Figure 1. Hologram made in a workshop. Photograph by Tom Sloan

PHOTONICS: The Science of Light

MAKING HOLOGRAMS Workshop:

Holograms for security, advertising, teaching, medicine and art.

Student Workshop (15-18 years).

Information for students:

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1. INTRODUCTION

This workshop is designed to teach you about photonics, holography and light theory. We hope that you enjoy the workshop.

What is Photonics? Photonics is the science and technology of light: making light, controlling it and sensing it. Photonics (like electronics) technologies are found in all of the technologies we use in our daily lives; smartphones, laptops, the internet, medical instruments and lighting. Learning about holography will teach the students the basics of how light works.

Careers with Photonics: There are thousands of different careers which rely on people with knowledge and skills in Photonics. This includes people who work in telecommunications, security, marketing and manufacturing and medicine (including imaging for diagnosing illness and treatment with light, using; scans, laser surgery, radiation therapy or researching how to prevent illness). Photonics applications are helpful to thousands of jobs, but there is a shortage of people with the skills to use them

Please read more about careers with Photonics here: **https://www.optics4kids.org/careers.** (Apologies for the title of the website! It isn't just for 'kids'!)

Please download the free **Photonics4All** App, available from Google Playstore, or download from Apple.

1.1 SAFETY

There are two hazardous aspects of making holograms; the lasers you will be using, and the chemistry that you will need to develop your holograms. Please read the instructions below and work safely.

a. The laser

The laser provided is a red laser diode similar to the type found in barcode scanners, DVD players or laser pointers.[1] Since laser beams tend not to spread out, light from a laser can travel directly into your eye through the pupil and focus to a very small, bright spot on the retina which can damage the eye.
It is therefore very important to:

NEVER LOOK DOWN A LASER BEAM!

NEVER POINT A LASER BEAM AT ANYONE ELSE!

A lens should have been unscrewed and removed from the front of your laser diode; this instantly makes this laser safer as the beam will now spread out as soon as it leaves the laser, lowering the power. Remove the lens if it's still on the laser. Next attach the diode to the battery pack if it hasn't already been done, by fixing the same coloured wires from the diode to the battery pack via the connectors. Secure the wires either with electrical tape or wire shrink wrap to secure the wires to the battery pack.

b. The developing chemistry

There should be three plastic containers for your holographic chemistry: 'Developer A', 'Developer B' and 'Bleach'. These bottles contain a hazardous chemical.

When developing the holograms use gloves, lab coat and safety glasses to protect you against spills and splashes. Follow your instructor's advice for disposing of the chemicals. In the UK we flush excess or spilled chemicals down the sink with running water because such small amounts of chemicals are used.

2. THEORY

This section explains what a hologram is, how it is made, and the science behind the process.

2.1 WHAT IS A HOLOGRAM?

Holograms are three-dimensional (3D) images made with lasers. Holograms are found on bank cards, bank notes, driver's licenses, labels and in displays for art and entertainment; you can even get holographic portraits. Holograms are also used in medicine and research.

[1] Do not try to use any other laser for making holograms though as this laser diode has been specifically designed for making holograms; the beam is linearly polarized and not affected by the diode heating up over time.

Figure 2 overleaf shows a security hologram on a bank card. The hologram is stuck on the card to stop people from trying to fraudulently copy it. Figure 3 shows a hologram made from a 'CT' Scan made from hundreds of X-Ray images of a skeleton inside a mummy. The mummy was covered in bandages and you couldn't see the skull - archaeologists were able to explore the mummy without destroying it. Holograms from scans of live people can be used when planning difficult surgeries. Figure 4 depicts a hologram of a Fabergé Egg designed to be displayed in a Museum, because the egg is too fragile and expensive to transport easily. Figure 5 shows art holograms – holographic portraits mounted in the floor of people looking upward.

Figure 2 A security hologram on a *Visa* debit card

Figure 3 hologram of medical scans of a mummy by the company *View Holographics.*

Figure 4 Hologram of a Fabergé egg by *HIH.*

Figure 5 Holograms by the artist Shu- Min Lin, Venice Biennale, 2015.

2.2 THE SCIENCE BEHIND HOLOGRAPHY

Understanding how a hologram work includes knowing about the following aspects of light theory; a) the electromagnetic spectrum, b) why laser light is special, c) how light interacts with physical objects d) how laser light reacts and e) how is the hologram made? The hologram also needs to be developed and lit to see it. These different aspects are described below:

a) The electromagnetic (EM) spectrum

The EM Spectrum consists of different wavelengths; radio waves, microwaves, infrared, visible light, ultraviolet, X-rays and gamma rays. All these wavelengths of light play an important part in our lives; we use radio, microwaves and infrared for example in telecommunications so we can talk, snapchat, email and see one another from all over the globe; our internet systems relying on infrared lasers to send signals down fibre optics from one computer to another across the web. Astronomers, use ultraviolet light, x-rays and gamma rays and visible light to watch the stars and the planets, and some of the technology they use ends up working in hospitals, enabling medical imaging and cancer treatments. Scientists working with all areas of the EM Spectrum rely on understanding photonics, the science of light. People who use photonics in their careers need to know how to control light waves for different purposes.

b) Why laser light is special

White light (visible light) is composed of multiple wavelengths, or all the colours of the rainbow as shown in figure 6 below, but **laser light** is only made of one colour (i.e. one wavelength) as shown in Figure 7 below. We measure light in nanometers, or billionths of a meter. To understand what sort of distances we are using; 1nm is the amount that your hair or nails grow in 1 second.

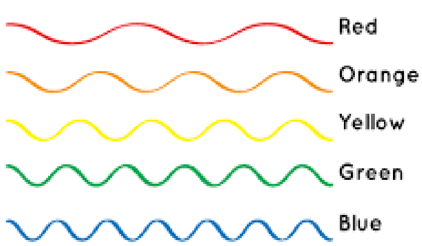


Figure 6 White light

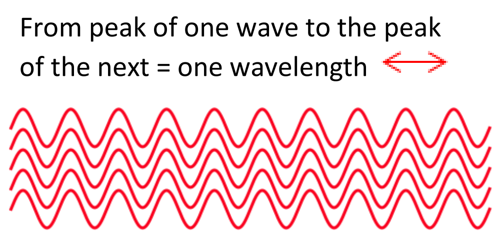
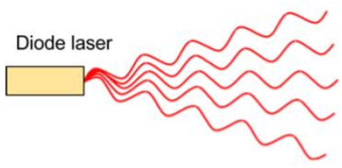


Figure 7 laser light

We will be using a diode laser which gives out red light measuring approximately 650 nanometers (1 nanometer = 0.000000001 meters) to make our holograms. Laser light is also **coherent**, it has the same wavelength and it travels precisely in step, like marching soldiers, whereas light from a torch will be quite random and have multiple wavelengths within it.



