Holography
ELE 198DL Lab Manual

Introduction/Overview:

The purpose of this lab will be to create three dimensional images of objects of your choice using Holography.

In the first week of the lab you will familiarize yourself with the optical components we will be using by building a Michelson interferometer. The Michelson interferometer will also help to determine whether your optical set up is stable enough to generate high quality holographs. The optics for this experiment are non-trivial, and must be aligned carefully. You may have to spend some time aligning mirrors, lasers, and lenses. Don’t get discouraged, this is an inevitable aspect of any optics lab. Make sure you are comfortable with the alignment and the workings of each of the components you are using. By the end of the first week you should be able to identify the interference fringes from the Michelson interferometer experiment and understand their origin.

In the second week you will build a transmission holography setup. The system you will build is similar to the Michelson interferometer you built in the first week, with some modifications. Once your system is built, you will expose a hologram plate. Find a simple object with 3-dimension properties. Of course, while everything is three dimensional, you don’t want to pick something like a piece of paper, whose 3D image won’t look too different than its 2D image. You will then expose the hologram plate. After you have exposed your plates, the course TA will develop them for you. If you wish to see the development process, just let the TA know and s/he will arrange for you to be present and help with development.

Because this is a two week lab, you will get only one opportunity to develop your holograms. Choose a second object and take another hologram, in case the first doesn’t come out. Once you have exposed two hologram plates, the TA will develop the plates and you will be able to look at the holograms at the beginning of the next lab.
This week we will build what is called a Michelson Interferometer. Although we will be using this device to familiarize ourselves with the optics we will be using and to determine whether our system is stable, Michelson Interferometers (MI) have many other uses in the real world. Some of these we will discuss later on. First, we should introduce the actual optical set-up for the interferometer.

Figure 1 shows the optical layout for a typical MI. There are two different brands of lasers in the lab for our use, both of which are 5mW linearly polarized HeNe lasers. There is one Edmund Optics NT62-723 laser and two ThorLabs HNL050L lasers. The laser light as it enters the interferometer set-up first hits the beam splitter. Half of the light is reflected towards the Moving Flat mirror (path 1) and half is transmitted through to the Fixed Mirror (Path 2). The light is then reflected from the mirrors. The light traveling on Path 1 comes back to the beamsplitter, where half of it is reflected back to the laser (we don’t care about this beam) and half is transmitted through to the Target screen. The light traveling on Path 2 also comes back to the beamsplitter, where half of it...
is transmitted through to the laser (we don’t care about this beam) and half is reflected to the Target screen. The light hitting the target will create an interference pattern. This is not obvious from looking at the diagram, even if the idea of interference is well understood. To refresh your memories, we will briefly discuss the phenomenon of interference before we continue, as it is the integral physical phenomenon behind holography.

The classic example for discussing interference is what is known as the two-slit interference experiment (often referred to as Young’s double slit experiment). Before we dive into this, let me just remind you that light can often be thought of as a wave. Figure 2 shows how we might depict a light beam as wave. In Fig. 2a, a simple sine wave shows the peaks and valleys of the electric field of a light wave. Figure 2b shows a different way of looking at the same beam. In Fig 2b, we show not the sine wave, but only lines corresponding to the peaks of the wave, these lines are referred to as “wavefronts”, and for this lab, it will be helpful to be able to think of light waves both as waves, and as collections of traveling wavefronts. When we wish to talk about interference, both methods of describing light waves (traveling waves and traveling wave fronts) are used. The distance between the wavefronts (or the peaks of the sine wave) is, not surprisingly, known as the *wavelength* of your light. Wavelength is typically denoted by the Greek letter lambda (\( \lambda \)).

![Figure 2: Two different methods for depicting a traveling light wave. In a) the magnitude of the wave’s electric field is shown. The wave is traveling in the x direction, as indicated by the blue arrow. In b) the light is shown as a collection of its wavefronts (the peaks of the sine wave). Again, the direction the light is traveling is indicated by the blue arrow.](image-url)
Interference is most easily seen with coherent light, which means that all the waves which make up the beam of light you are looking at are in phase (the peaks of the sine wave all travel together). Consider a coherent light wave which is split in half at some point and then recombined. If the two split beams of light travel the exact same length while they are split, then when the light recombines, the peaks of the sine waves match up. However, if one arm of the light travels farther than the other, then interesting things start to happen. The difference in the distance the light in each “arm” travels is referred to as the “path difference”.

