Experiment 9: Holography PHY 431

If waves emanating from coherent sources reach some locations in phase, bright interference fringes can be observed there. If you were to reverse the direction of the coherent waves, these waves, now emanating from fringe locations, would come in phase at the location of original sources, yielding an enhanced light intensity there. This is exploited in holography where fringe patterns produced by coherent light reflected off objects are recorded in thick films. When these fringe patterns are subsequently illuminated with coherent light, they become sources that can produce images of original objects through interference, in a complete reversal of the process of producing the original fringes.

Bring some small, rigid items (keys, toy cars, coins) to use as objects. We will follow a method that has been specifically designed to make holograms in a teaching lab setting. The success rate for the process strongly depends on adhering to laid out procedures. You will use a red diode laser that has a much longer coherence length than the HeNe lasers which can also be used as sources of coherent light. **Q1.** What is the definition of coherence length? How long must it be for the present experiment to work?

You will use photographic plates optimized for 633 nm light. With their narrow sensitivity range, the plates will be affected by the red laser light, but only little by small amount of white light, and even less by a light concentrated in another wavelength region. Each team will receive a darkroom bag with several plates. It is important that the bag be kept closed at all times to avoid fogging of the plates. After pulling one plate, pack the other plates back, ensuring that they are shielded from light. You **do not** need to hand in a hologram with your report. You can keep a hologram as a souvenir instead. However, you should accurately describe your procedures and results.

Each setup has a laser attached to a clip, a battery pack, beam blocks, a lab jack, a mouse pad and a darkroom bag with photographic plates. During the process of producing a hologram all components in use should be placed in sand to minimize vibrations. **Q2.** Why do large vibrations ruin a hologram? You will be making two types of holograms, a reflection hologram, which can be viewed with white light and a transmission hologram which requires a laser for viewing.

Reflection Holograms

A. Place the laser and battery pack in the cup of sand on the lab jack. The diode laser should illuminate horizontal area in the form of large ellipse within a foot or so. Orient the light to illuminate the mouse pad in the sand box. Place small, fairly flat objects on the mouse pad in a 2 inch area.

Make sure these objects can support a glass plate without shifting. Now place the beam block into the sand between the laser and the object. Draw a diagram of how the light will hit the plate. Make sure that the laser stabilizes for at least 5 minutes before making an exposure.

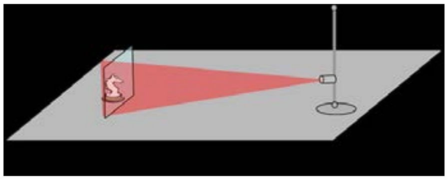
B. Using your body to block any room light, remove a plate from the bag. The emulsion side will feel sticky to a wet finger. Place the plate on the objects with the emulsion side up (towards the laser). When everything is ready, remove the beam block from the sand, but still hold it in place to block the beam for about 10 seconds (this lets all vibrations settle). Unblock the beam for 10 seconds, then put the block back into the sand.

C. A developing setup is arranged, having 5 trays. The image development progresses from left to right – do not move the plates from one tray backwards to an earlier tray. **You must use gloves when developing the plates – the developer and bleach can hurt your skin!** Hold the plate by the sides and agitate slowly in the solutions. Try not to spill!! If the plate sits on the bottom, it may not develop properly. The protocol for development is as follows:

  a. Place the plate in the developer for 30 seconds – the plate will turn black.
  b. Rinse it in the first large tray for 3 minutes.
  c. Bleach for 1 minute – the plate should turn clear.
  d. Wash in the second large tray for 3 minutes.
  e. Rinse in the wetting solution for 30 seconds.
  f. Wipe edges with a Kimwipe to remove large drips.
  g. Place against the wall for a few minutes for drying.

D. You may look at your hologram after development, but the images might not be visible until the hologram is fully dry. To see the hologram, shine a strong white light on the plate and look at it from the <u>same</u> side. You may need to tilt the light and/or the plate until you see the shiny image in the glass. **Q3.** Can you see multicolored stripes in the hologram as well as your object? What is causing this?

E. Now generate a hologram with the laser in the sand box shining horizontally at the object. Place the plate upright a few inches *in front* of the object (to give some depth to the image).

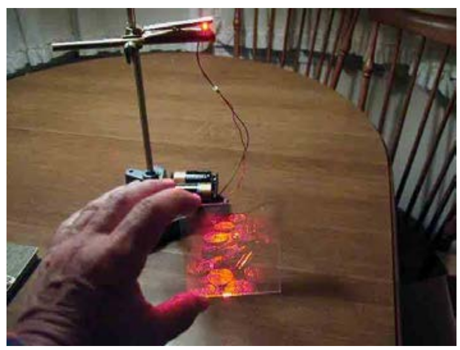


Repeat steps B and C. When distance of an object from the plate increases, it becomes less and less likely for a substantial portion of a fringe surface to be parallel to the plate and the hologram evolves towards a transmission type.

Transmission Holograms

F. Traditional transmission holograms have used a beam splitter to create two separate light paths, one of which is reflected off the object, then recombined on a photographic plate to create an interference pattern. However, a beam splitter is unnecessary as long as some of the light can hit the plate directly. Therefore change your setup so the plate stands vertically *behind* the object in the sand box. Use an old plate to check that your plate and object are both well illuminated by the laser and that the plate receives scattered light from the object. You may have better success by placing the laser back on the lab jack and using fairly flat objects on the mouse pad. *Note: If an object just blocks the light* *reaching the plate, the only recorded image for that object will be the shadow.* Repeat Steps B and C.

