



# LIGO

**Laser Interferometer  
Gravitational-Wave Observatory**  
Supported by the National Science Foundation  
Operated by Caltech and MIT

## Interferometer Build (inexpensive)

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**Grade(s): HS, 10-12**

**Subject Areas: Physics**

**Topic: Waves, Interference, Light**

**Time Length: 90 minutes**

**Standards:**

**HS-PS4-3.** Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.

**HS-PS4-5.** Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

**Objective:**

- **Students will build a device that demonstrates wave interference between two light beams.**

**Safety Considerations: Eye damage due to laser light.**

**Materials:** Laser pointer (class 2 or 3a), 2 blocks (2-3 cm), 4 clothespins, Poster tac (two small pieces), 4 small pieces double-stick tape, 1 coverslip or microscope slide, 1 expander lens (plano-convex), 2 2 cm first surface mirrors, ruler, protractor or 90 degree edge, pencil/pen and cardstock or paper, manila folders to eliminate light bleed, index cards

**LIGO's Connection:** LIGO uses an interferometer (with 4km long arms) to detect gravitational waves.

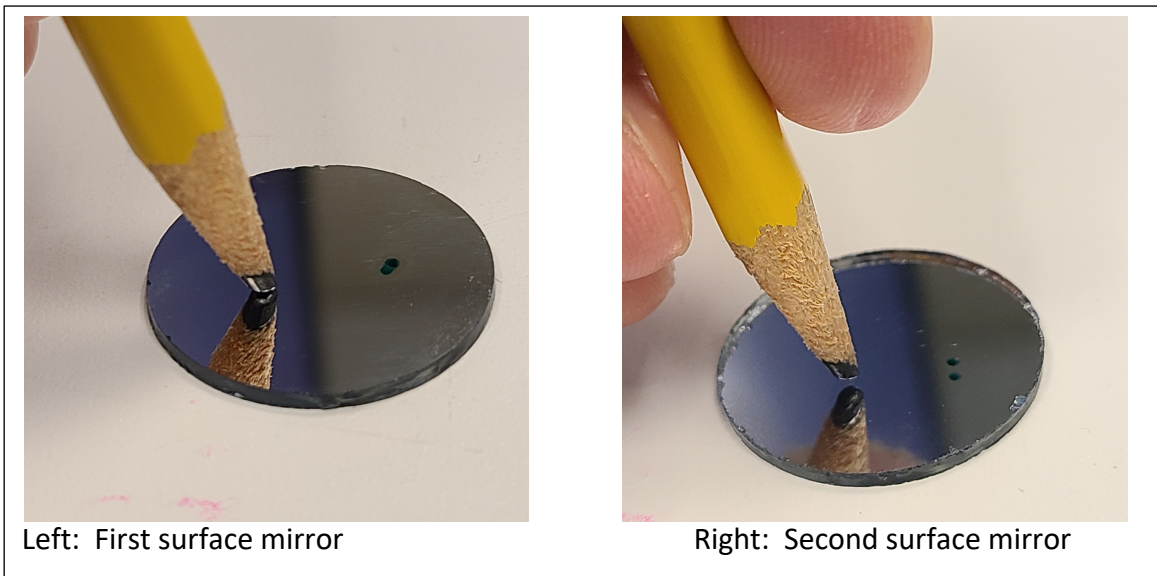
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**Prerequisites:** Prior to using the lasers, students should be taught about laser safety. A simple laser safety video is put out by the US FDA: [https://youtu.be/FPPnFg\\_ujJI](https://youtu.be/FPPnFg_ujJI)

**Advanced Preparation:** First surface mirrors generally come protected, and this protective coating may need to be removed