Figure 3 shows the recombined light waves for four separate path differences and what the beam might look like when it hits a target (a piece of paper, for instance). If the path difference ($\Delta \lambda$) is 0, when the two beams are added together the intensities add and the combined wave looks just as the original wave did before it was split. This is what we call “constructive interference”. In Fig. 3a, the path difference is $\lambda/8$, so the amplitude of the combined wave is smaller. As the path difference increases, the recombined wave amplitude decreases. Finally, when the path difference is $\lambda/2$, the two waves cancel each other out, and no spot would be seen on the target (Fig 3d). This situation is referred to as “destructive interference”.

![Figure 3: Shows effects of path difference ($\Delta \lambda$) upon recombining waves. d) depicts destructive interference.](image-url)
Study Fig 3 and make sure you understand the concepts underlying constructive and destructive interference. You can see that a path length difference is equivalent to a phase shift between the two waves, this is why waves interfering constructively are often referred to as “in phase” and those interfering destructively are referred to as “out of phase”. Additionally, convince yourself that a path difference of $\lambda$ (or $n\lambda$, where $n$ is any integer) is equivalent to a situation with no path difference.

In a two-slit interference experiment a coherent light source (laser) is directed towards an opaque screen with two openings consisting of very narrow vertical slits, separated by some distance “a”. When the laser hits the wall, all of the laser light is blocked, except that which is incident on the slits. The slits cause the light to emanate from the other side of the wall with semicircular wavefronts instead of the straight wavefronts on the first side of the wall (see Fig. 4). Because there are two slits in the wall, two waves sources are generated, one emanating from each slit. A screen is then placed at some distance from the wall. A fringe pattern will appear on this screen. This fringe pattern is a result of the constructive and destructive interference along the screen. For each point on the screen, one can calculate the path length from each slit to that point on the screen. Figure 4 shows how this path difference is found. The left schematic in Figure 4 shows the double slit, the emanating wavefronts, and the screen. Lines are drawn from each slit to an arbitrary point “y” on the screen ($\ell_1$ and $\ell_2$). These are the path lengths for each slit to the point “y”.

In order to find the path difference ($\ell_1 - \ell_2$) we must make some assumptions. The first is that the angle ($\theta$) between each path and the normal connecting the screen and wall is approximately the same. This makes sense if the distance between the screen and the slits is much greater than the distance between the slits themselves. This is a reasonably assumption, as slits tend to be quite close ($<<1$mm) for this experiment and the screen to slit distance is typical on the order of 1m. The second assumption is that a line dropped from slit 1 to $\ell_2$ such that it is perpendicular to $\ell_2$, divides the length $\ell_2$ into two lengths, $\ell_2-\ell_1$ and $\ell_1$. This assumption rests on the same approximation as the first. Convince yourself that for long path lengths ($\ell >> a$) this makes sense. After this, finding $\Delta \lambda = \ell_2 - \ell_1$ is easy. These simple approximations allow us to determine $\Delta \lambda = a \cdot \sin(\theta)$. Thus, on the screen, one should see a constructive interference fringe every time $\sin(\theta) =$
n*λ/a, where n is any integer. If we say \( \sin(\theta) \approx \frac{y}{d} \) (again, using the small angle approximation), then we should see interference fringes on our screen for all
\[
y = n*(\frac{d\lambda}{a}).
\]

The double slit interference experiment is the classic example of interference effects. If you understand what we just did, then you should be able to grasp the Michelson Interferometer quite quickly. In order to explain the effects we will be seeing, it will be easiest to draw the optical set up for the MI in a slightly different manner. In Figure 5, we see the MI laid out in a manner for which tracing wavefronts becomes more intuitive. Convince yourself that the set up in Figure 5 is equivalent to that of Figure 1. In Figure 5, we have essentially folded the MI upon itself, removed the beamsplitter, and assumed that half of the light incident on M1 from the laser is transmitted to M2, where it is reflected straight through the back side of M1 to the screen, where it interferes with the light which was reflected off of M1. Figure 5 shows this more convenient method for analyzing the MI, and also shows an expanded view of the mirror area. When we analyze the MI, we are assuming that the laser beam expands as it comes out of the laser (this is the origin of the angled wavefronts shown in Figure 5). The angles shown in Figure 5 are greatly exaggerated to make the geometry easier to understand.

