



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.

Handout for Young Minds! (10-14 year-olds)

Table of Contents

Description	Page Number
1. Introduction	3
2. Safety	3
3. What is a hologram?	4
4. The science behind holograms	5
5. Holography set-up	7
6. How to make your hologram	9
7. How to develop your hologram	11
8. How to dry your hologram	12
9. How to light your hologram	13
10. Troubleshooting	14
11. Extension activity: making a <i>Mobile Ghost</i>	15
12. What have we learned?	16
13. Concluding thoughts	17

1. INTRODUCTION

Today you are going to make holograms as part of a workshop on 'Photonics' and learn all about light. We hope you have fun!

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 holograms will teach you the basics of how light works, and how we can use it to help us.

Careers with Photonics: There are thousands of different careers, or jobs, which rely on people knowing about Photonics: people who work with engineering and physics and the internet, people who work in medicine diagnosing illness and treating it with light (scans, laser surgery, treating cancer with radiation), or researching how to prevent illness need to work with light. Photonics is helpful to thousands of jobs, but there is a shortage of people with the skills to fill them.

Read more about careers with Photonics here: <https://www.optics4kids.org/careers>

2. SAFETY

There are two slightly dangerous parts to making holograms;

1. the laser you will be using to make your holograms,
2. the chemicals that you will use to develop your holograms.

The laser is called a laser diode, similar to the type of red lasers you see in barcode scanners in shops, in DVD players or laser pointers. Since laser beams tend not to spread out, they can travel directly into our eyes and be focused to a very bright spot on the retina (the back of the eye) which can damage your eye. **IT IS VERY IMPORTANT TO REMEMBER:**

**NEVER LOOK DOWN A LASER BEAM! and
NEVER POINT A LASER BEAM AT ANYONE ELSE!**

If you do get to work with the chemicals, make sure you **wear safety glasses, gloves and lab coats. Also, wash your hands after you use the chemicals.** The chemicals will hurt if they get in your eyes, are poisonous to drink and may ruin your clothes with dark spots.

3. WHAT IS A HOLOGRAM?

Holograms are three-dimensional (3D) images made with lasers. Holograms are found on bank cards (Figure.2), 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.

Figure 2. below shows a security hologram on a bank card. The hologram is stuck on the card to stop people from trying to 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. Shows 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 – portraits mounted in the floor of people looking upward.

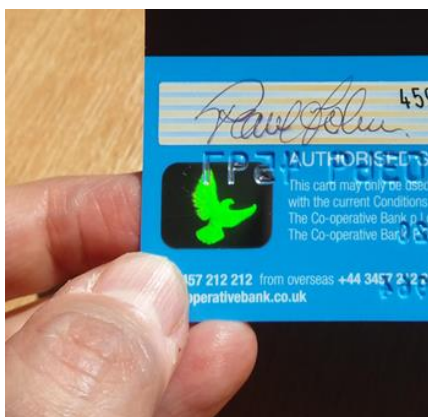


Figure 1. A security hologram on a Visa debit card



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.

4. THE SCIENCE BEHIND HOLOGRAMS

In this section we will learn the following about light and lasers; what a spectrum of light is; why laser light is special, how light travels, what happens when light hits an object and how the hologram is made.

What is a spectrum of light?

White light is made up of all the colours of the rainbow. These colours are known as a **spectrum** and they become visible when white light hits a prism or a rain drop. While light always travels in straight lines, the light from a laser beam travels in tiny waves within those lines and all the different colours in white light are made up of different sized waves. These waves are so small that they are billionths of a metre in length and are measured in nanometers (nm). To get an idea of how small this is; your hair and nails grow at about 1 nm a second. An illustration of different light waves is shown below in Figure 6. (You will though never be able to see the waves as they are too small).

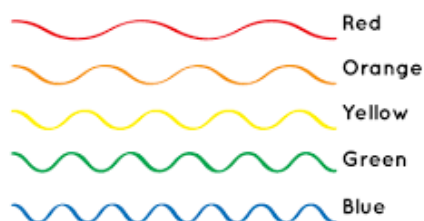


Figure 6. Light Waves

Why is laser light special?