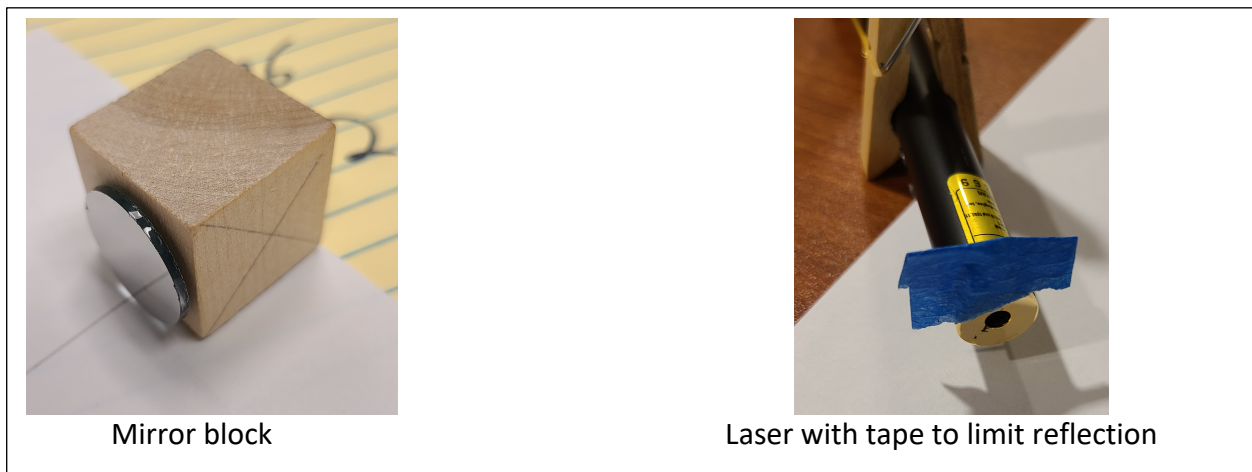
### Activity:

**Identify mirror sides (if the mirrors are 2-sided) and create mirror blocks:** Have students explore the two sides of the mirror. Ask them if they notice anything different. Tell them to gently place their soft-leaded pencil up to the mirror and look at it from various angles. And/or have them put a small dot on the mirror with a transparency (overhead) marker and look at the dot from various angles. The first surface mirror reflects from the surface itself, meaning the pencil tips seem to touch each other when viewed at any angle. The second surface mirror has a piece of transparent material (typically glass) over the reflective surface, so it will create visible gaps between the two pencil tips when viewed at angles of 45 degrees from the mirror's surface. Similarly when an overhead transparency dot is placed on the mirror, one dot will appear on the first surface mirror, while two overlapping dots will appear on the second surface mirror when viewed at angles of 45 degrees from the mirror's surface.



Use a piece of poster tack to stick the second surface side of the mirror to a block (so that the first surface side is the side showing a reflection). Do this for both mirrors. Next, Using a ruler draw a line from corner to corner across the center of one side of each mirror block to form an X. This forms a target for lining up your laser.

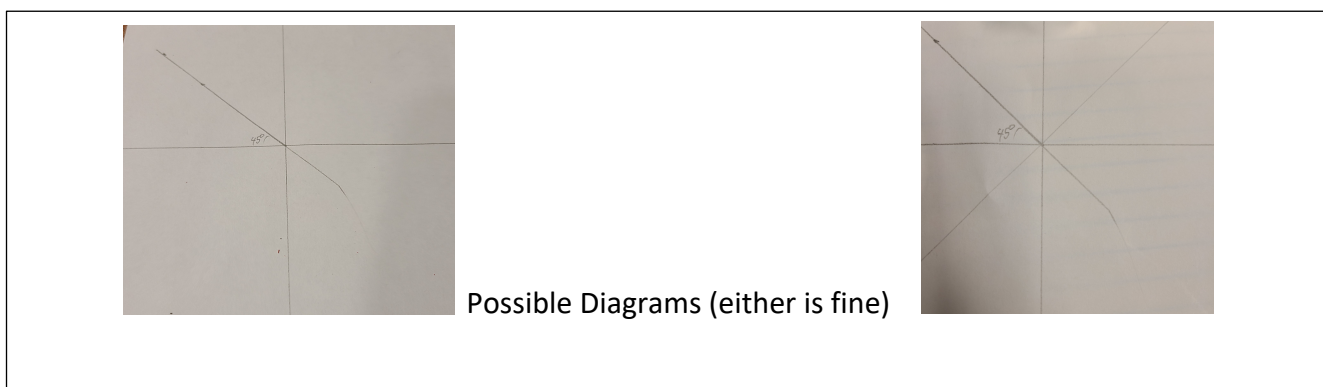
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**Setting up for Safety:** Have the students put manilla folders up around the  $\frac{3}{4}$  the perimeter of the table to help ensure stray laser light won't go out into another person's area. Cover the areas except where the students will be. Have several index cards available to trace and block laser light.