Figure 4: a) Young’s double slit interference experiment. B) Expanded view of a) near slits.

Assuming \( d \ll x \) and \( \theta \) small
\[
\xi_2 - \xi_1 = a^*\sin(\theta) \quad \text{or} \quad \Delta \lambda \approx (a^*y)/d
\]
Using some simple trigonometry, we can see that the path difference for the two beams of light in our MI is $\Delta \lambda = 2d \cos(\theta)$. We know that when $\Delta \lambda = \lambda$, we get constructive interference. Thus, for a given $d$, we can figure out the radial spacing between interference fringes on our screen if we know the distance (optical distance, this includes reflections) from the laser to the screen. See if you can figure out what the spacing between fringes should be on the screen.

The interference pattern on the screen from the MI should be a series of circular rings. This is assuming your mirrors are perfectly parallel. If they are not, you will see a very different interference pattern, known as localized interference. See if you can guess what these patterns would look like if first mirror is perfectly flat and the second mirror is tilted a) downward or b) to the side (hint: think about the double slit case we just discussed).

Figure 5: Schematic drawings for Michelson Interferometer, collapsing the two paths on top of each other, with greatly exaggerated angles.
Now we are ready to start building our interferometer. Follow the instructions below to assemble the optical components as shown in Figure 1. We will not precisely be creating the same setup as Figure 1 because we do not have a mechanism to move the “moving” mirror. Instead, we will use a cover slide (thin glass sheet) with a rotating mount to simulate a path length change (see below). Remember, light travels slower than it does in air when it is in a medium with $n=1$. So even though each arm of the set-up might be the same length, the optical length of the arm with the glass slide will be longer. As we rotate the slide, we increase the effective thickness of the glass the light must travel through, changing the path-difference between the arms. Alignment is essential for this experiment, so it will be easiest to assemble this set-up piece by piece. It would probably make sense to keep the laser on while you are assembling the optics, as you will want to check your alignment as you progress. However, you should be very careful about placing optics into position while the laser is shining on the optics, since you could accidentally steer the beam into a classmate’s eyes. The best idea is to close the shutter on the laser while you are putting pieces into place and doing the rough alignment. For the fine alignment, open the shutter and use the beam.

1) The laser should remain fixed in place. The laser will be mounted at the end of the optical table. Place a spatial filter (pinhole) directly in front of the laser. This will help to clean up the main beam and cut down on interference from unwanted reflections.

2) With the laser on, first put the fixed mirror in place using a kinematic mount (instead of the normal lens mount). The light reflected from the mirror, assuming the laser is mounted flat, should reflect directly back into the laser, through the spatial filter. There will be knobs on the back of the mirror mount that will help with the fine alignment of the mirror.

3) Next, put the beamsplitter in place. The beam splitter should be at a 45° angle to the beam path, and should not significantly change the location of the beam on the fixed mirror.

4) Use a cover slide mount with a post/post holder to make a target screen. Use a piece of paper or a business card in the mount for the laser light to shine on. The
beam splitter should be angled such that the laser light hits near the center of the target screen.

5) Next place the “moving” mirror on the table. Mount it the same way as the first mirror, using a kinematic mount. The distance between each of the two mirrors and the beamsplitter center should be as close to equal as possible. The moving mirror should reflect the laser light back to the beamsplitter at exactly the point where the laser light is first incident on the splitter. The two beams (one from the moving mirror through the beamsplitter and one from the fixed mirror reflected off of the beamsplitter) should both be hitting the target now at exactly the same point on the screen (when you block one arm of the beam path or the other, the position of the beam on the screen should not change).

6) Place a rotating base between the beam splitter and the “moving” mirror. Use a cover slide mount on a post to hold a single cover slide. As you use the base to rotate the cover slide, the length of glass that light passes through changes slightly (on the order of hundreds of nanometers). Due to glass having a different refractive index than air, this path length difference will lead to a change in the phase of light that goes through the cover slide. As a result, the diffraction pattern seen on the screen will change.

7) Can you see interference fringes? (You will probably need the room lights off to be able to see them) What do they look like? If you see fringes, but are not sure if they are the fringes you want, try the following: block the beam in one arm of your set-up, unblock this beam, and then block the beam in the other arm. If your interference pattern goes away each time, you are most likely looking at the right interference. If the pattern stays for either (or both) blockings, you are seeing interference from double-reflections, this isn’t what we are looking for (though the physics is the same).

