John B. Johnston, The Faraday Center, 103 Creamery Rd., Livingston Manor, NY 12758
(845) 439 - 4706

Interference and two historic discoveries - In the 1960's, two national high school physics curriculums were developed to boost enrollment, PSSC by M.I.T. and HPP by Harvard. Each program developed new, innovative laboratory exercises and demonstrations that eventually benefited <u>all</u> high school programs. Two of these important demos, one from each program, are described below.

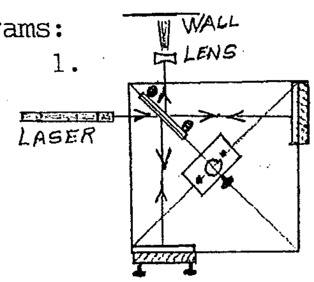
A. The Michelson interferometer from PSSC uses reflection and interference. If sound waves needed a medium, a substance, to travel through, didn't light waves need something similar for their transmission? Before 1887, it was widely believed that they did and it was an invisible (mysterious?) substance called "aether". The resulting "ether theory" suggested that the ether was universal and drifted through space like a current or wind. However, many scientists remained skeptical; there was no evidence of such a substance. In 1887, the team of Albert Michelson and Edward Morley decided to investigate the problem. Michelson created an ingenious device, the interferometer, that utilized the interference of waves to form interference patterns that could be studied.

How does the interferometer work (1.)? It "splits" one beam into two parts (beams) via a "beam splitter" (partial, two-way mirror), reflects them off of front surface mirrors, and then recombines them on a screen. When the two beams recombine (interact), they interfere and form interference patterns (fringes) on a screen (wall?). If any path length is altered, the fringes will shift their positions. (The path length can easily be affected by changing the density of the air near a mirror, e.g., by clapping your hands; the fringes will shift as a result.) The interferometer is a very sensitive instrument; when the scientists rotated the apparatus at different angles, they found no "drift" or change in the fringe patterns. They concluded that no ether was present and that light and its electromagnetic wave relatives actually preferred empty space; the "ether theory" perished. For his many contributions to the knowledge of light, Michelson became America's first physics Nobel laureate in 1907.

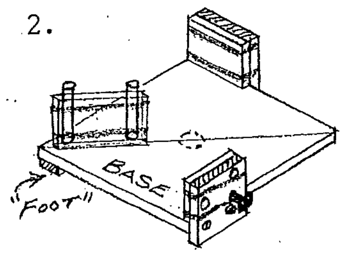
The PSSC interferometer's simple design makes the device easy to replicate. The materials required are some 3/4" plywood, $\frac{1}{2}$" plywood (pine?), $\frac{1}{4}$" dowel, four #6 x $1\frac{1}{4}$" coarse thread drywall screws, three $\frac{1}{4}$" x 20 x 1" thumb screws, two front surface mirrors, one beam splitter, six rubberbands, a diverging lens, a screen (wall?), and a laser pointer. All three mirrors are 3" x 2".

Diagrams:

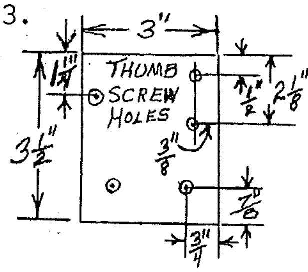
1.



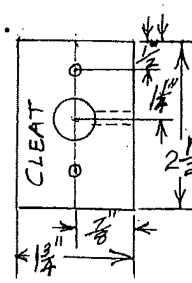
2.



3.



4.



Construction: Cut out an 8" sq. base from the 3/4" plywood (2.). Cut out two $3\frac{1}{2}$" x 3" mirror holders from $\frac{1}{2}$" plywood or pine. Cut two $\frac{1}{4}$" dowels 3" long. Drill $\frac{1}{4}$" holes in the base for the dowels (all the way through). Drill three holes, 15/64" dia. for plywood <u>or</u> 13/64" for pine, in one mirror holder for the "self-threading" thumb screws (3.).

Decision time! Do you want to use the apparatus on a tabletop <u>or</u> attach it to a ringstand for easy height adjustment? If it's the latter, you must add a pine cleat (4.) which will hold a thumb screw and have a 17/32" dia. hole in the center of the base (with cleat) for the $\frac{1}{2}$" dia. ringstand rod. A 13/64" dia. hole will be needed in the side of the pine cleat for the thumb (set) screw. Another $\frac{1}{4}$" x 20 x 1" thumb screw and the 3/4" pine block should be added to the "materials" list.

