Microwave Interferometer: Michelson-Morley Experiment

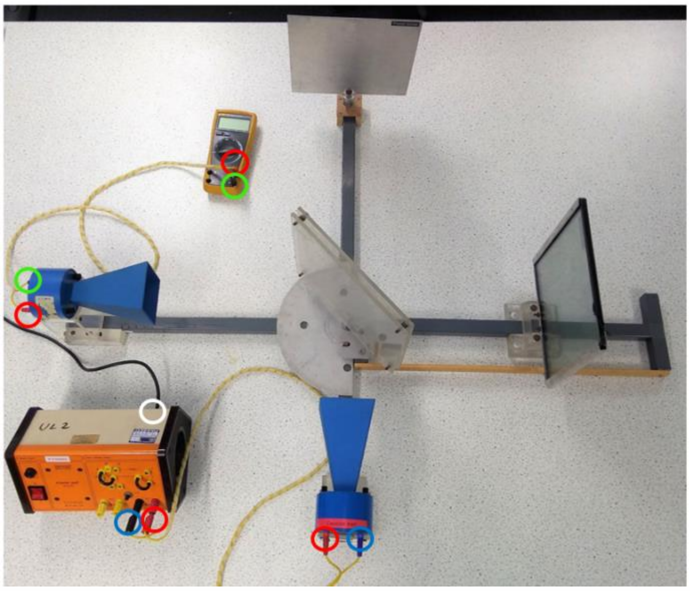
In 1887 Michelson and Morley famously used an optical interferometer, a device invented by Michelson for this experiment, to search for the relative motion of light through the Luminiferous Aether, a hypothetical medium through which light was thought to propagate. The famous null result of the Michelson-Morley experiment effectively disproved the existence of the aether and paved the way to Einstein's theory of relativity and the revolution of Modern Physics in the twentieth century. Michelson interferometers can be used to study other types of electromagnetic radiation and still operate at the frontiers of science. In 2016, an interferometer was used at LIGO to discover the first direct evidence of gravitational waves.

Safety	**Microwave generator**: The microwave transmitter can become hot during use. It is best not to handle the transmitter once it has been powered up. **Sharp edges:** The edges of the metal and glass surfaces used for the experiment have been smoothed down or taped over. However, caution is advised when adjusting the apparatus.

Set up instructions for staff

Instructional videos on how to set up this experiment are available on the Lancaster Physics/ Outreach/ Lab in a Box webpage.

Please fully assemble the experiment before powering up.



Cable Connection Guide and experimental Setup:

Please assemble the experiment before connecting it to the grid.

1. (B & R/ **B** & R) Cable: Connect to blue and red plugs accordingly to the positive and negative signs to the microwave generator and connect the **black** and red plugs to the power unit respectively.
2. (B & R/ **B** & R) Cable: Connect to blue and red plugs to the microwave receiver accordingly to the positive and negative signs and connect the **black** and red plugs. respectively to the multimeter respectively.
3. The **Black** cable, highlighted in white, is connected from the power unit to the grid.

Figure 1: Photograph showing the fully assembled Michelson–Morley experiment with instructions on how to connect each cable.

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Background

The Michelson-Morley experiment was conceived at the end of the 19th century as a way of detecting the presence of the hypothetical "aether", a substance that was believed to fill all space and to provide a medium for light to travel through. Michelson and Morley set out to detect the relative motion of the earth with respect to the aether, which they believed would alter the measured speed of light. Their apparatus measured the difference between two beams of light propagating in two different directions.

Figure 2 shows a schematic of the Micheslon-Morley apparatus. In this experiment, we will use the interferometer to measure the wavelength of a beam of microwaves. The apparatus can also be used to determine the refractive index of a glass plate, which can be added to the setup, as shown in the diagram.