Diode laser beams – typically used in laser pointers or DVD players - are elliptically shaped, however a lens on the front of the laser collimates, preventing it from spreading out. However we will use the laser <u>without</u> the lens, i.e. the elliptically shaped, spread beam – see Figure 8.

Figure 8 Laser light from a diode

c. How light interacts with objects

Light reflects and refracts and interferes. Here's a reminder about what students know about light:

Reflection: When light strikes an object some of it will be absorbed and some reflected. Reflection involves a change in direction of light wave and the angle of incidence will be the same as the angle of reflection. This is the law of reflection depicted below in Figure 9.

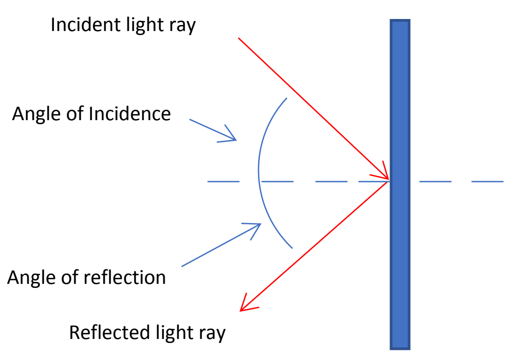


Figure 9 Law of reflection

Refraction: Light bends as it travels from one medium to another. In the case of holography light bends as it travels through the air, and through the glass plate with the holographic emulsion attached to it as shown in figure 10. The **emulsion** is a layer of transparent gelatine containing tiny particles of light-sensitive silver halide.

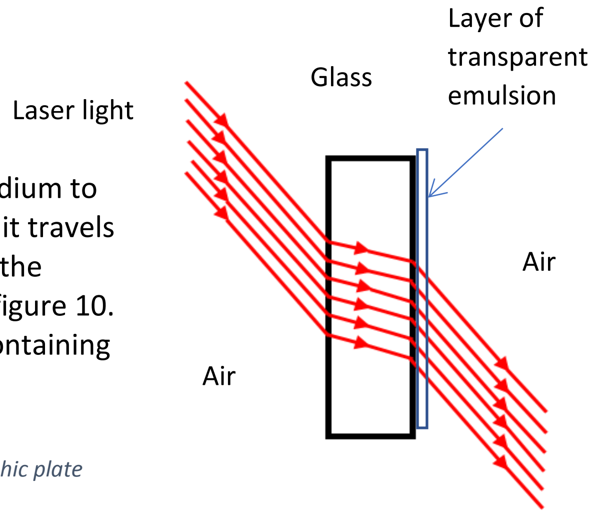


Figure 10 Light refracting through the holographic plate

d) How does laser light interact?

Interference is the phenomenon that occurs when two waves meet while traveling along the same medium. When the crests (upward displacement) or troughs (downward displacement) of the laser light meet we see constructive interference (bright areas of light) and when we have a crest and a trough meeting we see destructive interference (dark areas). An I**nterference pattern** is the overall pattern resulting after two or more sources of light have interfered, this basically shows us how much light we have at a particular point on a surface.

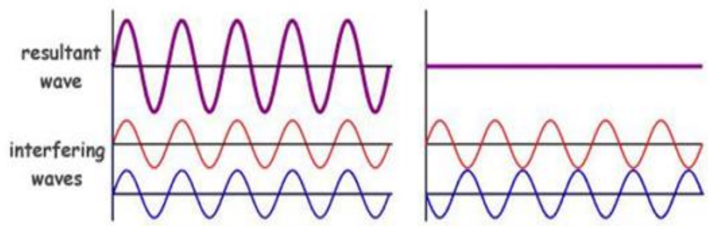


Figure 11. Interference of light

e) How is the hologram made?

The light from the laser travels to the holographic plate, refracts through the glass and emulsion side and then hits the object. This is the reference beam (RED). The objects used will be shiny so the light will be reflected back. This is the object beam (BLUE). The beam reflected from the object will copy the shape of the object and when interfering with the reference beam, the latter will "see" the changes in the object beam due to the object. These two beams will interfere and interact with small particles of silver in the holographic plate causing them to blacken when developed. They will blacken based on how much light they interacted with (we know that the interference pattern has areas with more light –these will be darker – and areas with less light which will appear dark). – See Figure 12.

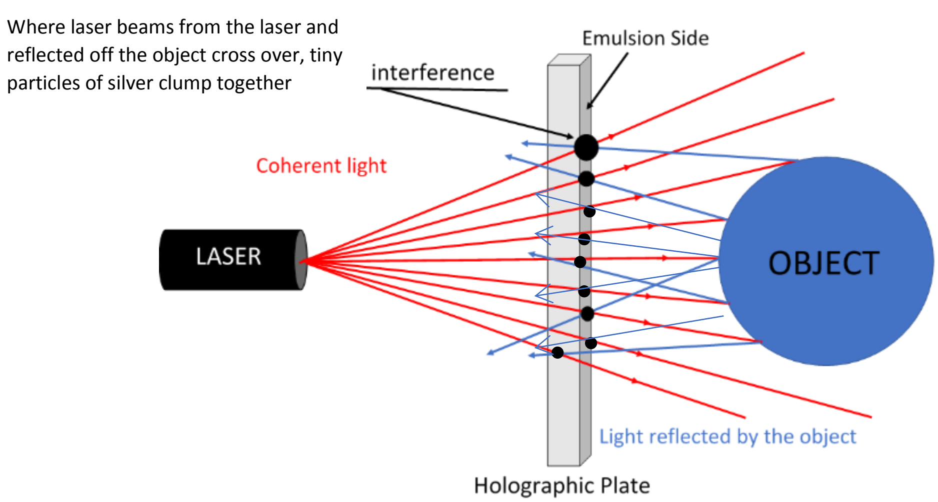


Figure 12. beams from the laser and object beam interacting

During the process of making the hologram – light has to be shone on the object for a set amount of time. This is known as an 'exposure'. The silver in the emulsion reacts to light during that time. Once the hologram has been exposed, then it needs to be developed in trays of chemicals.