8) Are your fringes moving even if nothing is agitating the table? If you see changes in your fringe pattern with time, it means something in the set up is not stable. Try tightening set screws and other components to decrease the noise in your system. Record the optical set up and your results in the log book.
9) If you do not see circular fringes, tweak your alignment until you do. Record everything in your lab book.

10) Can you measure the spacing between fringes? How does this compare to your calculated measurement (using $\lambda = 632.8\text{nm}$). If you have circular fringes, can you adjust the translational stage so that they collapse upon themselves? What does this point on the translational stage correspond to?

11) The center point of your interference pattern corresponds to 0°. The path difference between the two beams at this point should just be double the difference between the mirrors and the beamsplitter. As you rotate the glass slide, this point should oscillate in intensity. Does it? If you didn’t know the wavelength of the laser, how could you use this set-up to determine the laser wavelength? This is essentially how a Fourier Transform Infrared (FTIR) Spectrometer works. Your TA has experience with FTIRs, feel free to ask them about these types of spectrometers, they are very different than the one you built in the first weeks of class!

Interferometers are extremely sensitive. Very small changes in the set up can cause rather large changes in the pattern you see. For this reason, they are often used to measure the refractive index of materials (by placing an unknown material in one beam path) or as spectrometers (to measure the wavelength of light). In fact, one of the integral experiments in modern physics used the Michelson interferometer (the Michelson-Morley Experiment) to disprove the existence of the ether and to prove that the speed of light is constant. In this lab, however, you are simply using the set-up to get familiar with the holography optical components and to test the stability of your optical set-up. Because the interferometer is so sensitive, we will be able to see if the vibrations in the room are on the scale of one wavelength, a size that, though small, will make holography almost impossible.
Hopefully you are now comfortable with building a sensitive optical set up and with the practice of optics alignment. We are now ready to build our holography set-up. The schematic for the set-up is shown in Figure 6.

Before we build our holography set up, it would make sense to discuss the physics involved. In many ways, the holography set-up you will construct is little more than a fancy black and white camera. For a camera, light reflects of the object you wish to image, is collected by various lenses, and is then projected onto the camera’s film, producing a 2D image of the reflected light on the film surface. Our holography set-up works in a similar manner, except in addition to the 2D image, we capture information about the 3D shape of the object. This is because the light bouncing off of the object (the object beam) interferes with the light from the reference beam to create an interference
pattern on the plate surface. It is this interference pattern which gives us our three- dimensional information, information which is carried in the phase of the incident laser light. Because we are collecting all this extra information we will require a much higher resolution film than is typically used for black and white photography. Good photographic film can resolve 90 lines per mm, while good holographic film can resolve up to 3000 lines/mm. This extra resolution is necessary, since holographs do not just record a physical image, they record the interference of light waves, and thus resolution on the order of the wavelength of light is required.

A typical photograph is produced by capturing the intensity of light reflection off of the object of interest. The light reflected is usually white light (room light or sunlight) and incoherent. The laser, however, produces coherent light at only one frequency (632.8nm, for a HeNe laser). Of course, if we were to shine a laser on an object and look at the reflected light, we would learn nothing about the phase of that light. Think about this for a second: over time, two out-of-phase beams of equal intensity, incident on two different points on your film, will expose the film equally. If this doesn’t make sense, go back to Figure 3 and picture the intensity of each of the $E_\lambda$ and $E_{\lambda+\Delta\lambda}$ beams if they were never recombined. In order to learn anything about phase, one must have a reference beam. This reference beam (as can be seen in Figure 6) illuminates our entire plate evenly, so that the phase information from the object beam can be recorded.

The reference beam is a plane wave through the entire length of its path. The object beam travels as a plane wave as well, until it hits the object, at which point it scatters in a manner determined by the physical characteristics of the object. The object beam goes from a plane wave before the object, to a complex system of wave fronts after the object. This complex system of wave fronts interferes with the reference beam at the surface of the plate. Where we have constructive interference, the light intensity is greater, and the emulsion is more “exposed”, while where we have destructive interference, light intensity is weaker, and the emulsion is less exposed.
Once you have exposed and developed your hologram you may use it to reconstruct the original object just as you can use camera film to reconstruct a 2D image of the object you captured on film. With typical photography you can view your negative (the developed film) and see the captured images on the film. In Holography however, you cannot see the object image on the exposed and developed plate with the naked eye. This is because photographs are exposed with white light, and to reconstruct the image, one only needs white light. To reconstruct a hologram, you need the light which exposed the hologram in the first place, namely laser light.