Laser light is different to white light in that it is only made up of one colour. We will use a red laser diode – similar to the type of laser found in scanners in shops, DVD players and laser pointers – to make our holograms. Usually laser light emerges from a laser in a thin red line. However we have removed a lens from our diode laser and the beam will spread out as shown below in Figure 7.

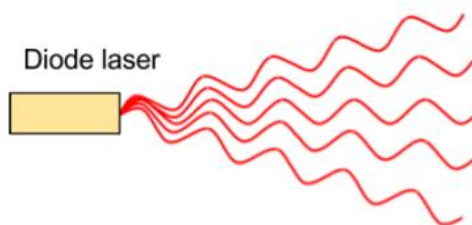


Figure 7. Laser light from a diode with the front lens removed

How does light travel?

While we know that light travels in straight lines and in waves, when we are learning about holograms we need to understand what happens when light hits objects, so we need to know about reflection and refraction. This is explained on the next page.

Reflection: When light hits a shiny object, such as glass or mirror, some of the light will be absorbed and some reflected. Reflection involves a change in direction of the light wave. The light will reflect off at the same angle that it hit the object. This is known as the law of reflection, shown below in figure 8. The light in is known as the incident light ray, and the light out is known as the reflected ray.

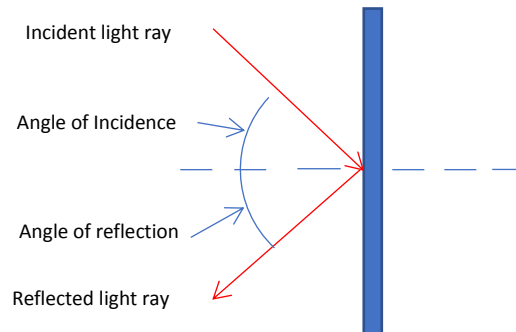


Figure 8. Law of reflection

Refraction: Light bends as it travels from one medium to another. In a hologram light bends as it travels from air through glass, and the holographic emulsion as shown in figure 9 below (the **emulsion** is a layer of transparent gelatine containing tiny particles of silver halide crystals which are light sensitive). These particles of silver direct light around and help form the holographic image.

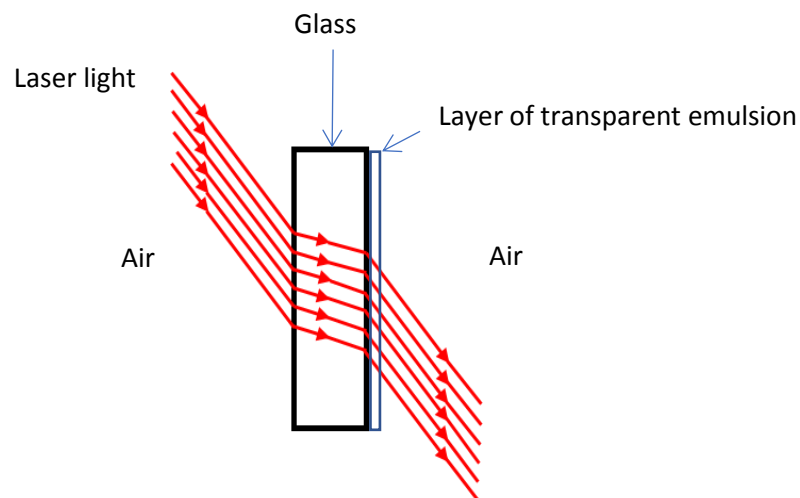
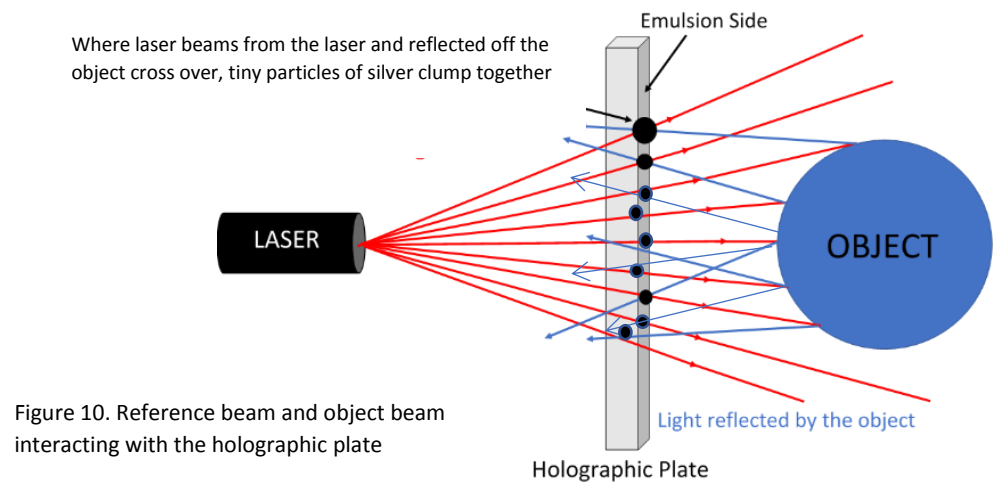