e. Developing the hologram

The processing of the hologram is illustrated in figure 11 to the right. The exposed plate is put in a tray full of developer for ten seconds and during that time the particles of silver that reacted to laser light blacken. Some of the particles didn't react to the laser light and they are removed in another tray full of bleach. When the plate is bleached it leaves behind some particles of silver which reflect light and direct light to produce a holographic image.

f. Lighting the hologram

Once a hologram is made, it has to be lit with a beam of light travelling at the same angle that the light first hit the hologram. Light is directed by the tiny particles of silver in the hologram to produce a holographic image which looks just like the image that the light reflected off.

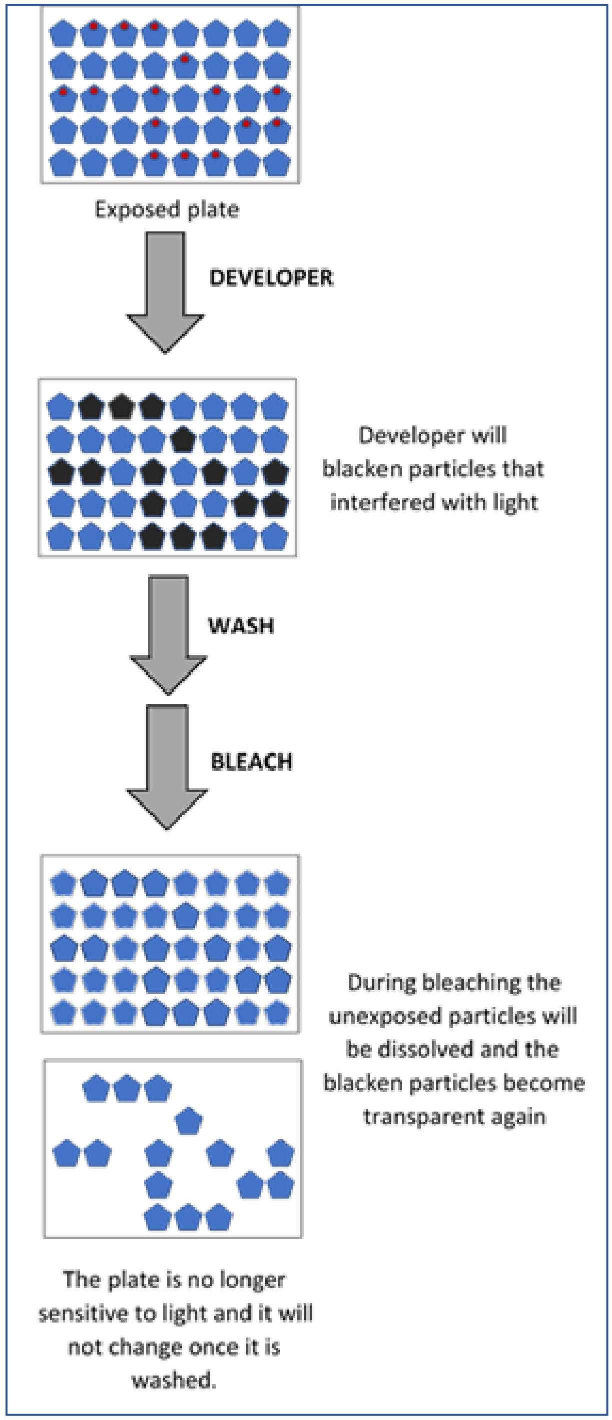


Figure 13 developing the hologram

3. WORKSHOP PREPARATION

There are three elements which need preparation; first, ensuring that the room is darkened. Secondly, prepare the laser set ups and thirdly mix and lay out the chemicals. All three aspects are described below:

a. **Darken the Room**. It is essential to have a darkened room to make holograms in as the holographic plates you will be using are light sensitive. The lab should be darkened, make sure that as little light as possible is coming through windows and doors. You can cover windows with black bin bags and tape.

b. **Holography set up.** The wavelength of light we are using is very small (635nm) which means that any tiny movement in the room while the holograms are being made can change the interference pattern being produced by the laser beam during the exposure and ruin the final image. THE HOLOGRAMS ARE SO SENSITIVE THAT THE FOLLOWING CAN RUIN THEM:

- **Air Conditioning – moving the air**
- **A machine running in another room – vibrating the floor**
- **A car passing by the building – moving the air and floor**
- **A noisy airplane flying past – vibrating the walls and air**
- **A student leaning on a table that the set-up is on – vibrating the table**
- **Students talking in another room – vibrating the air**

To prevent as much vibration as possible, we use sand as a dampening agent in our set-up. Try to make sure that the environment you are setting up in is as quiet as possible. For example, make sure that machinery has been turned off when making holograms, make sure everyone is quiet during the exposure – and that no-one is touching tables, talking or moving their feet or chairs.

c. **Developing set-up.** Make sure you follow the safety advice given by instructors. If you get chemicals on your cloves you may end up with brown spots on your clothes, so use a lab coat, and protect your eyes with safety glasses, use gloves, and wash your hands after using the chemicals.

3.1 HOLOGRAPHY SET-UP

This section describes how to set the equipment up to make a hologram and includes a) a diagram to illustrate the set-up, b) suitable objects to make holograms of, and c) a step-by-step guide to setting up the equipment.

a) The holography set-up

The set-up is shown below in figures 14 & 15. For safety reasons it is preferable to set up the laser in the mug facing away from you, towards the wall.

