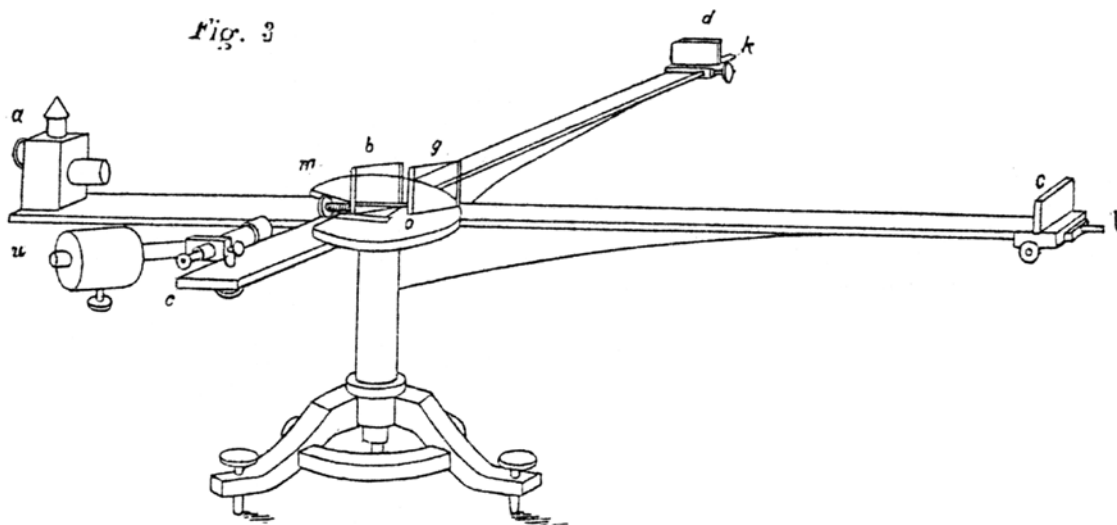


Lab in a Box – Microwave Interferometer

In 1887 Michelson and Morley used an optical interferometer (a device invented by Michelson to accurately detect aether flow) to try and detect the relative motion of light through the luminous ether. A diagram of his first interferometer is shown below:



The famous null result of the Michelson-Morley experiment disproved the existence of the aether and led Einstein's theory of relativity and the revolution of Physics in the twentieth century. Michelson interferometers can be used with other types of electromagnetic radiation and are still used today. In 2016 an interferometer was used at LIGO to find the first direct evidence of gravitational waves.

Today you will be using a microwave interferometer to measure the wavelength of the microwaves in use and to also determine the refractive index of glass. Study the apparatus. A diagram of the microwave interferometer is shown below:

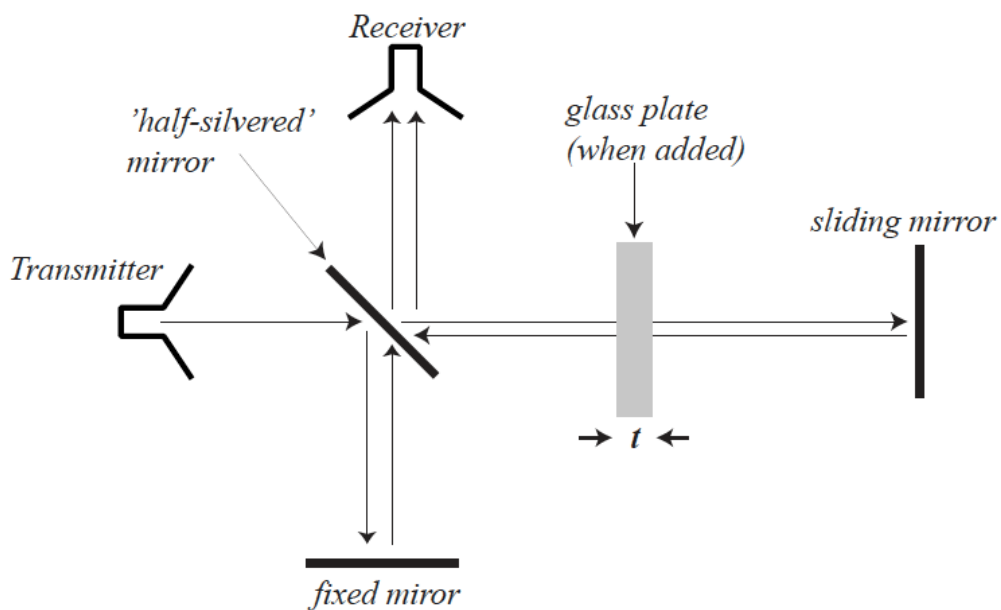


Figure 2

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Microwaves leave the transmitter and hit the half silvered mirror, where they are partially reflected and partially transmitted. Reflected rays will travel to a fixed mirror, reflect normally, pass back through the half silvered mirror and travel to the detector. Microwaves that are transmitted will be reflected back from the moving mirror and also travel through the glass if it is present, before being reflected by the half silvered mirror and reaching the receiver.