Figure 9. Laser Light refracting through the holographic plate

How the hologram is made

Both reflection and refraction are important in making a hologram. Light from a laser travels to the holographic plate (shown in red), refracts through the glass and emulsion side and then hits an object. The objects we use to make holograms of are shiny so the light is reflected back onto the holographic plate (shown in blue). The beam reflected from the object copies the shape of the object. When light from the laser meets the reflected light from the object these two beams interact with each other and impact the millions of tiny particles of silver in the holographic plate, causing the particles of silver to blacken when

they are developed. The particles will blacken based on how much light they interacted with shown below in figure 10..



5. 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 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. See drawing below in figure 10. Try to make sure that the environment you are setting up in is as quiet as possible. For example, make sure your workshop leader has turned off machinery when making holograms, make sure you and your fellow students are quiet during the exposure – and not touching tables, talking or moving their feet/chairs.

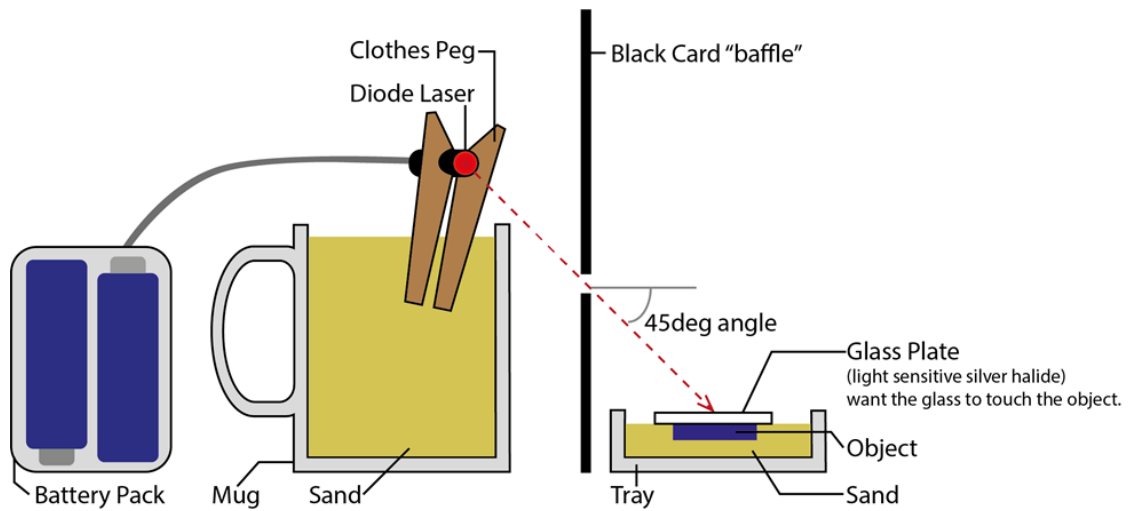


Figure 11. Holography set up drawn by Larissa Kunstei

This is your holography set-up. Your laser is fixed in a clothes peg as shown in figures 11 above and 12 & 13 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.