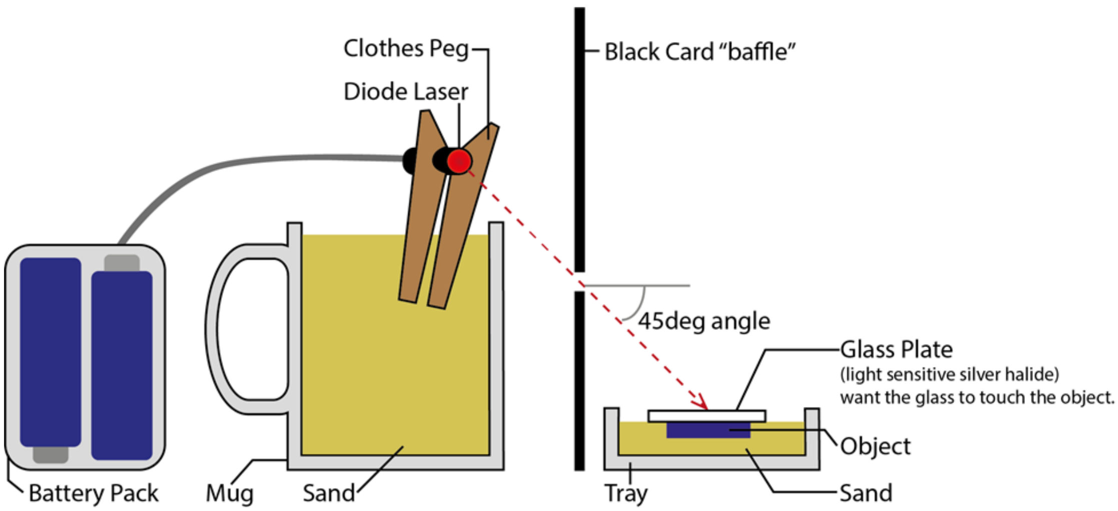


Figure 14. Holography set up –Figure made by Larissa Kunstei.

Your laser is fixed in a clothes peg as shown in figures 14 above and 15 below. The laser should always face away from you towards the wall. Put your object on the sand with the laser shining on your object as shown in figure 16.

Figure 15 set-up of holography equipment

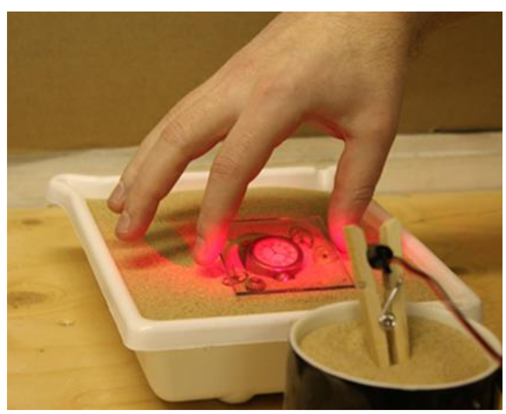


Figure 16 preparing and illuminating objects

Figure 17 suitable objects for holograms

b) Suitable objects

Use small, shiny flat objects to make holograms of with the set-up we are using. Examples are shown above in Figure 17 on the left.

Use an old/exposed plate to design your set-up as shown above in figure 16. Please note that the top of the object must be positioned closest to the on-coming beam, because the final hologram is lit from the same angle at which it was exposed.

c) Step-by-Step Guide to setting up the equipment.

i. Make a firm base for the laser: fill the mug with sand.

ii. Unscrew the lens from the laser and clip a wooden clothes-peg carefully around the diode holding it at the edges. N.B. Don't put your fingers over the front of the laser as you may damage it. Push the peg and laser firmly into the sand.

iii. Make sure that the laser is placed facing away from you so you, or other students cannot accidentally look into the beam. **(It won't hurt you, but may dazzle your eyes temporarily!)**

iv. Place the mug on the table. At approximately 15-20 cm place the tray filled with sand (fill it fully so you will not get any shadow from the edge of the tray).

v. Place the object on the sand. Put the batteries in the laser and turn it on, fully illuminating the object. Reposition the mug with the laser until the object is well lit. (Example shown in Figure 14) Use an old/exposed plate to design your set up.

   Please note that the top of the object must be positioned closest to the on-coming beam, because the final hologram is lit from the same angle at which it was exposed. Once the object is fully illuminated, place a piece of cardboard in the path of the beam between the laser and object.

3.2 DEVELOPING SET UP

On a table in another part of the darkened room there will four developing trays: In the first tray there should be equal amounts from solution A and B developer, (125ml of each solution), in the second tray, distilled water, and in the third tray bleach solution (approximately 400ml) and the last tray there should be more distilled water.

When you are ready to develop the instructor will mix A &B solutions together.

The order of the trays is:

DEVELOPER (A+B) → DISTILLED WATER → BLEACH → DISTILLED WATER

There should be safety glasses, rubber gloves and lab coats for the students who will be developing the holograms.

Plug in a **green** safe light. Make sure that when you start shooting the holograms there are no trip hazards in the room (no boxes or bags on the floor) as the room will be very dark.

4. MAKING YOUR HOLOGRAM:

Making your hologram consists of a process of exposing, or shooting your hologram, developing, drying and lighting the hologram. These different processes are described in detail below.

4.1 HOW TO EXPOSE YOUR HOLOGRAM

WITH THE LIGHTS OFF (90% darkness is OK)

CAUTION! Holographic plates are transported in light-tight boxes. As the holographic emulsion is light sensitive: **Only open the box of holograms in the dark!!!!**

How to handle a hologram: A holographic plate is made of two sides: a glass side and an emulsion one. The emulsion side contains silver particles that interact with light and should **NOT** be touched. This side should be facing the object when we shoot the hologram and facing upward when we develop it (so it doesn't get scratched).

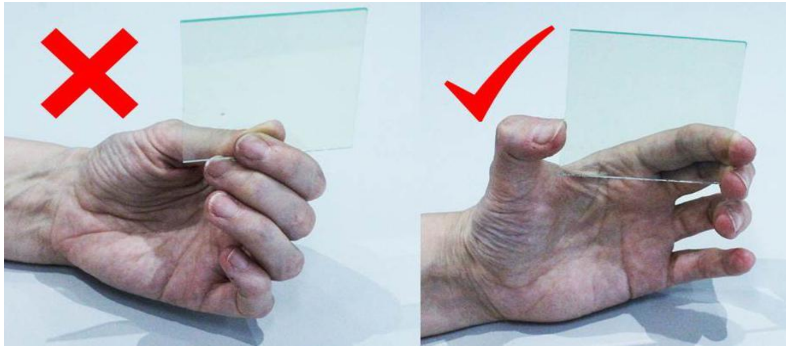


Figure 19 holding holographic plates

To find the emulsion side we can blow on the plate and see which side fogs up – that is the glass side. **NOTE**: when you blow on the hologram keep it close to your mouth and observe if it fogs up WHILE you blow on it. You will need to do this in the dark. Turn and face a dim light source, such as the light coming from under a door. Don't cover the plate with your hand, or you won't be able to see whether it fogs up or not.