Optional, but recommended: add a small piece of masking tape to the top of the laser to block upwards reflection off the front of the laser. When looking at the laser light, always view the paths from the side so as to ensure that the laser light does not hit you in the eye. Use a lower power laser – class 2 (or II) works, though you can go up to a class 3r or class IIIa (these classes have changed designation over time, but for our purposes IIIa = 3a = 3r).

**Making a Diagram and Plan:** Laser light goes straight, so students will draw a straight line on a piece of paper the long way (the 11" direction), about 7-10 cm in from one side. We want to split the laser light so it goes perpendicular, to the first laser path, so students should put another line the short way, about 7-10 cm in from the top. In order to split this we will need to put a lens in to split it at a



45 degree angle. Draw a line at a 45 degree angle to either of your two lines (it doesn't matter which

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direction the line goes – up to the right or left, except this will determine which direction you need to put the second mirror. If you specifically want the option of sending laser light either way, then have the students draw two 45 degree lines. Have students make a prediction as to which way the laser light will go when travelling from the bottom up to the 45 degree line.

**Aiming the first arm:** Students should line the laser along the long line, and put the side of the mirror block with an x on it facing the line, so when the laser gets activated it hits the side of the block.

Turn the laser on and check alignment. The laser should be hitting somewhere near the center of the X. This is not critical, but it should NOT be hitting the table or going above the block – since this would indicate a major vertical alignment issue. Turn off the laser. Now rotate the block so the mirror is facing the laser. Put an index card behind the laser, move to the side and turn on the laser. The laser beam should be roughly coming right back to the laser itself. If the laser is not heading back towards the laser, hold the block and push the edge of the mirror and see how the laser beam path changes. Adjust the mirror.

**Adjusting the mirror:** By pushing on different edges of the mirror to get the laser to come back towards the original laser (at this point, you should mainly be concerned with whether the laser is hitting the ground or going above the laser). Every time you press the mirror you may notice that the beam comes back a bit, as the poster tack stretches, then returns back towards its original position.

Turn the laser off, and rotate the block back so the X would be hit by the laser. *With LIGO we “lock” each arm so that the laser is fully aligned, then we try to “lock” the whole interferometer. Locking an arm means aligning the laser so that the laser beam goes right back to the laser, although for more details on our interferometer see the LIGO related background.*

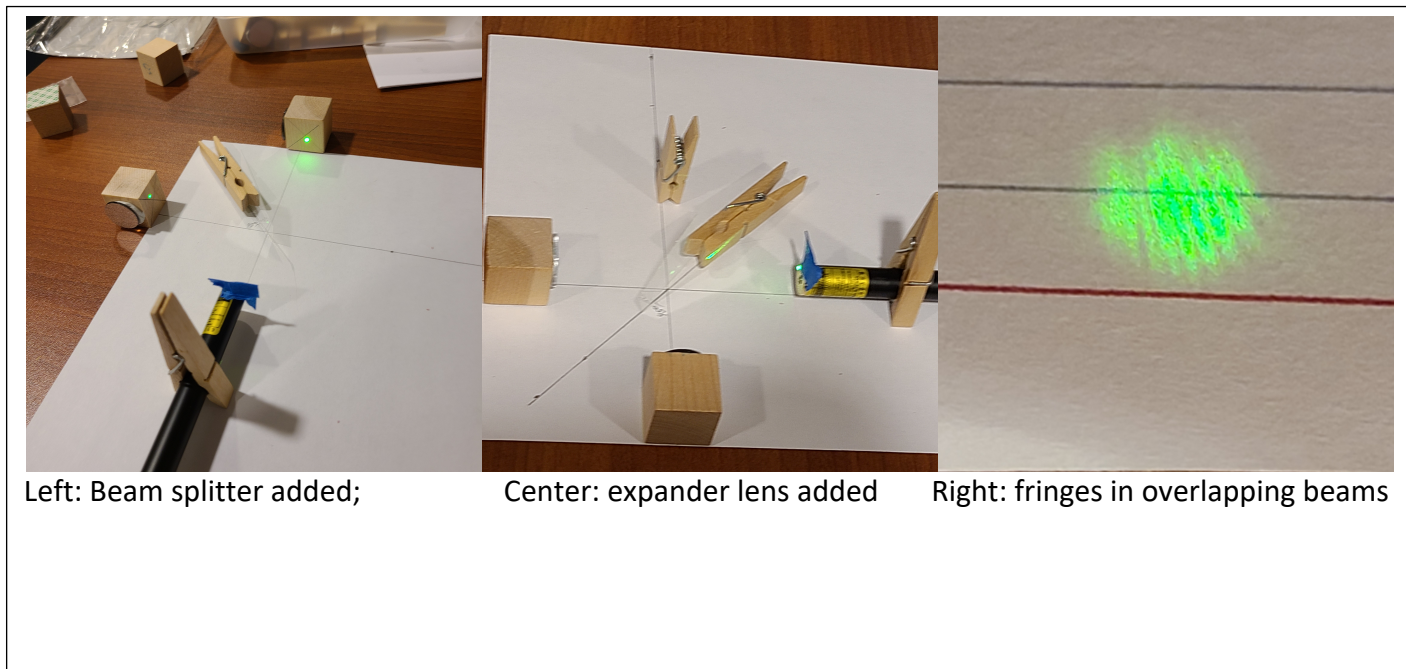
**Aiming the second arm:** Have students put the beam splitter along the 45 degree line, and tell have the students put the X side of the wooden block along the path you think the laser light will take. Put a bent index card or file folder on the opposite side of the beam splitter (the path you think the laser light will not initially take). Students should turn on the laser temporarily to check to see if they were correct. If incorrect, move the block to the correct spot. If correct, the laser should be hitting