Figure 12. Holography set-up

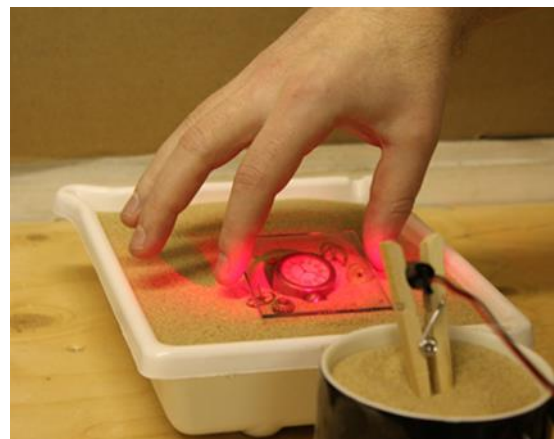


Figure 13. Set-up with object in place



Figure 14. Suitable objects for holograms

Use an old/exposed plate to design your set up as shown above in figure 13. 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.

Suitable objects to make a hologram of are small, shiny flat objects with the set-up we are using. Examples are shown above in Figure 14 on the left.

A good result could look like the image below in figure 15.

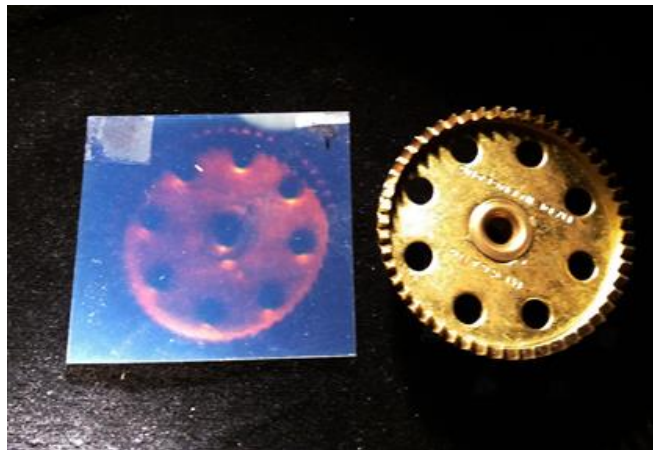


Figure 15. Example of a good hologram with the object

Once the object is fully illuminated, place a piece of cardboard in the path of the beam between the laser and your object to make sure that the light is blocked and not reaching the object.

During the process of making the hologram – light has to be shone on the object for a set amount of time. You may need to experiment to find out for how long, but probably 20 seconds. This is known as an ‘exposure’. The silver in the emulsion on your holographic plate reacts to light during that time. Once the hologram has been exposed, then it needs to be developed in trays of chemicals.

6. HOW TO MAKE YOUR HOLOGRAM

How to handle a hologram: Always hold your holographic plate at the edges as shown in the illustration below in Figure 15, so you don’t damage it.