Figure 20. the glass side of the plate fogs up

i. Take the holographic plates out of their wrappers, remove any plastic edge strips which might be protecting the plate, hold the plates: by the edges.

ii. **CLOSE THE BOX**. Breathe on the plates and figure out which is the emulsion side – the side that does not fog. Place the holographic plate with the emulsion side facing the object.

iii. Allow about one minute for the object to settle, with everyone in the room still and quiet.

iv. Lift the cardboard 1-2 cm above the table while still blocking the laser light, and wait 10 seconds for the vibrations to subside. **(Don't touch the table as it will ruin the hologram!)**

v. Lift the cardboard all the way up, allowing the laser light to escape from under the card and fully light up the holographic plate and object. Hold for approximately 25 seconds then replace the book in front of the laser blocking out the light again. This is known as **'shooting'** or **'exposing'** the holographic plate.

vi. Give the plate back to the instructor – who will put them back in a box, then **CLOSE THE BOX**.

TURN THE LIGHTS BACK ON!

The interference pattern is now recorded on the plate – the structure is produced by the formation of clumps of silver where there was a light spot. When we put the plate in the first tray (the developer, the combination of solution A and B) the particles that interact with light will blacken. After development we need to wash the plates (for 30 seconds) in distilled water to remove the developer and then bleach them. In this step, the bleach will remove the particles that did not interact with light. After this step we just need to wash the plates again.

4.2 HOW TO DEVELOP YOUR HOLOGRAM

Put on a lab coat to protect your clothes, along with safety glasses and rubber gloves, and process the exposed holographic plate according to instructions that accompany the JD-4 chemistry. (Please note the chemicals can drip and ruin expensive shoes).Follow the instructions provided with the developer.

LIGHTS OFF!

i. Remove the holographic plate from the box. Close the box.

ii. Mix Developer A & B together in a tray.

iii. Place the hologram emulsion-side-up in the developer for 10 seconds (4 students at a time can place holograms in the corners of the developing tray – count down 3-2-1- and place all the plates in the developer together). Agitate the tray for the 10 seconds (a student should time the developing).

iv. The instructor should then remove the plates very quickly after the 10 seconds is up (or the plates will over-develop and turn opaque).

v. Place the holograms in the **wash** tray with de-ionised/distilled water. (Always place holograms emulsion side-up to prevent scratching the emulsion). Agitate the tray for 20 seconds to wash the holograms.

vi. Remove your hologram from the tray to drop into the bleach together.

vii. Bleach the holograms for approximately 1 minute until they are completely transparent, then for a further 10 seconds.

viii. The instructor should then remove the holograms from the bleach and place in last wash tray.

ix. Rinse the holograms for 20 seconds in the last tray. You can take the hologram out of the water yourself. Watch the process carefully so you can remember which hologram is yours.

N.B. Replace the distilled water after every 4 holograms are developed. Wash your hands when you have finished developing!

4.3 HOW TO DRY YOUR HOLOGRAM

LIGHTS BACK ON!

Once the holograms have been processed, wipe the glass side with a small bit of tissue paper as shown in figure 21 (blow on the hologram to check which side mists up – that's the glass side).

NB: If you wipe the wrong side you will ruin your hologram.

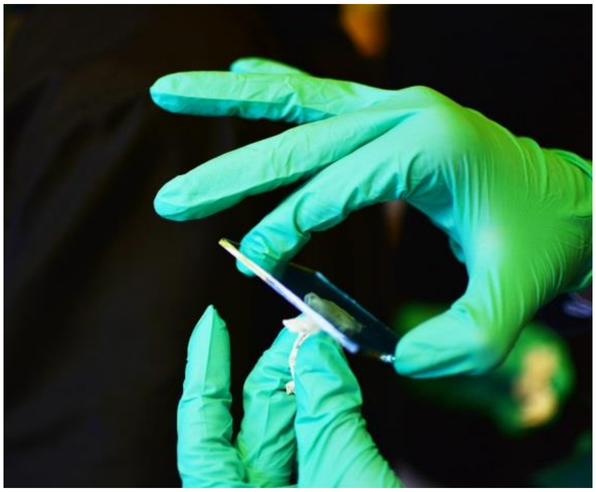


Figure 21. Wiping the GLASS side

Figure 22 Drying the hologram

Next dry your hologram off with a hair dryer (hold hair dryers at arm's length from the hologram as shown in figure 22 and dry both sides - don't touch the emulsion). Alternatively, the plates can be left to dry off overnight.

Make sure that the plate is thoroughly dry. Never touch the emulsion or you will get finger prints on the hologram which cannot be removed.

4.4 HOW TO LIGHT YOUR HOLOGRAM

If the plate is not yet dry - light the hologram from the back (emulsion side with the light shining towards you through the plate). See figures 23 and 24 below. The angle you light the hologram will depend on how much you tilted your hologram when you shot it.

Figure 23. Viewing a wet hologram- showing the hologram to others

If the plate is dry aim a torch light at the glass side of the hologram. Rotate the hologram and tilt the hologram until you see a reddish coloured object appear as shown in figure 25. You should see a hologram if the plate is dry. The best lighting for the hologram is bright sunlight!