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somewhere near the center of the X. This is not critical, but it should NOT be hitting the table or going above the block – since this would indicate a major vertical alignment issue. Turn off the laser. Now rotate the block so the mirror is facing the laser. Put an index card behind the laser, and turn on the laser. The laser light should be going through and while some will bounce back towards the laser, some should follow go to where the index card or file folder was put – on the other side of the beam splitter. Turn off the laser. If the laser hits the ground or goes too high or falls too much to one side or another adjust the mirror.

**Getting the two laser beams aligned:** Rotate the first arm’s mirror back into place. Now, turn the laser on, and you should see two laser beam dots near each other. By moving the beams splitter slightly you may realign both beams horizontally. You should get the laser beams close to each other. At this point you may want to fix one or both of the mirror blocks down using a piece of double-stick tape. Then realign them.



**Expanding the beams and overlapping for fringes:** When the laser beams are next to each other, aim them through the expander lens (it helps to put the expander lens closer to the beam splitter). This may require either raising the expander lens or adjusting the mirrors. When both beams are through the expander continue adjusting the mirrors until the beams overlap and you see black

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fringes where the beams overlap. Once you see fringes, by pushing the mirror, you should see the fringes shift as the mirror slowly adjusts when the poster-tack pulls it back into position. Every time you press on the table you should see the fringes shift – or the interferometer probably isn't correctly aligned. You may see some interference pattern within a single laser path, but this pattern won't shift readily, unlike the dark fringe pattern when two beams overlap.

**Activity Follow up:** If the air is heated or cooled along one arm, it leads to the interference lines moving.

**Underlying Science:** We are partially aligning the laser beams, and experiencing interference within the laser beam, resulting in maxima (constructive interference where you see bright fringes) and minima (destructive interference where you see dark fringes). If the beams were fully aligned, your interference band would become as wide as the beam. Note that in this interferometer build we are using lower quality optics, which can give you inherent flaws or artifacts in the light beam that make the light beam less uniform. We then blow up the size of the laser beam to see the interference happening as the two beams overlap. As one tunes an interferometer the fringes become bigger and bigger until they encompass the whole beam itself. With our optics and controls this probably won't be possible.

**LIGO Connection:** LIGO is an interferometer, but we are actually an interferometer with arms that have the laser light bouncing around inside of them about 300 times (on average) in the before leaking out. This means there are small differences between what we said above, and our interferometer. For example, we said: *“With LIGO we “lock” each arm so that the laser is fully aligned, then we try to “lock” the whole interferometer. Locking an arm means aligning the laser so that the laser beam goes right back to the laser.”* Yet, since we have additional “resonant cavities,” we get the laser resonating in each cavity. This design is called a Fabry-Perot interferometer, or a Michelson interferometer with Fabry-Perot cavities. Such a design requires adding additional partially silvered mirrors at the beginning of each arm, after the beam splitter. This increases the amount of light power in each arm, which would make it more dangerous to our eyes, and make it harder to get established fringes (it also makes us more sensitive).

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**Resources:**

[Laser Pointer Safety](#)

**Credit:** Created by LIGO Livingston with contributions from the Exploratorium

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