Assemble the parts as pictured in (1.) and (2.). With the base on the table, add some glue (Elmer's?) to the two dowels, and press (hammer?) them in. With the base on a $\frac{1}{2}$" piece of scrap, attach the mirror holders on the sides with the drywall screws. Glue a small $\frac{1}{2}$" piece underneath as a third "foot" on the other corner. If you decide to add the pine cleat, follow the diagram (1.) for placement. <u>Attach</u> the cleat with #6 x $1\frac{1}{4}$" drywall screws, <u>then</u> drill the 17/32" dia. center hole. <u>Detach</u> the cleat and carefully drill the 13/64"dia. thumb screw hole; "thread" the hole with the thumb screw. A little soap or paste wax on the screw's threads helps. However, if the task gets a little too difficult, use a $\frac{1}{4}$" x 20 tap, but only part way in. (Taps usually tear out too much material, leaving a loose fit. Practice on some scrap pine first.)

Presentation: Attach the mirrors and beam splitter with rubberbands. Aim the laser at the beam splitter and adjust, with the thumb screws, the other mirror until the two beams on the screen overlap. Insert the diverging lens to enlarge the fringe patterns. As a result of reflection and interference, you have repeated history; however, the use of the laser as a light source makes it much easier!

B. The Crick-Watson investigation of DNA used diffraction and interference. In 1953, after decades of study by many researchers, especially in the areas of x-ray crystallography and molecular biology, the team of Francis Crick and James Watson arrived at an explanation of DNA's structure, that it was a double helix, a "twisted ladder". It was revealed via x-ray diffraction that produced an X - shaped interference pattern.

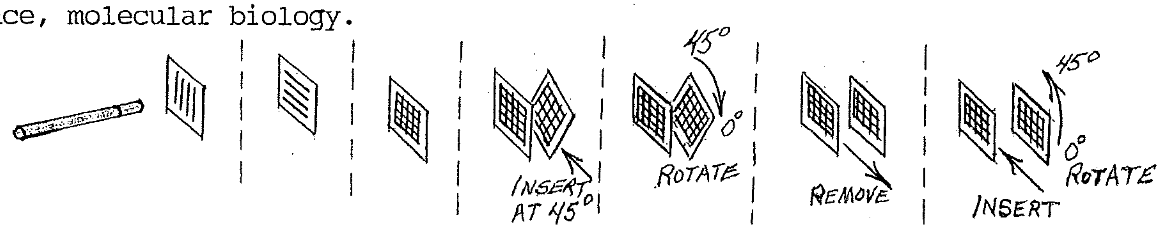
Around 1970, HPP had an apparatus company (Damon) marketing fine screens (very small wires and spaces in an alum. frame) that could act like crystals; a "molecule" would be present where the wires in the screen crossed each other. A laser could act like an x-ray source. Together the laser and screen could produce interference patterns similar to those produced by x-rays acting on molecules in a crystal. A reasonable simulation for students became available, an end view, looking down the axis of rotation of the double helix.

The screens came in three "sizes", 250, 500, and 1000 wires (lines?) per inch. The screens, like photo slides, could be placed in holders (wooden?) and/or handheld while demonstrating. In reality, the screens were another form of diffraction grating only in 2-D, so the same equations for regular gratings still applied.

Presentation: For this demo, a well-darkened room and a red laser beam are recommended. If possible, choose the finer two screens, 500 and 1000 wires (lines) per inch. Begin (5.) by showing the students the horizontal pattern from a regular grating, followed by the vertical pattern from a rotated (90°) grating. Now show them the pattern from one of the screens with the horizontal and vertical patterns combined. Stop! Turn off the laser. At this point, without the students knowing it, slip in the second screen, rotated at 45° relative to the first screen; keep it hidden. Turn the laser back on and observe the new pattern. Can the students figure out ("see") the two patterns that are present? If they can, they are Nobel Prize winners like Crick and Watson! Now slowly rotate the second screen back to 0° (parallel) with the first screen. Do the students get the picture yet? Remove the first screen so they can see the pattern of the second screen.

Put the first screen back in place, and slowly rotate the second screen back to its original 45° position. Do the students begin to understand the "twist" of the helix and how it was discovered? Of course, the DNA investigation was far more complicated than this simple demo suggests, but it does offer a small "window" into the original thinking involved. In this case, diffraction and interference were very useful "tools" in advancing a whole new science, molecular biology.

5.



Clarification: The "beam splitter" in A. is part reflector (mirror), part transmitter (transparency). It does so by having small (empty) spaces between opaque spots, usually as a result of "sputtering", the application of a microscopic coating on glass with a reflective (metallic) material. The opaque, metallic spots do the reflecting (in both directions) and the small, in-between (empty) spaces do the transmitting. Be aware that the glass companies do not use the term "beam splitter" as physics people do. Instead, they use terms like "two-way mirror", "mirrorpane", etc. The edges of the glass will be "clean cut" and "seamed" so you won't get cut. Expect the cost of the "beam splitter" (special order?) to be much more expensive than the front surface mirrors that they usually have on hand.

Also in A., as might be expected, the interference (fringe) patterns are much clearer (more distinct) if a quality gas laser is used. Experiment.