The receiver is connected to a voltmeter which will give you an idea of the microwave intensity.

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Questions

Q: Move the movable mirror backwards and forwards along the apparatus. You should notice the voltage is high at some points and low at others. Why is this the case?

The optical path can be changed using two methods, the first is simply by moving the movable mirror. This method can be used to determine the wavelength.

Q: What is the change in path length due to the movement of the mirror?
Measure the distance moved by the mirror in order for ten fringes to pass

Q: Why measure the distance moved after 10 fringes as opposed to 1?
Use your measured distance to obtain a value for λ . Don't forget to include uncertainties!

Compare your result to the value given on the back of the transmitter (2.8cm)

Q: Does your value of λ agree with the one given? What is the largest source of error?

We can also change the optical path by altering the refractive index of the medium in which the radiation is travelling. The refractive index of a material is the ratio of the speed of electromagnetic radiation in a vacuum over the speed of electromagnetic radiation in the material. It is always greater than 1, so electromagnetic waves always propagate slower in a material than in vacuum. You can use this effect to measure the refractive index of glass.

Firstly, move the position of the sliding mirror until maxima is found. Now add the sheet of glass and the fringe 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. Let this distance be represented by L.

Q: Which way must you move the sliding mirror so the same maxima is found?

For thickness t and refractive index μ , the change in optical path is:

$$(\mu-1)t = L$$

The $(\mu-1)$ term is the difference in refractive indices, as the μ for air ≈ 1 .

Using $t = 5.8$ mm, obtain a value for μ , and compare it with the accepted value of 1.5.

Q: Does your value agree with the accepted value? What was the largest source of error?

Q: Could you improve the experiment in any way?

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Answers

Q: Move the movable mirror backwards and forwards along the apparatus. You should notice the voltage is high at some points and low at others. Why is this the case?

At voltage maxima the optical path difference is equal to an integer number of wavelengths, so constructive interference occurs and the signal is greater. At voltage minima, the optical path difference is equal to a half integer number of wavelengths so destructive interference occurs and the signal decreases.

Q: What is the change in path length due to the movement of the mirror?

For a change in path length d over m fringes:

$$d = \frac{m\lambda}{2}$$

Q: Why measure the distance moved after 10 fringes as opposed to 1?

The percentage uncertainty will be lower when measuring 10 fringes due to the larger value for d .

Q: Does your value of λ agree with the one given? What is the largest source of error?

The largest source of error probably comes from the crude method of moving the sliding mirror by hand, meaning it is hard to find the point at which the maxima's are truly located

Q: Which way must you move the sliding mirror so the same maxima is found?

The mirror must be moved forwards, towards the half silvered mirror. This is because the travel time for the microwave is greater due to the beam moving slower in the glass.

Q: Does your value agree with the accepted value? What was the largest source of error?