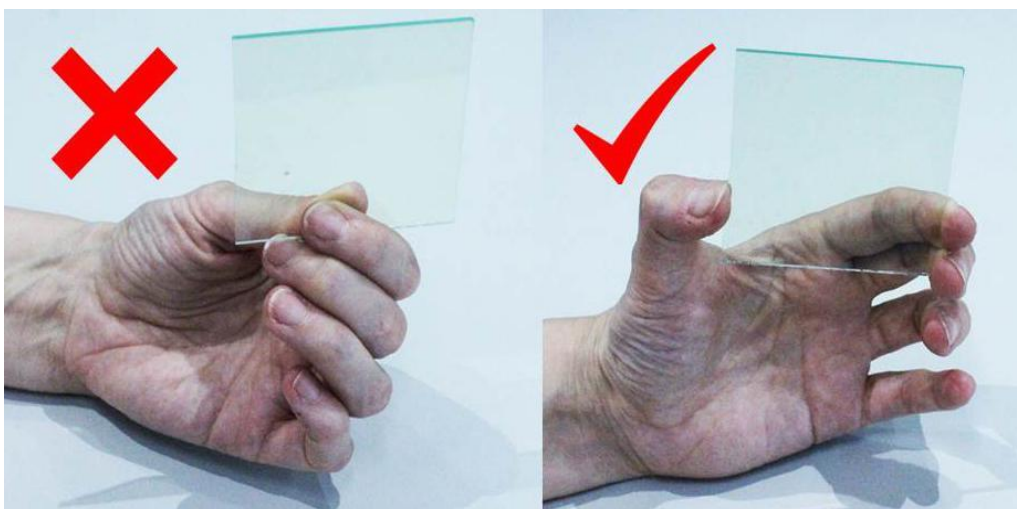


Figure 16. How to hold a holographic plate

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, trapped in a layer of gelatin (like jelly) and should NOT be touched. This side will be facing the object when we shoot the hologram and facing upward when we develop it (so it doesn't get scratched).

Holographic plates are similar to photographic film: if they were not developed and we open them in a lit room we destroy them and they can't be used anymore.

Only open the box of holograms in the dark!!!!

To find the emulsion side we can blow on the plate and see which side fogs up – that is the glass side, as shown below in Figure 17. **NOTE:** when you blow on the hologram keep it close to your mouth and observe if it fogs 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.



Figure 17. Finding the glass and emulsion side of a holographic plate – practice in the light!

WITH THE LIGHTS OFF (90% darkness is OK)

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 in Figure 14) Use an old/exposed plate to design your set up. (Real plate must only be used in the dark). 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.

Shooting the Hologram

Take the holographic plates out of its wrappers, remove any plastic edge strips which might be protecting the plate, remember to only hold the plate by the edges!

CLOSE THE BOX.

Breathe on the plate to figure out which is the emulsion side (the side that does not fog). Place the holographic plate with the emulsion side on the object .

Allow about one minute for the object to settle, holding still and quiet.

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 it will ruin the hologram!)**

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.

Give your plate back to your workshop leader. Make sure they put the hologram back into a box and **CLOSE THE BOX** of holograms so your hologram doesn't get ruined

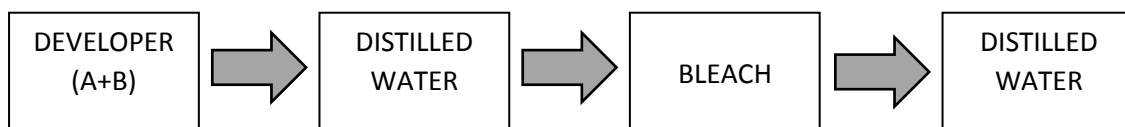
TURN THE LIGHTS BACK ON!

SAFETY!!! Put on a lab coat to protect your clothes, along with safety glasses and rubber gloves. (Please note the chemicals can drip and ruin your shoes – so if you're worried about your clothes get someone else to develop the hologram).

7. HOW TO DEVELOP YOUR HOLOGRAM

The holographic 3D Image is now recorded on your plate – tiny clumps of silver have been produced in the plate where the laser light hit the plate, but we need to 'develop' the plate in chemicals to be able to see the image. This is the developing process; put your hologram in developer, wash, bleach and then wash it.

Four different trays of chemicals and water are set up for your hologram.



Developer:

Drop the hologram glass-side-down in the developer together with three other students (count 3-2-1 then drop the holograms in the developer together). The Workshop leader should wash the developer over the holograms for 10 seconds and remove them immediately after 10 seconds is up (or they will turn opaque).

Distilled/deionised water wash 1:

The workshop leader will place the hologram glass-side-down in the water and wash the water over the plates for 20 seconds in distilled water to remove the developer.

Bleach:

Remove your hologram from the water and drop it in the bleach at the same time as the other students drop their holograms. Count 3-2-1 drop! When the plates become entirely transparent, count for another 10 seconds, then remove the plate.

Distilled/deionised water wash 2:

The workshop leader will place the hologram glass-side-down in the water and wash the water over the plates for 20 seconds to remove the bleach. Watch the process carefully so you know which hologram is yours.