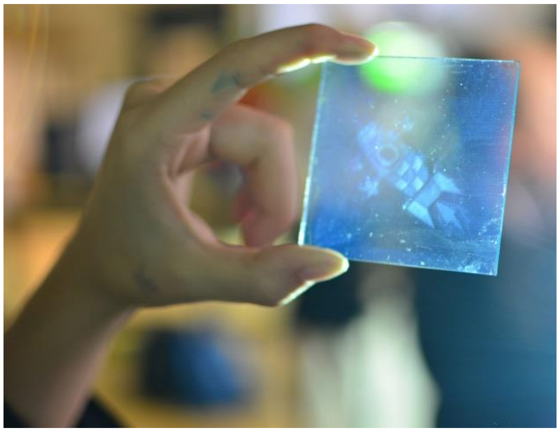


Figure 24 Viewing a wet hologram (rainbow coloured)

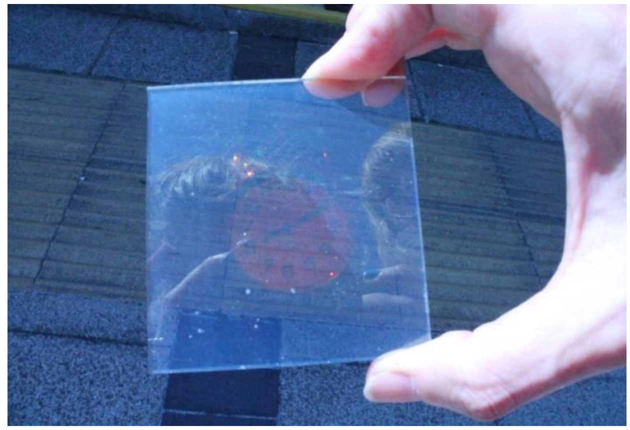


Figure 25 Viewing a dry hologram (red)

4.5 HOW TO LOOK AFTER YOUR HOLOGRAM

Once the hologram is completely dry it can be wrapped either in the black paper it came in, in its original box, or in white paper.

Keep the hologram away from moisture or water. The hologram can be painted black with spray paint to protect the emulsion. Spray the side that doesn't fog up (the emulsion side) to seal the hologram.

5. TROUBLESHOOTING

This activity is experimental. Each time you make holograms the results may be different due to vibration which will either make the holograms dimmer, or they don't show up at all.

When the hologram is lit if there are any areas of darkness on the plates, this means there has been movement which has ruined the hologram during exposure. If there are dark lines on the object, the object has moved. If there are dark lines or dark areas on the plate, then the plate moved. The following can cause movement problems:

- air-conditioning, or the heat of the room, machinery on in other rooms in the building
- students moving about during exposure or touching the tables during the exposure
- trucks passing by the venue
- doors slamming

In the developer - If the plates don't turn black quickly, this means they needed more laser light exposure. In the bleach – if the plates take a long time to clear – the exposure was too long.

Any chemical marks are often due to problems with leaving the holograms in the bleach for too long, or washing the holograms in dirty water. Keep replacing the water in the wash trays.
The object the student chose might be unsuitable. The best objects for holograms are small, reflective objects as shown above in figures 23 and 24. . Unsuitable objects would include: anything made out of material, anything flimsy, glass, dark in colour, green objects (will appear black in the red light), anything with a lot of depth.

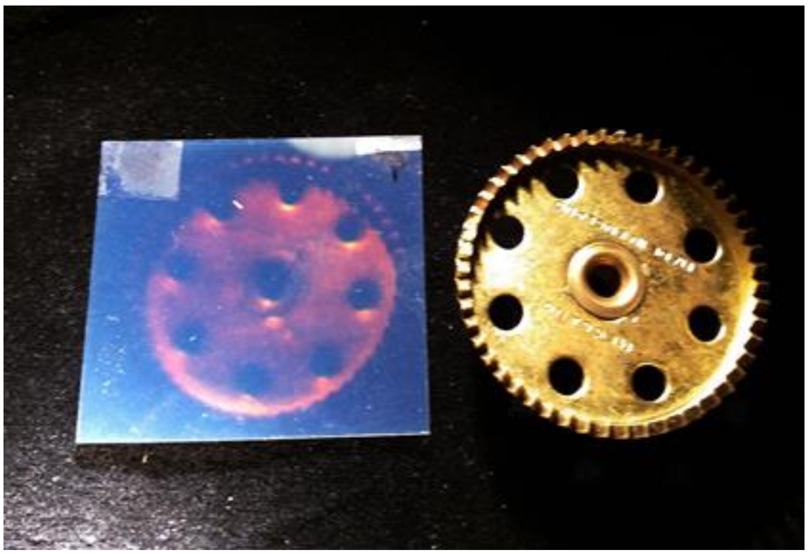


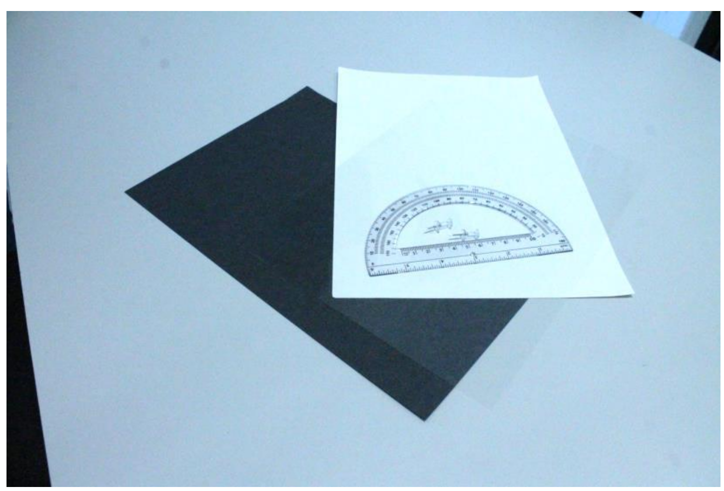
Figure 26 Example of a very successful hologram

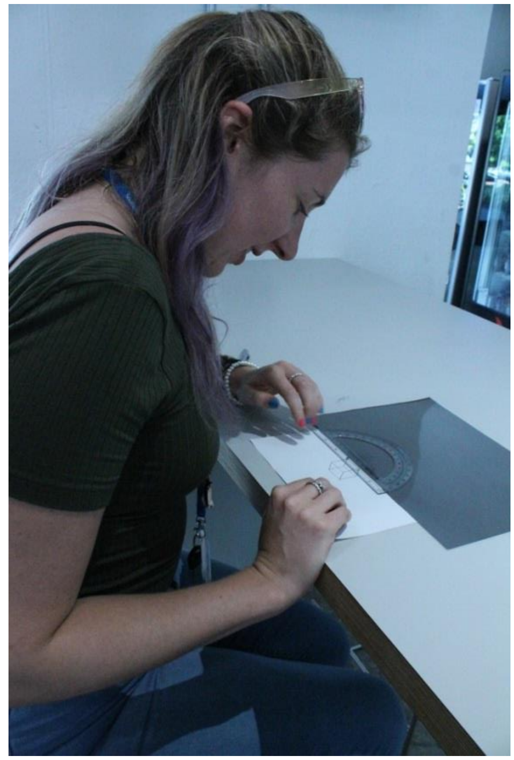
6. EXTENSION: MAKING A SCRATCH HOLOGRAM

Create an image scratched out of acetate, or Perspex, that appears three-dimensional and animates as you move the hologram under a light.