The largest source of error is the same as above for the same reasoning

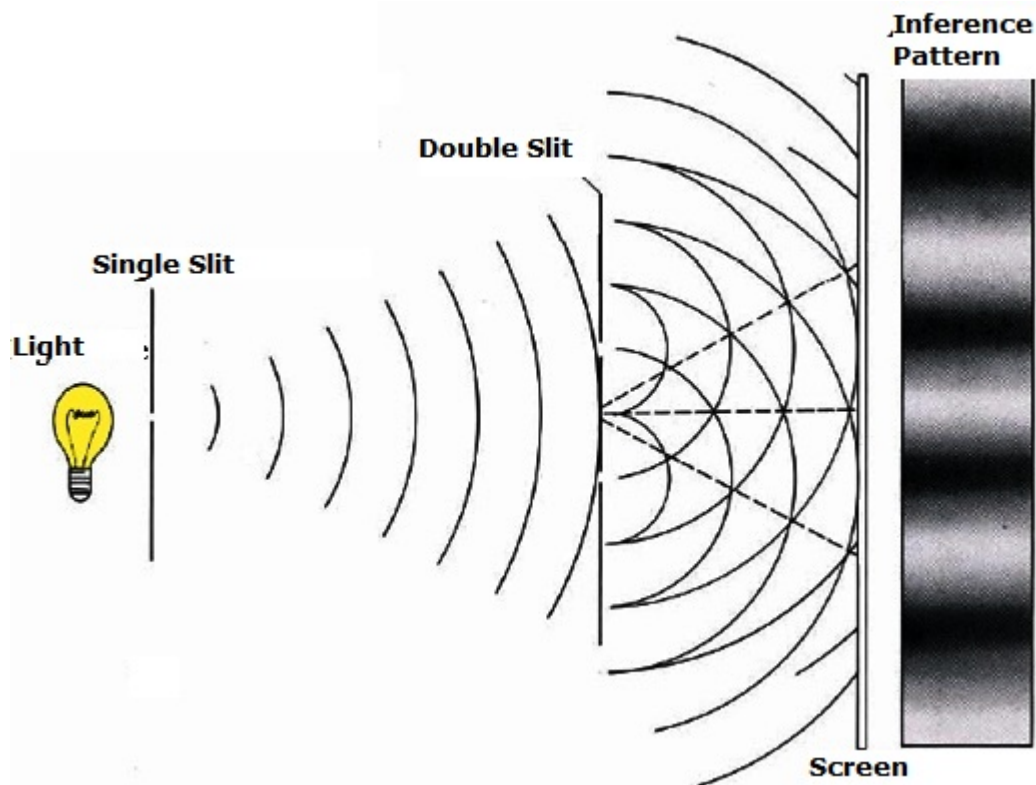
Q: Could you improve the experiment in any way?

The uncertainty in distance measurements could be reduced by using micro meter screws which would allow for more precision in both movement and measurements.

Lab in a Box – Microwave Interferometer

Young's Double Slit Experiment

The double slit experiment was first performed by Thomas Young in 1803 and was pivotal in the acceptance of the wave theory of light. A light source was shone through a single slit, then through a double slit and the resulting interference pattern was observed on the screen as shown in the diagram below:



Q: Why is a single slit placed before the double slits?

The bright fringes on the screen are a result of constructive interference (waves in phase), whereas the dark areas are a result of destructive interference (waves in antiphase).

In this experiment you will witness the same phenomena, but with microwaves instead of visible light. Remember, microwaves are a type of EM radiation just like light, but their wavelengths are much longer (1cm – 1m compared with light 400nm-700nm), so they behave in the same way even though we can't actually see them.

Study the apparatus. A microwave transmitter is connected to a DC power supply and plays the same role as the lightbulb in the above diagram. The transmitter can rotate to up to 90 degrees with respect to the central fringe in each direction. The transmitter sends the microwaves through the double slit, where they are detected by the receiver which acts as a screen. The receiver converts the microwave intensity into a voltage which is displayed on the voltmeter.

Take measurements of the voltage at 5 degree increments from -70 degrees to +70 degrees and plot your results using EXCEL.

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Q: What shape of curve do you expect?

Your data should paint a picture of the microwave interference fringes analogous to those of visible light shown above. If it looks unclear, try taking more measurements around the points of the highest intensity.

Next you will attempt to determine the microwave wavelength. The central equation for this part will be:

$$m\lambda = d \sin \theta$$

Where m is the order of interference, λ is the wavelength, d is the distance between the centre of each slit and θ is the angle that the microwave transmitter makes relative to the normal of the double slit.

Our goal is to find a relationship between m and θ and use it to determine the wavelength.

Begin by obtaining a measurement for d , remembering to measure from the middle of one of the slits to the middle of another.

Q: What is the uncertainty in your measurement of d ?

Next, find as many maxima as you can by looking for the point at which the voltage is highest. For each maxima determine its m value and record the corresponding angle, remembering to include an uncertainty in the angle measurement.

Again using excel plot a graph of $\sin \theta$ (y) against m (x)

Trigonometric functions in Excel use angles in radians. You can easily convert from degrees to radians by using the RADIANS function in excel.

The relationship should be linear. Verify this by using excel to fit a trend line and calculate the gradient

Q: What is the physical meaning of the gradient? i.e. What part of the above equation is it equal too? (Hint: Try to arrange the equation in the form of a straight line, $y = mx + c$)

Q: How can you use the gradient to determine the wavelength?

Q: Does your value for the wavelength agree with the value given on the back of the microwave transmitter within experimental uncertainty? If not, which source of error do you think was responsible?

Q: In what ways could the experiment be improved?