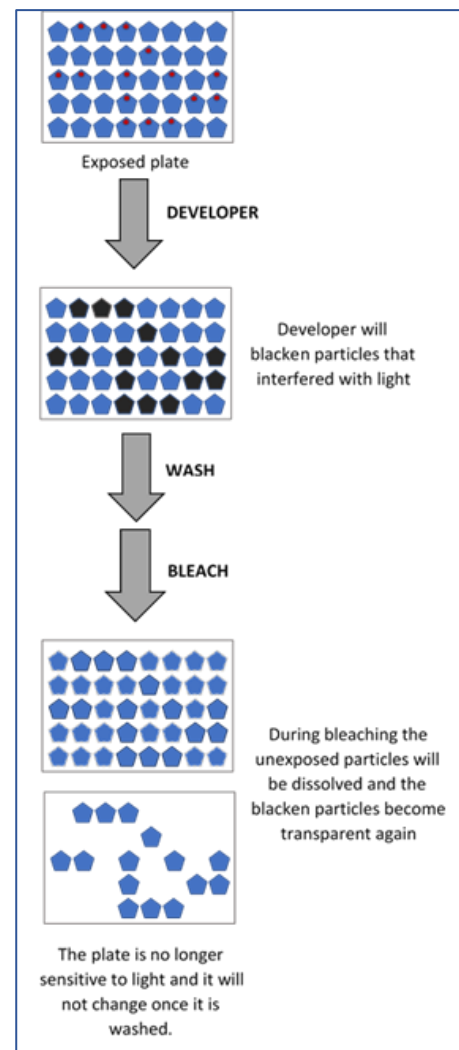


Figure 18. The developing process

TURN THE LIGHTS BACK ON!

8. HOW TO DRY YOUR HOLOGRAM

Once the hologram has been taken out of the water, wipe the glass side (blow on the hologram to check which side mists up – that's the glass side) as shown in figure 19. CAREFUL! If you get the wrong side you'll ruin your hologram. Next dry your hologram off, with a hair dryer (hold the hair dryer at arm's length from the hologram and dry both sides as shown in Figure 20). Alternatively, the plates can be left to dry off overnight. Make sure that the plate is thoroughly dry before placing it in paper. Never touch the emulsion or you will get finger prints on the hologram which cannot be removed.



Figure 19. Wiping the GLASS side



Figure 20. Dry the hologram

9. 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 21 & 21. The angle you light the hologram will depend on how much you tilted your hologram when you shot it.



Figure 21. Viewing a wet hologram

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 23. You should see a hologram if the plate is dry. The best lighting for the hologram is bright sunlight!

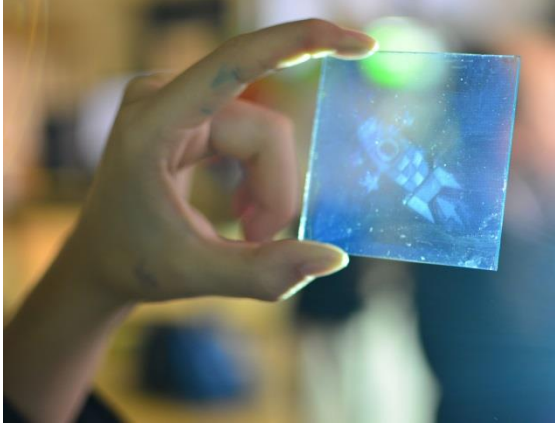


Figure 22. Viewing a wet hologram illuminated from behind (rainbow colour)