To reconstruct a holograph you must place the hologram plate back into your optical set-up and shine the reference laser on the plate in the exact manner in which it illuminated the plate during exposure (As shown in Figure 7(c)). Because the silver halide film on the plate has been exposed and developed, it is patterned according to the interference of the reference and object beams in the exposure set up. When you shine the reference beam on this patterned surface, it is transmitted in such a way that the

Figure 7:  a) Object viewed with no plate. b) Schematic of exposure process for holograms and c) schematic of hologram reconstruction process. I have chosen only to show the object beam’s reflection off of a handful of points, in actuality, the object beam scatters off of an infinite number of points along the entire object’s surface.
reference beam light is scattered through the plate and to the viewer’s eye (Figure 7c)). The wavefronts of scattered light which the viewer sees in Figure 7c), are exactly the same wavefront the viewer saw in Figure 7(a), where there was no plate, only light scattered off of the object. The exposed, developed, holographic plate scatters the reference beam in such a manner that it recreates the wavefronts associated with scattering off of the object. For the viewer, the wavefronts seen in Figure 7a) and 7c) are indistinguishable. Thus, your eyes see an object where, in fact, no object exists. The 3D shape of the object is stored in the phase information of the scattered object beam relative to the reference beam. However, intensity information (just as with a typical camera) is also recorded. The “shinier” the surface of the object, the more light is reflected towards the plate, and the stronger the interference fringes become. The rougher the surface, the weaker the reflection to the plate, and the weaker the interference signals become. In this way, the holographic plate stores both intensity and phase information, unlike normal photographic film, which stores only intensity information.

What is interesting about holography is that, unlike photography, there is no point to point correspondence between the object and the film. In photography, a given point on the object reflects light to a point on the film (as per our in-class discussion of imaging) In holography, a given point on the object surface scatters the laser light over the surface of the entire hologram. This leads to one of the most interesting aspects of holography, namely the fact that you could break your hologram in half, and each half of the plate could still reconstruct the entire object you recorded. Obviously, photographic film cannot do this; if you cut a negative in half, you will only be able to see the half of the image when you look at either of the two pieces. However, for a hologram, the reconstructed images from the two halves of the broken hologram are not identical. In fact, they are images of the object from different angles.

To understand why this works, it is easiest to think about the angle of scattering from three points on the object. Figure 8 shows this simplified scenario. The top point, on the figure’s cheek scatters light mostly to the top half of the hologram, since the lower half is blocked by the Albert’s shoulder. Light scattered from the middle spot is not obstructed, and thus is scattered to the entire surface of the hologram. The light from the bottom spot
scatters mostly to the bottom half of the hologram, since the figure’s hand is blocking the top half.

![Figure 8: Depiction of the scattering of laser light off of three distinct points of the object.](image)

If you were to use only the bottom half of the hologram to reconstruct the image, your reconstructed image would appear as though you were viewing the figure from the bottom (because, for instance, information from the mustache is blocked by Albert’s shoulder). If you used the top half, it would appear as though the figure was being viewed from the top (because, for instance, the hand blocks information from the figure’s thigh). Each area of the hologram plate can reconstruct an image of the entire object, and each of these reconstructed images appears as the object would if viewed from that part of the plate. When you add all of the area of the plate together, you get the reconstruction of the object from all of these viewpoints, which is why it appears to be three dimensional when we view it.