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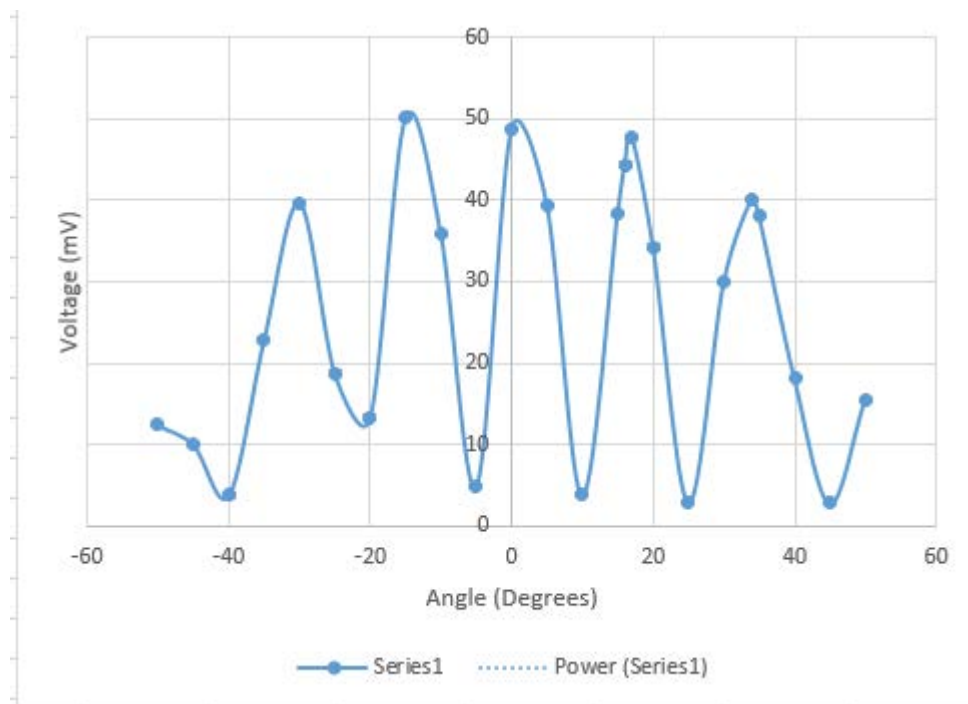
Answers to Double Slit Experiment

Q: Why is a single slit placed before the double slits?

This ensures the light reaching the double slits is coherent and can be treated as two coherent point sources at each slit.

Q: What shape of curve do you expect?

The voltage will peak at points of constructive interference and be near zero at points of destructive interference. The peaks will begin to decrease in magnitude with larger angles due to the decreasing light intensity. A sample graph is shown below:



Q: What is the uncertainty in your measurement of d ?

The uncertainty for a single should be the precision of the instrument. Assuming a ruler is used with mm intervals the uncertainty will be ± 0.1 cm.

Q: What is the physical meaning of the gradient?

If the graph is arranged into $y=mx+c$, then: $y = \sin(\theta)$, $x = m$ (order of interference), which means:

$$\sin(\theta) = m \times \lambda/d$$

$$\text{Therefore, } m \text{ (gradient)} = \lambda/d$$

Q: How can you use the gradient to determine the wavelength?

Multiply the obtained gradient by the measured value for d

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Q: Does your value for the wavelength agree with the value given on the back of the microwave transmitter within experimental uncertainty? If not, which source of error do you think was responsible?

The largest source of error probably originates from the difficulty of finding the angles at which the voltage is truly the highest due to moving the transmitter by hand. Also, the protractor used to measure the angles is not the most precise so the error in the angle could also contribute.

Q: In what ways could the experiment be improved?

Exploit a more stable way of changing the angle of the transmitter to allow more precision and also use a measuring instrument with smaller increments eg by the use of angular micrometre screws, which would allow for greater precision in movement and measurement.

Lab in a Box – Microwave Interferometer

Risk Assessment

Task: Laboratory demonstrations of 3cm Microwave experiment			
Department	Physics	Assessment ID	
Assessor	Phil Furneaux	Date of assessment	20-10-16
Authorised by		Review date	

Step 1 List significant hazards	Step 2 who might be harmed	Step 3 determine appropriate controls	Step 4 make it happen
Electric shock From the plug to the power supply	Person setting up experiment	Do not turn on plug switch until plus is safely plugged into socket	procedure
Damage to equipment		The apparatus will only be used under supervision of a demonstrator	supervision
Cut to hands by glass	Experimenter	The sides of the glass will be taped over to cover the sharp edges	Check equipment before use
Burn from hot microwave generator	Experimenter	Set up experiment as instructed and do not touch the microwave generator once it is turned on	procedure