

TITLE: Interferometry: The Michelson Interferometer

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Summary:

The lesson begins with a demonstration introducing students to interference fringes formed by a layer of air between two pieces of glass. After formal lecture on the concept of interference, students begin to use the concept by building/modeling a Michelson Interference by following a model given all necessary materials.

Engineering Connection

Interferometry is used in communications, medical imaging, astronomy, and structural measurement. With the use of an interferometer engineers and scientists are able to complete surface inspections of micro machined surfaces and semiconductors. Medical technicians are able to give more **concise** diagnoses with the employ of interferometers in microscopy, spectroscopy, and coherent tomography.

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Grade level: 11-12

Time Required: 100 minutes (2 meetings)

Learning Objectives

Students should be able to demonstrate the following outcomes:

- Identify the main components of a Michelson interferometer and their relative positions in the device
- Draw the paths that light follows through a Michelson interferometer.
- Define and identify interference pattern and explain how an interference pattern forms in an interferometer.
- Describe what will happen to the interference pattern when a mirror is moved.

Connections to Science Standards

National Science Education Standard Content Standard A-Science as Inquiry ABILITIES NECESSARY TO DO SCIENTIFIC INQUIRY

- **IDENTIFY QUESTIONS AND CONCEPTS THAT GUIDE SCIENTIFIC INVESTIGATIONS.** Students should formulate a testable hypothesis and demonstrate the logical connections between the scientific concepts guiding a hypothesis and the design of an experiment. They should demonstrate appropriate procedures, a knowledge base, and conceptual understanding of scientific investigations.
- **DESIGN AND CONDUCT SCIENTIFIC INVESTIGATIONS.** Designing and conducting a scientific investigation requires introduction to the major concepts in the area being investigated, proper equipment, safety precautions, assistance with methodological problems, recommendations for use of technologies, clarification of ideas that guide the inquiry, and scientific knowledge obtained from sources other than the actual investigation. The investigation may also require student clarification of the question, method, controls, and variables; student organization and display of data; student revision of methods and explanations; and a public presentation of the results with a critical response from peers. Regardless of the scientific investigation performed, students must use evidence, apply logic, and construct an argument for their proposed explanations.
- **USE TECHNOLOGY AND MATHEMATICS TO IMPROVE INVESTIGATIONS AND COMMUNICATIONS.** A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. The use of computers for the collection, analysis, and display of data is also a part of this standard. Mathematics plays an essential role in all aspects of an inquiry. For example, measurement is used for posing questions, formulas are used for developing explanations, and charts and graphs are used for communicating results.
- **FORMULATE AND REVISE SCIENTIFIC EXPLANATIONS AND MODELS USING LOGIC AND EVIDENCE.** Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation.
- **RECOGNIZE AND ANALYZE ALTERNATIVE EXPLANATIONS AND MODELS.** This aspect of the standard emphasizes the critical abilities of analyzing an argument by reviewing current scientific understanding, weighing the evidence, and examining the logic so as to decide which explanations and models are best. In other words, although there may be several plausible explanations, they do not all have equal weight. Students should be able to use scientific criteria to find the preferred explanations.
- **COMMUNICATE AND DEFEND A SCIENTIFIC ARGUMENT.** Students in school science programs should develop the abilities associated with accurate and effective communication. These include writing and following procedures, expressing concepts, reviewing information, summarizing data, using language appropriately, developing diagrams and charts, explaining statistical analysis, speaking clearly and logically, constructing a reasoned argument, and responding appropriately to critical comments.

Connections to Science Themes and Concepts

The activity connects to these aspects of physical science:

- Properties and behavior of waves
- Interferometry
- The use and building of models in scientific investigation

Introduction/Motivation

Interferometers allow students to watch the constructive and destructive interference of light. However the interference pattern itself is a black box since the eye cannot recognize individual crests of light waves. A model of an interference pattern will give students a way to penetrate the black box by visualizing the formation of interference fringes.

Demonstration: Interference Fringes

Theory

When light of a single color (or wavelength) passes through the layer of air between two flat pieces of glass, part of the light is reflected by the glass-to-air boundary and part is reflected from the air-to-glass boundary. If the difference in the paths of the two rays is equal to a multiple of whole wavelengths, the light amplitude will add to form a bright band. The dark bands are formed by rays that cancel each other. A good source of light that has some single colors is a fluorescent light. The light looks white to your eyes even though it contains a bright green component caused by the mercury vapor in the tube.

Materials

- 2 glass flats (glass microscope slides)
- sheet of black construction paper
- a light source such as an overhead fluorescent light

Procedure

1. Stack the two glass flats one on top of the other. Put the flats on the black construction paper or cardboard provided. Place the flats under a fluorescent light.
2. View the flats at an angle so the fluorescent light can be seen in the reflection as shown below. Observe the interference fringes. They will appear as contour lines or concentric rings that are somewhat irregular.
3. Press on the glass flats with your finger and observe the effect on the interference fringes.