Now that we understand the basics of holography, we can start to put together the holography set-up.
The optical components you will be using will be given to you. They consist of:

a) Two spatial filters. These are simply pin holes whose size you can vary with the moving arm extending radially from the holder. Do not push on the arm with any significant force, the pinhole can jam.

b) One beamsplitter. The beamsplitter will be the same one you used for the Michelson interferometer experiment. It is designed to pass 50% of incident light and reflect 50%. One can also use a variable beamsplitter, changing the proportion of light going through the object beam. Using such a beamsplitter would allow you to find the best ratio of object to reference beam intensity for your set-up.

c) Two diverging (or beam-expanding) mirrors. The two mirrors we will use are designed to rapidly expand the reference and object beams so that they can cover the entire hologram and object, respectively. If your beam is not expanded to a diameter large enough to cover the plate or the object, try adding a concave (diverging) lens to the beam path.

d) One or more flat mirrors. You can use the mirrors to direct your beams around the optical breadboard...you can use these to increase path length if your beam is not large enough to expose the entire plate. Be careful, however, your mirror should be large enough so that you don’t lose any of the beam!

e) Hologram plate holder. There is one Hologram plate holder, which holds the plate along the bottom edge and fastens to the plate with two padded screws. For alignment purposes simply use a piece of cardboard in place of the holographic plate. Do not use an actual plate until your set-up is completely aligned and ready for exposure. Practice placing plates into the holder with your eyes closed so that you are prepared to use this during exposure (when the room should be totally dark!).

f) Objects. You can use any object you wish. Typical objects are matchbox cars, toy soldier-type figures, or anything else that has an interesting 3D shape. The object should be reconstructed at its original size. Interestingly enough, whether or not you are able to reconstruct the entire object has nothing to do with the object size. As long as the object beam illuminates the entire object, you will be
able to reconstruct the entire object. The higher the contrast between the shiny and non-shiny parts of your sample, the better the holograph will be.

g) We will use 2.5” square hologram plates. These plates are sensitive to room light, so make sure you do not expose them to room light at any point. The only light hitting your plate should be the laser light during exposure!

As you align the holography set, keep in mind the following:

a) The alignment should proceed much as the alignment process did for the Michelson interferometer. All mirrors should be flat, with their surfaces perpendicular to the table top. First align the beamsplitter. After the beamsplitter align the two diverging mirrors (with additional flat mirrors if you need to increase path length). For all mirror alignment, first turn the mirrors so that the laser is doubled back on itself. Make sure the tilt is aligned (the laser beam shouldn’t change height), and then rotate the mirror so that your laser is directed in the correct direction.

b) The laser beam should travel at the same height throughout the entire set-up. The alignment tricks described in a) are used to ensure this.

c) Make sure that you have enough space to expand the object beam to the point where it illuminates the entire object. Be careful, however, you don’t want any of the object beam light to hit the plate (except after scattering off of the object). This is a trade-off. The closer the object is to the plate (and the smaller the object is relative to the plate), the ‘more’ 3D the object will appear. However, if you get too close to the plate, your object beam could directly hit the plate (without first scattering off of the object), which would expose your plate with light carrying absolutely no information about your object.

d) Make sure the reference beam is large enough to cover the entire plate.

Once you have finished alignment, place the object on the object stand and make sure that it is directly in the middle of the object beam. It is very important that once you have the optics set up, you record the configuration of your optics with care to record the exact distances involved. This is because after you have exposed and developed your
holograph, you will want to use this hologram to create a 3D reconstruction of the object you imaged (this is the whole point of the lab!). In order to do this you will need to reconstruct the exact optical set-up you used to expose the plate (this is not exactly true, in actuality; you need only reconstruct the reference beam arm of the set-up). At this point you are ready to place the plate in position.

Turn on the green safety lamp and make sure it is directed away from the optical set up. Turn off the room lights and make sure that there is absolutely no stray light in the room. Close the curtains surrounding your area so that your optical table is in total darkness. You will also need to block the laser beam such that absolutely no light is hitting the plate holder. There will be a special shutter constructed for this purpose. Ideally, the shutter set-up is not attached to the optical table in any manner. This is because when we start our exposure by opening the shutter, we do not want to exert any sort of force on the optical table, as the resultant vibrations would destroy our hologram. If the shutter is mounted on the table, be very careful, when opening and closing it, that you do not shake the table.

At this point, put on a Nitrile glove, and remove your plate from its photo-protective box. You will need to place the plate such that the side with the emulsion is facing the laser light. On the edge of the plate, touch the front of the plate with a moist, ungloved finger. If the surface is sticky, this is the side with the emulsion on it. Place the plate in the plate holder and tighten the screws. It is advisable to put a mark in one corner with a razor blade so that you remember the orientation of the plate. At this point your optical set-up is aligned, the plate is in place, and you are ready to expose. The green safelight does not produce much light, you will have to wait a while for your eyes to get accustomed to the dark. Also, before you turn off the lights, make sure that everybody knows what their respective jobs are. There should be one person responsible for putting the plate in the holder, one person should be in charge of the shutter, one person should be timing, and one person should be in charge of the light-tight box which will hold the plate one you have exposed it. Some one will most likely need to be holding the green light near to the plate mount while the plate is mounted. Also, make sure everyone else
in the room who is not in your group is aware of what you are doing, so that no one opens
the door or the curtain or makes excessive noise.

