09 |
| 3 | 0,22 | 5,5 | 0,17 | 8 | 0,1 |
| 3,1 | 0,19 | 5,6 | 0,18 | | |
| 3,2 | 0,16 | 5,7 | 0,18 | | |
| 3,3 | 0,12 | 5,8 | 0,18 | | |

Table 2. Measurements taken from the standing waves experimental setup.

Using the data, the variation of intensity as a function of distance $x$ (the separation between the emitter and the point detector) was plotted. The resulting graph is shown below:

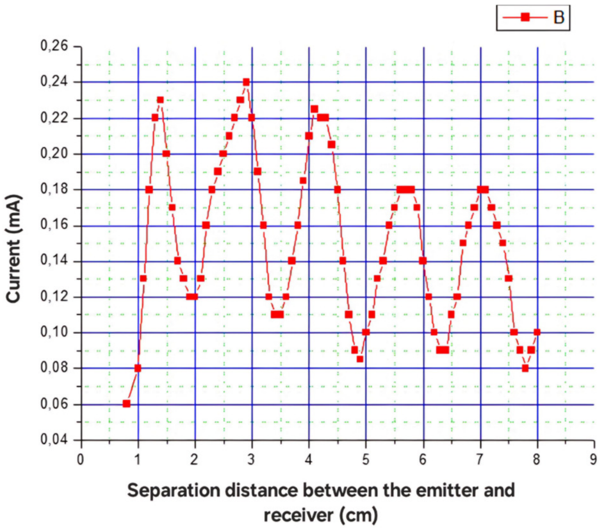

Fig. 10. Experimental graph obtained from Table 2 for standing waves.

The graph reveals five maxima in the experimental function, whose positions and amplitudes are listed in the following table:

| Maxima | X( cm) | I ( mA) |
|---|---|---|
| 1 | 1.4 | 0.23 |
| 2 | 2.9 | 0.24 |
| 3 | 4.1 | 0.225 |
| 4 | 5.7 | 0.18 |
| 5 | 7 | 0.18 |

Table 3. Data of the maxima obtained from Figure 10 of standing waves.

Using Eq. 3, the wavelength was calculated, with the results presented in the following table:

| Maxima | Distance between maxima (cm) | Λ ( mA) |
|---|---|---|
| 1 y 2 | 1.5 | 3 |
| 2 y 3 | 1.2 | 2.4 |
| 3 y 4 | 1.6 | 3.2 |
| 4 y 5 | 1.3 | 2.6 |
| | | |
| | **Average** | **2.8** |

Table 4. Wavelengths calculated using the standing waves method.

Therefore $\boldsymbol{\lambda = 2.8\ cm}$. This yields an error of 2.1% compared to the theoretical value.

### MICHELSON INTERFEROMETER.

For this experimental setup (see Fig. 8), the following data were obtained by moving a mirror from an initial position of 21 cm relative to the beam splitter to a final position of 36.6 cm:

| X (cm) | I (mA) | X (cm) | I (mA) | X (cm) | I (mA) |
|---|---|---|---|---|---|
| 21 | 0,42 | 25,25 | 0,18 | 30,7 | 1,08 |
| 21,2 | 0,9 | 25,4 | 0,018 | 30,9 | 0,36 |
| 21,5 | 1,98 | 25,6 | 0,63 | 31,1 | 0,06 |
| 21,6 | 2,28 | 25,7 | 1,32 | 31,3 | 0,33 |
| 21,75 | 2,46 | 25,9 | 1,8 | 31,4 | 0,99 |
| 21,95 | 2,43 | 26 | 2,22 | 31,7 | 1,71 |
| 22 | 1,95 | 26,15 | 2,37 | 31,85 | 1,92 |
| 22,1 | 1,41 | 26,3 | 1,95 | 32 | 1,5 |
| 22,2 | 1,05 | 26,5 | 0,96 | 32,25 | 0,3 |
| 22,3 | 0,72 | 26,6 | 0,36 | 32,45 | 0,06 |
| 22,4 | 0,21 | 26,7 | 0,12 | 32,8 | 0,66 |
| 22,5 | 0,3 | 26,8 | 0,18 | 33 | 1,41 |
| 22,6 | 0,66 | 26,95 | 0,48 | 33,15 | 1,98 |
| 22,75 | 0,96 | 27,1 | 1,08 | 33,35 | 1,8 |
| 22,85 | 1,32 | 27,3 | 1,74 | 33,5 | 1,26 |
| 22,9 | 1,83 | 27,4 | 2,19 | 33,8 | 0,3 |
| 23 | 2,13 | 27,5 | 2,28 | 34 | 0,09 |
| 23,15 | 2,4 | 27,7 | 1,74 | 34,3 | 0,66 |
| 23,25 | 2,52 | 27,9 | 0,78 | 34,4 | 1,26 |
| 23,4 | 2,1 | 28,1 | 0,18 | 34,6 | 1,74 |
| 23,6 | 1,14 | 28,2 | 0,09 | 34,8 | 1,89 |
| 23,7 | 0,6 | 28,4 | 0,48 | 35 | 1,32 |
| 23,85 | 0,24 | 28,6 | 1,32 | 35,15 | 0,66 |
| 23,9 | 0,27 | 28,9 | 2,1 | 35,25 | 0,18 |
| 24,1 | 0,72 | 29,2 | 1,95 | 35,4 | 0,006 |
| 24,3 | 1,68 | 29,4 | 0,96 | 35,7 | 0,42 |
| 24,4 | 2,16 | 29,65 | 0,09 | 35,9 | 1,08 |
| 24,5 | 2,4 | 29,9 | 0,63 | 36,1 | 1,53 |
| 24,8 | 2,52 | 30,1 | 1,26 | 36,35 | 1,68 |
| 24,95 | 1,95 | 30,2 | 1,8 | 36,6 | 1,08 |
| 25,05 | 1,2 | 30,3 | 2,07 |  |  |
| 25,15 | 0,54 | 30,55 | 1,86 |  |  |