Observations, Data and Conclusion

1. Were you able to observe the interference fringes? What did they look like?
2. What happens when the glass flats are pressed?

Background (For Teacher)

Interferometry is the technique of diagnosing the properties of two or more waves by studying the pattern of interference created by their superposition. The instrument used to interfere the waves together is called an interferometer. Interferometry is an important investigative technique in the fields of astronomy, fiber optics engineering metrology, optical metrology, oceanography, seismology, quantum mechanics, nuclear and particle physics, plasma physics, optical coherence tomography and remote sensing.

An idealized interferometric determination of wavelength obtained by looking at interference fringes two coherent recombined after traveling different distances. (The source is symbolized as a light bulb, but actually is a laser)

Typically a single incoming beam of coherent light will be split into two identical beams by a grating or a partial mirror. Each of these beams will travel a different route, called a path, until they are recombined before arriving at a detector. The path difference, the difference in the distance traveled by each beam, creates a phase difference between them. It is this introduced phase difference that creates the interference pattern between the initially identical waves. If a single beam has been split along two paths then the phase difference is diagnostic of anything that changes the phase along the paths. This could be a physical change in the path length itself or a change in the refractive index along the path.

Vocabulary

Interferometer, Interferometry, Michelson Interferometer Model, Interference, Interference fringes , Wavelength, Coherent light,

Guidance for Teachers

When engaging students in the activity itself, teachers must prepare to deal with questions about manipulating the interferometer. Teacher may show a video of how to design a Michelson Interferometer before students build their own. (See external links). Safety is extremely important when dealing with lasers for these activities.

Experiment 1: Building a Michelson Interferometer

Purpose

Interferometers are basic optical tools used to precisely measure wavelength, distance, index of refraction, and temporal coherence of optical beams. We will construct a Michelson interferometer, study the fringe patterns resulting from both a point source and a parallel beam.

One strategy for this activity involves building a permanent set of simulators that could be stored and re-used. Students could build the permanent model by following the directions below if the teacher has gathered the supplies. Another strategy asks students to build a quick temporary simulator on their desktops as they launch the activity. There are many possible

modifications of this activity; you might find alternate construction materials that perform successfully.

Materials list:

Aluminum Breadboard 12"X18"X1/2", 1/4"-20	1
50:50 Non-polarizing Beam Splitter cube (20MM)	1
Kinematic Mirror Mount	3
ø 1/2" (ø 12.7 MM) Protected Silver Mirror ,0.24" (6.0 mm) thick	3
Mirror Holder for 1/2"	3
Pedestal Base Adapter	6
Small Clamping Fork 1.25"	6
ø 1/2" X 2" Post	6
200-1100 Fixed Grain , 150 MHz, SiDetector, 120 VAC	1
Rectangular Continuously Variable ND Filter, 25 x 100mm, D: 0.04 - 2.0	1
FH2 - Filter holder for 2" Square Filters, Stackable	1
Filter holder for 2" Square Filters, Stackable	1
HeNe Lab Laser	1

Note: Materials maybe bought at ThorLabs (See Catalogue)

Outline of the Experiment

The Michelson Interferometer represents a device that takes advantage of the Wave Nature of Light. If light were not to be considered a wave, none of the observed interference patterns could occur in experiments as they do. In this section, how light can interact and interfere with itself to produce these fringes and patterns characteristic those of waves is described. (Figure 1 below for a model)

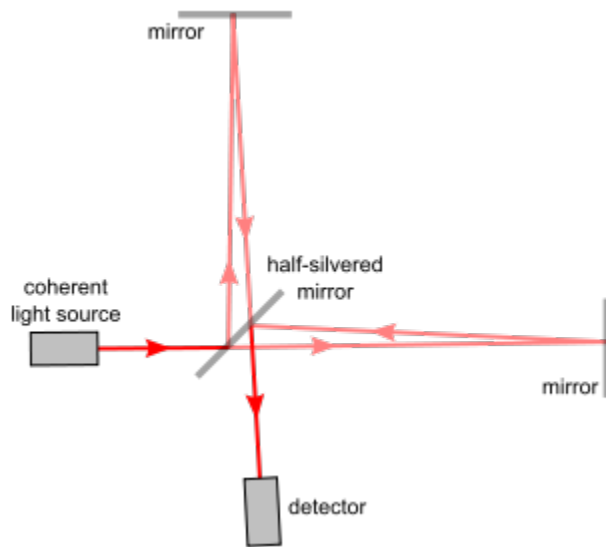


Fig. 1: Michelson interferometer.