Turn off the green lamp and wait a minute or so to allow any vibrations on the table
to die away. After this time is up, turn carefully remove the shutter from in front of the
laser (making sure not to shake the table or optics) and expose for 10 seconds.
Holograms are extremely sensitive to vibrations. This is because the image recorded
depends on the interference of wave fronts on the length scale of wavelengths (632.8nm).
For best results, it is recommended that you do not move or even breathe heavily during
exposure (tell the other people in lab to sit still and not breathe as well!). Additionally,
sound waves from music or conversation can cause vibrations, so try not to talk during
exposure. After 10 seconds replace the shutter, remove the plate from the plate holder,
and place in the photo-protective box. You may now turn on the lights, move, talk, and
breathe. You are now ready to develop your hologram.

Note: You will probably want to expose two holograms in the last week of the lab. They
can be developed simultaneously, which will save a lot of time.

Developing Your Hologram (this will be done by TA)

The developer chemicals used are, for the most part, non-hazardous. However, the
chemicals do contain small amounts of chemicals the EPA considers hazardous. You
**must** use gloves while developing your holograms. Make sure you properly dispose of
the chemicals once you are done developing. Developing will be done in my MNTL
research lab. Make sure all sources of outside light are covered with the black matting
material. Again, you need to wait for some time for your eyes to adjust to the green light.
Make sure you have someone in charge of timing and someone in charge of lighting. The
person holding the lamp may need to position the light very near to the person doing the
developing, as it is so weak.

The development chemicals will be stored in ~1L bottles labeled “Part A”, “Part B”,
“Bleach”, and “Wetting Solution”. You will have 7 trays. Make sure that all processing
is done with the special Green safety light. Do not expose your plate to any light other
than the green safety light until you have finished the bleach. In the first tray you will mix equal parts of developers “A” and “B”. You only need enough developed to cover the hologram, there is no need to fill the developer tray more than 1cm from the bottom. You will rinse your hologram in DeIonized water after every step (except the final wetting solution bath). The following table shows the development process, each step should be done in a separate tray.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Time</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developers A + B</td>
<td>20 sec</td>
<td>Gently slush the solution around. The plate should turn dark.</td>
</tr>
<tr>
<td>DI Water Rinse</td>
<td>Up to 3 min</td>
<td>Place in rinse tray. Agitate for at least 20-30 seconds, and up to 3 minutes.</td>
</tr>
<tr>
<td>Bleach</td>
<td>40-60s</td>
<td>Keep your slide in the bleach until the emulsion clears from the surface, plus 10-20 seconds</td>
</tr>
<tr>
<td>DI Water Rinse</td>
<td>3 min</td>
<td>Gently slush water</td>
</tr>
<tr>
<td>Wetting Solution</td>
<td>20-60 seconds</td>
<td>Make sure surface is evenly coated with wetting solution. Stand hologram on side on paper towel, wait to dry.</td>
</tr>
</tbody>
</table>

The hologram should now be developed. It is no longer sensitive to room light. Take a small white sticky label and label your hologram (preferably on the edge of the hologram, on the back side).

Viewing Your Hologram

To view your developed hologram, place it back in the plate holder with the emulsion side facing the laser beams. Block the object beam and make sure the object is no longer in your set up. Make sure the expanded reference beam is hitting the plate. Look through the plate, from the back side of the plate. If the plate is in the same position that it was exposed in, and your laser beam hasn’t changed, you should see a holograph of the
object you exposed in the position where the object was initially placed!! It can sometimes be tricky to see the object, so don’t give up immediately. On the other hand, it is possible that something went wrong during exposure or development without you knowing…this happens, it’s not the end of the world. Your grade for this lab depends on the quality of your work and the quality of the lab book. The quality of the lab book fundamentally depends on its honesty in reproducing your actions in lab and accurate reporting of your results, not necessarily on whether you were successful in making a holograph, though this would be ideal!!