G. Transmission holograms are not likely to be viewable until they have fully dried. However you may practice viewing the holograms that were produced on earlier days and have by now dried. To view such a hologram, shine a laser through the plate and look on the opposite side. **Avoid looking directly into the laser!** Alternatively, put the laser and plate back to supposed original positions and look for the image where the object would have been. The remarkable feature of transmission holograms is that they produce complete images after they are broken into pieces and only one piece is used for viewing. Rather than breaking a hologram shield a portion of illuminating light with your fingers and check whether the complete image is still there.



Optional Things to Try:

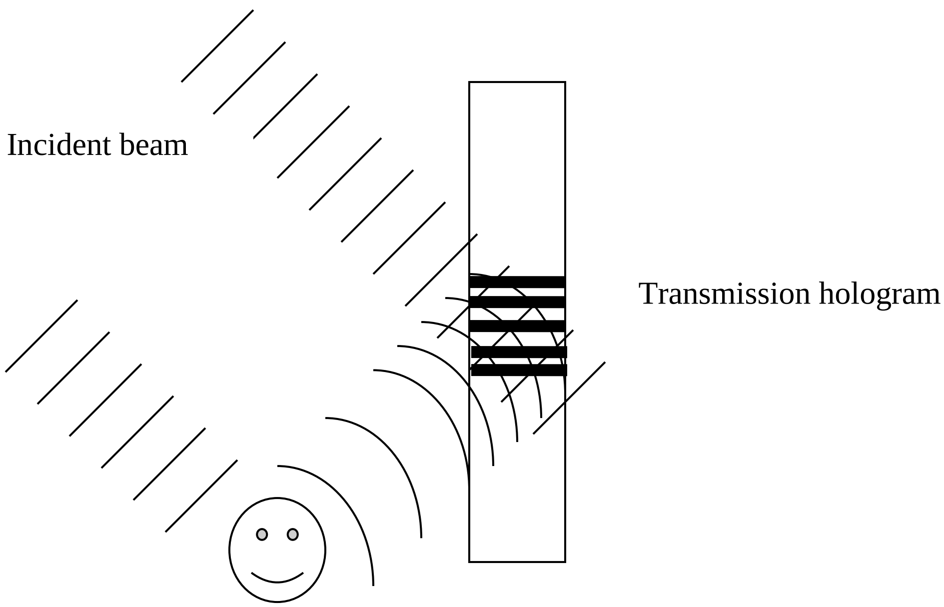
- Try making a hologram with two views of the same object. Expose the plate for 5 seconds in one position. Block the beam and move the plate to another position (make sure it is still in the path of the laser). Expose again for 5 seconds. Develop normally.
- Use a good transmission hologram to project an image, then place an unexposed plate in the middle of the image. Expose and develop normally. Try viewing as a transmission and reflection hologram.

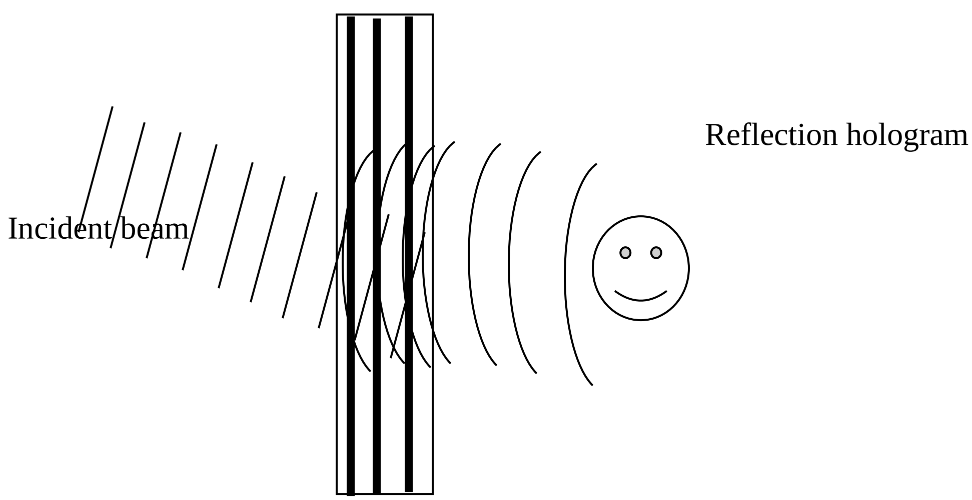
Examine the diagrams in the Appendix to answer the following questions

Q4. Why can transmission holograms be broken up and still make a whole image? Why doesn't this work for reflection holograms?
Q5. Why can reflection holograms be viewed with white light?

Appendix

A hologram is a recorded pattern that results from interference of two coherent beams of light, one of which is reflected from an object. The main difference between reflection and transmission holograms is the orientation of the interference fringes with respect to the photographic plate. In the transmission setup, the fringes tend to lie in planes perpendicular to the plate, while in the reflection setup the fringes tend to lie in planes parallel to the plate. (Note: Since the fringes are never either perfectly perpendicular or parallel to the plates, some features of the holograms do not divide sharply.)





Reflection of light off one of these planes follows the Bragg equation $\lambda = 2d\sin\theta$ where d is the spacing between planes, λ is the wavelength and θ is the angle of incident light for viewing. The emulsion on the plates is much thicker (~7 microns) than the wavelength so multiple planes of fringes are created in the reflection hologram.

For more information on holograms, the following websites are good places to look:

http://nobelprize.org/nobel_prizes/physics/articles/biedermann/index.html
http://www.holokits.com/holography_tutorials.htm