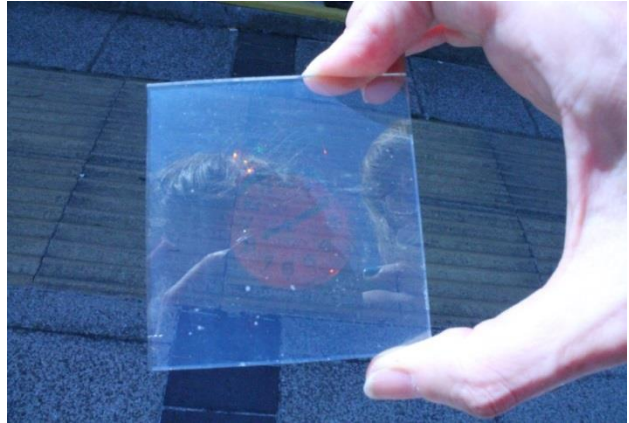


Figure 23. Viewing dry hologram illuminated from in front (red colour)

10. TROUBLESHOOTING

When the hologram is lit if there are any areas of darkness on the plates, this means there has been movement. 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
- people 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 you chose might be unsuitable. The best objects for holograms are small, reflective objects as shown above. 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.

11. EXTENSION: MAKING A MOBILE GHOST (A smartphone 3D Projection)

In this activity a smartphone is used, along with an inverted pyramid made out of acetate on top of the phone.

What is a Mobile Ghost?

More commonly known as Pepper's Ghost, the 'mobile ghost' is an optical illusion often used in haunted houses and concerts to make an image appear 3D and float in mid-air as shown below in Figure 24.



Figure 24. Student with their smartphone 3D Projection

The light theory which makes this illusion is as follows:

The ghostly image is formed when rays of light from an object are reflected off one surface onto another reflective surface into our eyes.

If the second reflective surface is transparent, part of the image is reflected and part is transmitted. The object appears slightly translucent and seems to float behind the transparent reflective surface. The 'Ghosts' look 3D because we see a slightly different image with both of our eyes. Our brain combines both views and interprets the object as being three dimensional.

1. Making your Mobile Ghost screen.

- 1.1. Cut out your template by cutting along the dashed lines on the acetate sheet.
- 1.2. Fold the template along the solid lines.

1.3 Tape the folded cut-out into a flat-topped pyramid shape as shown in Figure 24 below

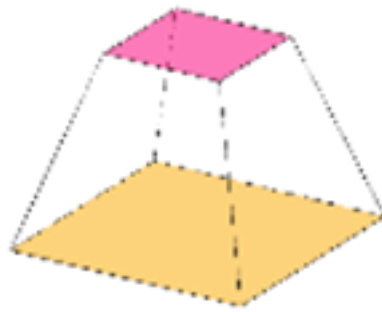


Figure 25. A mobile ghost screen

2. Viewing your Mobile Ghost

2.1 Download a ready-made Pepper's Ghost app such as "Hologram Pyramid Videos" from the Google Play store for Android, or the iTunes store for iOS.

2.2. Scan the QR code below for a quick link. <https://itunes.apple.com/us/app/hologram-pyramid-videos/id1100684856?mt=8><https://play.google.com/store/apps/details?id=com.holapex.hologram.a>
[pp&hl=en](https://play.google.com/store/apps/details?id=com.holapex.hologram.a)



2.3 If the FABLAB has an internet connection that the students can use ask them to search for Pepper's Ghost images. One can be found here:

https://www.youtube.com/watch?v=XH_5WyKeq2U

2.4 Place your inverted pyramid onto the smartphone screen and see the image appear to be floating in the center of your Mobile Ghost Screen.

Troubleshooting

If the floating animated image is difficult to see – turn the lights off in the room, or make sure that the image has a dark background

12. WHAT HAVE WE LEARNED?

As a result of taking part in these two activities we hope that you have worked with the science of light relevant to your studies at school, and may have learned something new.

You will have revised how light travels; in straight lines, reflecting, refracting (or bending) as it travels through glass. You should also have been reminded what happens when light is absorbed, and what the terms opaque and transparent mean.

You have learnt that when light from a laser is transmitted through a holographic plate, reflects off an object and back onto the plate, the combination of the two beams form an image in the light sensitive holographic emulsion. The emulsion darkens on contact with light, capturing the reflected light from the object as a result. Holograms have to be developed, and lit with a torch, or sunlight, to be seen.

You have learned new skills; making a *Mobile Ghost* projection and working safely with a laser to make a hologram.

13. 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.