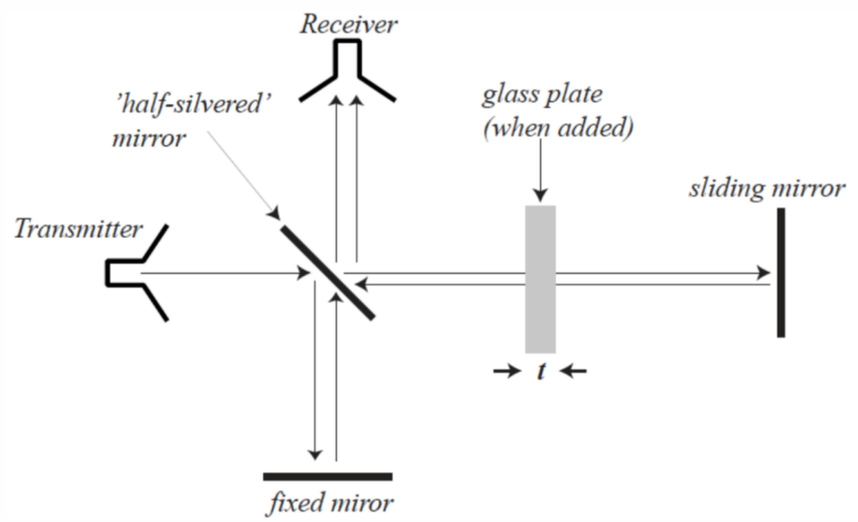

Figure 2: Schematic of the Michelson-Morley apparatus.

Our microwave interferometer works as follows:

- Microwaves from a transmitter hit a half-silvered mirror, where they are partially reflected and partially transmitted.
- The partially-reflected waves travel to a fixed mirror, where they are reflected, then pass back through the half-silvered mirror, and are detected by a microwave receiver.
- The partially-transmitted waves pass through a glass plate (if added to the apparatus), are reflected from a sliding mirror, then travel back through the glass plate, and are reflected again by the half-silvered mirror before reaching the receiver.
- The receiver is connected to a voltmeter which records the microwave intensity.

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1. What physical process will take place when the reflected and transmitted microwaves meet at the receiver?

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Task 1

The apparatus should be set up and powered up. Begin by moving the sliding mirror backwards and forwards along the apparatus. Notice how the voltage from the receiver is high at some points and low at others.

1. Why is this the case?

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By moving the sliding mirror, we are changing the "optical path" of the microwaves through the apparatus. The optical path is defined as the equivalent distance through a vacuum that would contain the same number of wavelengths as the path taken by the microwaves through our apparatus.

2. Derive an expression for the distance *d* through which the sliding mirror should be moved to change the optical path by *m* wavelengths (where *m* is an integer).

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Answer: $d = \frac{m\lambda}{2}$.

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Question 1 We can determine the wavelength of our microwave by varying the optical path of our apparatus. By moving the sliding mirror, measure the distance d required to traverse 10 maxima in microwave intensity. Then, using your relationship between the optical path and the wavelength, obtain a value for λ. Don't forget to include measurement uncertainties in your calculations!

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Now answer the following questions:

3. Why measure 10 interference maxima, as opposed to just 1?

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4. Compare your measured wavelentgh with to the value given on the back of the transmitter $\lambda = 2.8$ [cm]. Does your value of λ agree with the one given? What is the largest source of error?

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Task 2

We can also change the optical path by altering the refractive index of the medium through which the microwaves are propagating.

1. Write down an expression for the refractive index n of a material in terms of the speed of light c in a vacuum and the speed of light in a substance c_s.

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   Answer: $n = c/c_s$.

2. The refractive index always obeys $n > 1$. What are the implications of this formula for the speed of light in a material compared with the speed of light in a vacuum?

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We can use this effect to measure the refractive index of glass.

Firstly, move the position of the sliding mirror until a maxima is found. Now add the sheet of glass and the interference pattern should shift, resulting in a fall in the voltage. Adjust the position of the mirror to find the same maxima and measure the distance moved. Record the distance that you adjusted the mirror below:

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3. Which way must you move the sliding mirror so the <u>same</u> maxima is found?

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Question 2 For a glass plate of thickness t and refractive index n, the change in the optical path that results from introducing the plate into the apparatus is given by the following expression:

$$d = 2\left(n_{glass} - n_{air}\right) t$$

The change in optical path from moving the sliding mirror by distance L is given by:

$$d = 2L$$

Equating these two formula gives the following expression:

$$\left(n_{glass} - n_{air}\right) t = L$$

Moreover, the refractive index for air is $n_{air} \approx 1$. Therefore:

$$\left(n_{glass} - 1\right) t = L.$$

The known thickness of the glass plate is $t = 5.8$ [mm]. By combining this with your measured value of L, calculate the refractive index of the glass plate, n_{glass}.

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Now answer the following questions:

1. Compare your result with the accepted value $n_{glass} = 1.5$. Does your measured value of n_{glass} agree with the one given?

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2. Was your experiment successful? What do you think was the largest source of uncertainty? How do you think you could

improve your results?

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