1. Preliminary
 - a. Identify the new optical and mechanical components you will use.
 - b. Be sure that you understand the precautions to be taken with lasers, mirrors and beam splitters.
2. Set up the Michelson interferometer (See Figure 2 below (one that I have assembled) and follow Michelson Interferometer model)
 - a. Mount the laser on the optical table with the beam parallel to the table surface at a height of 6-1/4".
 - b. The moveable mirror will be the one in the direct path of the laser beam. Mount this mirror on the board.
 - c. Adjust the optical paths to be equal to a few millimeters, with about 6 cm from the beam splitter to each mirror.
 - d. Align the mirrors using the laser beam.
 - e. We beam light into the entrance of the interferometer from some light source. The light is split into two bundles on a beam-splitting plate (half-silvered mirror). One bundle hits the mirror M1 and the other the mirror M2. The bundles will reflect back in themselves at these mirrors and reunite at the beam-splitting plate. The respective bundles are split into two further bundles due to the characteristics of the beam-splitting plate and one bundle is led in the direction of an exit (a photo detector).
3. Adjust, manipulate and play with the mirrors now to observe interference fringes. (See Figure 3 for sample interference fringes)



Figure 2: Sample Michelson Interferometer Using Permanent Materials that I have assembled

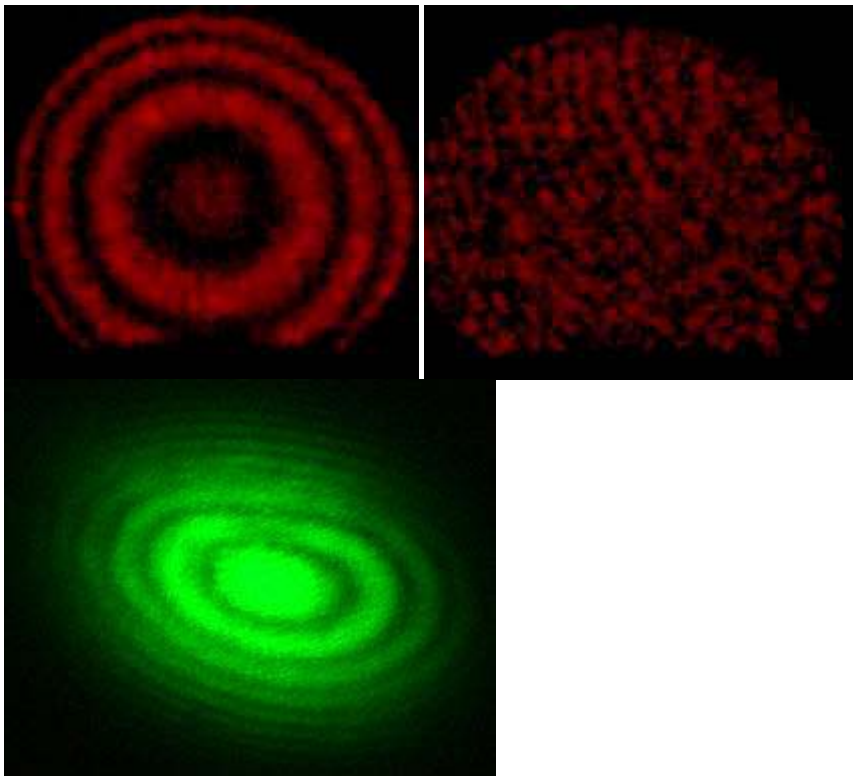


Figure 3: Pictures of fringes, both hyperbolic and circular in nature, as predicted by the theory discussed earlier that could be observed from this experiment. Interference pattern produced with a Michelson interferometer. Bright bands are the result of **constructive interference** while the dark bands are the result of **destructive interference**.

Assessment

1. Summarize what you have learned in this activity.
2. Explain how an interference pattern forms in an interferometer. Draw the interference patterns that you observed.
3. Make a diagram of the Michelson Interferometer that you built, draw arrows to show the paths that you think the laser light will follow through the interferometer. Remember that the beam splitter will split the light from the laser into two paths. Since there is more than one light path, you may want to use more than one color for your arrows.

External links

- [Diagrams of Michelson interferometers](#) (Accesses July 13, 2010)
<http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/michel.html>
- [Video of Michelson interferometer in action](#) (Accessed July 13 , 2010)
http://www.youtube.com/results?search_query=Video+of+Michelson+interferometer+in+action&aq=f
- Extended Michelson-Morley Interferometer experiment (Accessed July 13, 2010)
<http://www.youtube.com/watch?v=7T0d7...eature=related>

References

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<http://repairfaq.ece.drexel.edu/sam/MEOS/EXP10.pdf>

Michelson interferometer - Wikipedia, the free encyclopedia (Accessed July 10, 2010)
en.wikipedia.org/wiki/Michelson_interferometer

Interference (wave propagation) From Wikipedia, the free encyclopedia (Accessed July 12, 2010) en.wikipedia.org/wiki/Interference

The Michelson Interferometer. (Accessed July 12,2010)
www.phy.davidson.edu/stuhome/cabell_f/.../pages/Michelson.htm

National Science Resource Center (Accessed July 10, 2010)

<http://www.nsrconline.org/>