Parts List:

Protractor with a hole in the centre
2 x Push pins
Black paper
White paper
Acetate or a Perspex square (approximately 5cm x 5 cm) of Perspex, laser cut.
Masking tape



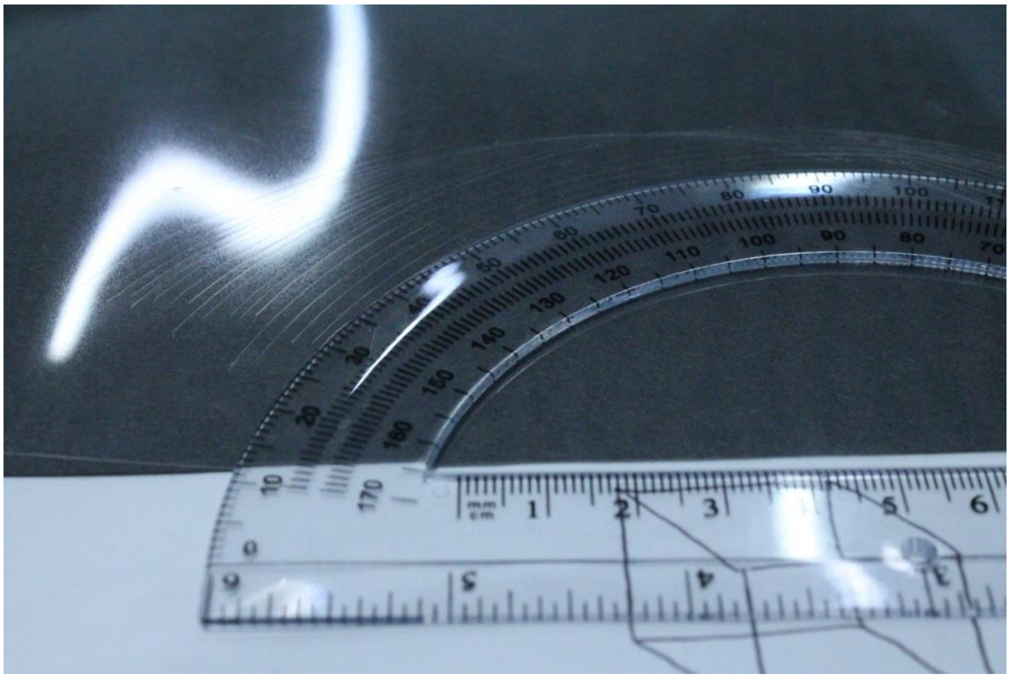


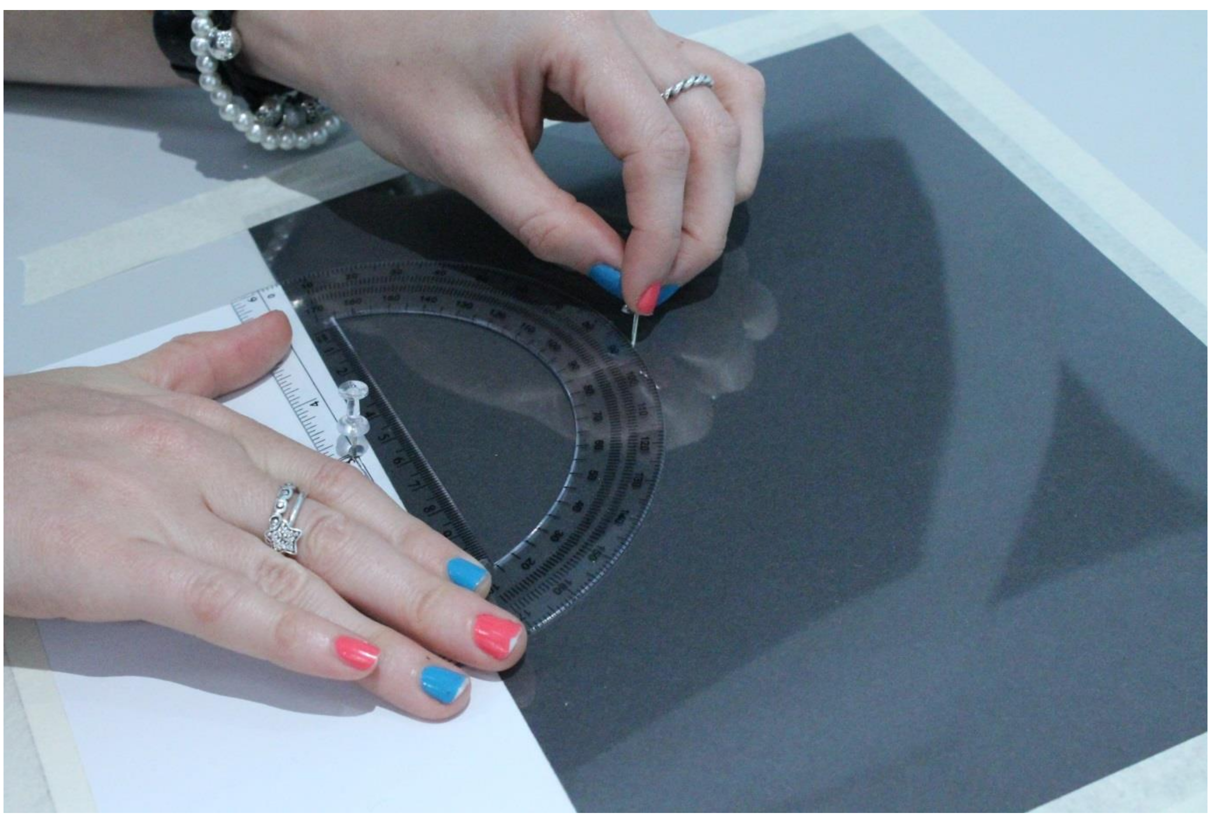
Draw an object at the bottom of a piece of paper. Line up the protractor over the drawing. Place hole in the centre of the bottom of the protractor on one point of your drawing. Place a piece of acetate over black paper just above the drawing and tape down both the black paper, and the acetate to keep them in place.