Table 5. Measurements taken from the experimental setup of the Michelson interferometer for microwaves.

The data produced the following graph, showing the variation of amplitude (mA) as a function of the mirror's displacement:

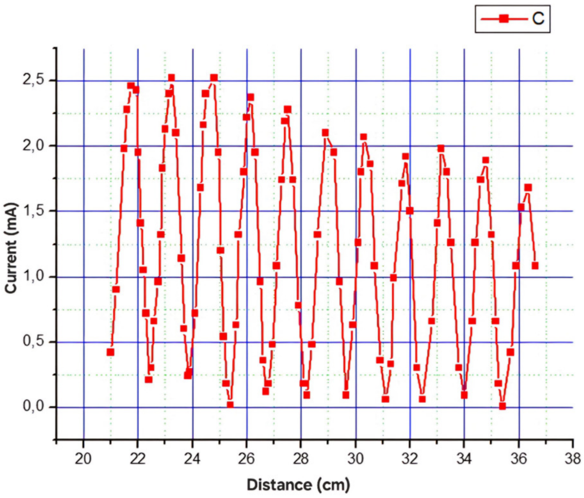

Fig. 11. Experimental graph obtained from Table 5.

The positions and amplitudes of the maxima and minima are summarized in the following table:

| Maxima | X( cm) | I ( mA) |
|---|---|---|
| 1 | 21.75 | 2.46 |
| 2 | 23.25 | 2.52 |
| 3 | 24.8 | 2.52 |
| 4 | 26.15 | 2.37 |
| 5 | 27.5 | 2.28 |
| 6 | 28.9 | 2.1 |
| 7 | 30.3 | 2.07 |
| 8 | 31.85 | 1.92 |
| 9 | 33.15 | 1.98 |
| 10 | 34.8 | 1.89 |
| 11 | 36.35 | 1.68 |

Table 6. Data of the maxima obtained from Figure 11 (Michelson interferometer for microwaves).

Using Eq. 4 and the total distance traveled by the mirror ($d$), the wavelength was calculated. The result is presented in the following table:

| Number of Maxima in d | d (Total distance traveled by the mirror) (cm) | $\lambda$ (cm) |
|---|---|---|
| 11 | 21.75 | 2.83 |

Table 7. Wavelengths calculated using the Michelson interferometer method for microwaves.

$\boldsymbol{\lambda = 2.83\ cm}$. With an error of 1% compared to the theoretical value.

## IV. CONCLUSIONS

During the practice, the following was concluded:

- Using the **double slit method**, the wavelength obtained was **λ = 2.95 cm,** with an error of 3.14% compared to the theoretical value.
- Using the **standing wave method**, the wavelength obtained was **λ = 2.8 cm,** with an error of 2.1% compared to the theoretical value.
- Using the **Michelson interferometer method**, the wavelength obtained was **λ = 2.83 cm,** with an error of 1% compared to the theoretical value.
- The most reliable and accurate method was the Michelson interferometer.
- The main source of uncertainty was due to any object interfering with the microwave emitter, especially metals (such as the holographic table), and the presence of a person moving closer to take measurement readings.
- To achieve greater precision and lower uncertainty, it would be advisable to conduct the experiment in a more isolated and controlled environment.

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