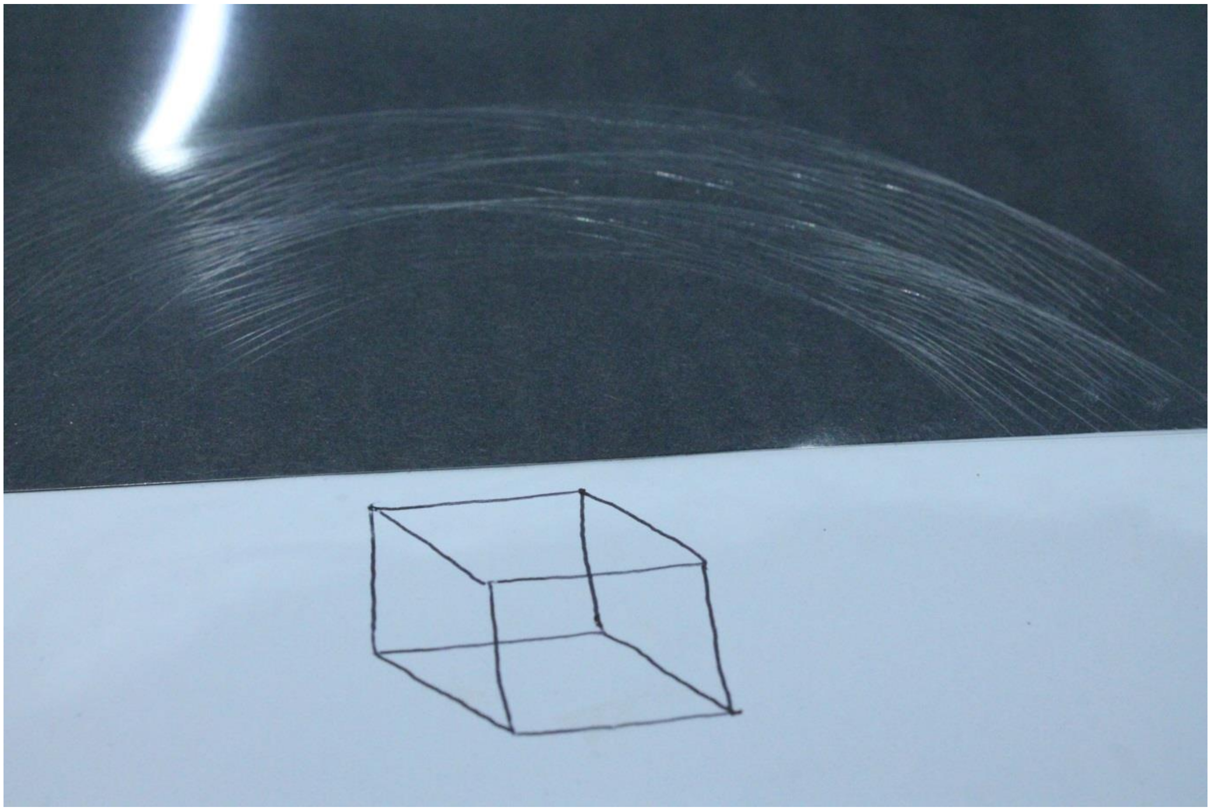
Once the acetate has been placed over the black card on top of your drawing, tape down the edges of the black paper and acetate and your drawing so that nothing moves.

Place a pin in the hole in the centre of the protractor into your drawing, at the end of one of the lines that you have drawn. Then very lightly scratch an arc into the acetate with another pin, drawing the pin from right to left, from approximately 130 to 30 degrees, making sure that only the finest line is barely visible. If you scrape the acetate and remove material you are pressing too hard.

Next, move the pin in the protractor hole approximately 1 mm along the line you have drawn on your object and make another scratch very lightly, following the curve of the top of the protractor as shown in the images above. Make approximately 20 pinholes and arcs for each line of your drawing. An example is shown below. Note how fine the lines are.







The scratches need to be very light - if you are scratching tiny pieces of acetate, or perspex out of the surface then you are pressing too hard.

When you finish tracing the lines of your object with pinholes and tiny scratches, shine a light on the scratch hologram. Either use a bright torch, or the data projector in your FAB LAB. (Or bright sunlight). You will see your object appear in the scratches and the object will move along the arc of the scratches as if you are seeing the object from different sides.

You could reproduce your initials, which will probably only be about 40 lines/scratches, or any other shape you wish.

7. WHAT HAVE WE LEARNED?

As a result of taking part in these two activities students will have revised some scientific light theory relevant to their studies at school, and may have learned something new. The students will have revised the terms reflection and refraction, absorption and transparency, constructive and destructive interference. Students will have learned that some materials, in this case emulsion on holographic plates, are sensitive to light and can capture images. Students have learned new skills; working safely with a laser to make a hologram, and they have made a Scratch Hologram, requiring dexterity and attention to detail.

If possible invite your parents or friends to come and see your work.

8. CONCLUDING THOUGHTS

There is an international shortage of people who know about Photonics, the science of light, and who know how to make holograms. There are so many different ways holography can be used, such as in security, advertising, medicine, art and education, but we need more people to experiment with it. Working with the laser technology you have used today has given you a lot of information that people who work in holography need to know in order to make successful holograms; they need to be able to control and manipulate light with reflection and refraction, and understand how to prevent vibration. Hopefully you will have enjoyed your experience today, and will want to learn more about light in the future.