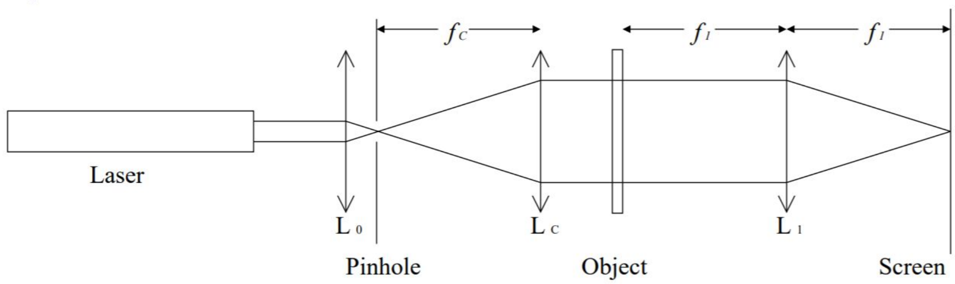
Fourier Optics Lab Book

Feb 4, 2019:

- Goal of the day:
    - Go over lab manual and get understanding of what the experiment is and what different steps we need to take - will allow us to manage our time and organise ourselves.
    - Go over equipment to make sure we have everything needed
    - Background research.
        - Starting point check out youtube video for better idea of what experiment does: https://www.youtube.com/watch?v=wcRB3TWIAXE

Fourier Optics Experiment Outline:

1. Frequency Analyzer:



- take photos of the resulting diffraction pattern
- the object is a diffraction grating which you can change
    - start with a simple grating and then try out more complicated ones to see what the resulting pattern looks like.
    - analyze the pattern to see if it agrees with theory

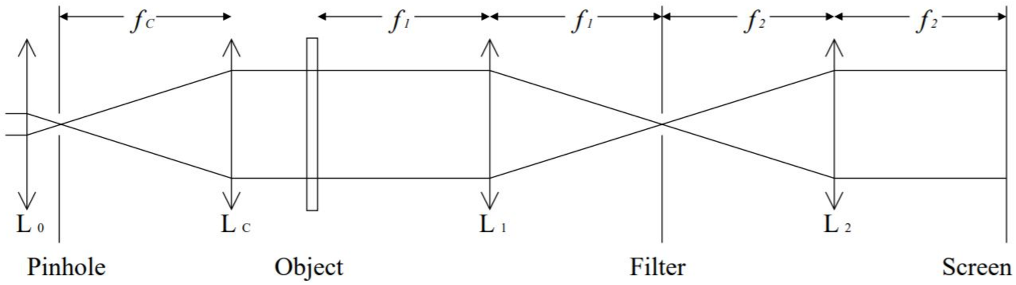
2. Uni-dimensional Periodic Functions:

- using any slides that present a periodic pattern will find spatial frequency using two methods
- one if using is traveling microscope to find the distance between gratings lines
- other is by measuring the diffraction grating and using equation 21
- try with other gratings (different directions, spherical)

3. Non-Periodic Functions:

- simple slit are non-periodic (pulse functions)
- figure out an analogous bandwidth theorem for position spatial frequencies
- show its valid by measure patterns of slits with different width

4. Inverse Fourier:



- test with this setup with any slide and verify it reconstructs

5. Spatial Filtering:

- want to be able to remove a part of the Fourier transform before transforming the diffraction pattern back to the image
- the zero frequency is found at the optical axis so a low pass filter only lets light near the origin pass where as a high pass filter only lets like radial away from the origin to pass

5.1 Uni-dimensional Filtering:

- build a high pass and low pass filter and test

5.2 Bi-dimensional Filtering:

- take a slide with different spatial frequencies (14, 20, 21) determine which regions have higher or lower spatial frequencies
- build a high pass and low pass filter
- test using image of a grid (slide 11) get only diagonal dots to pass

5.3 Image Processing:

- use cloud chamber simulation photograph (22) remove large tracks leaving only the curved ones using appropriate filters
- build filters which let you individually reconstruct the letters in the AB slide
- build filter which removes dots from photos of half-tone image (side 24)

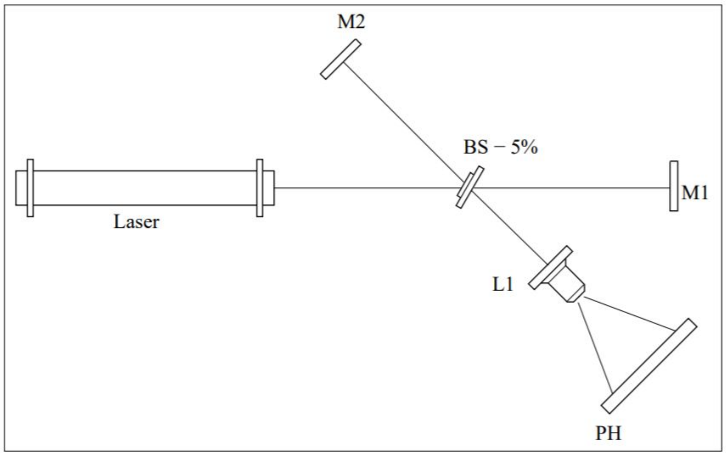
5.4 Supplemental Activities: *If time permits

- do things you find in textbooks
- prove the convolution theorem for Fourier transform

6. Holography:

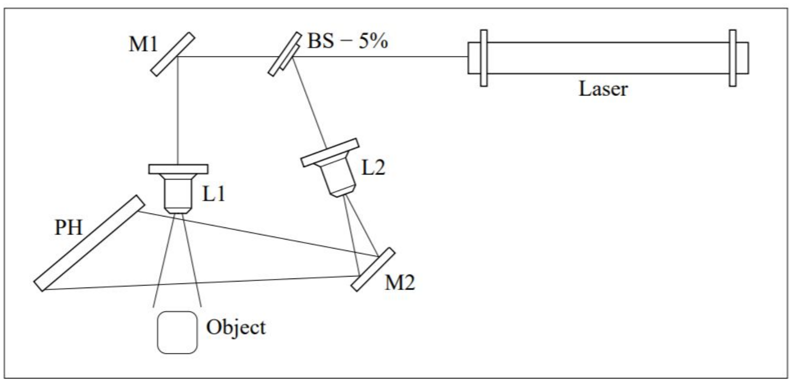
- a hologram is able to reconstruct a wavefront, we will use holographic film to do this

6.1 Michelson Interferometer:



- want system to be as stable as possible

6.2 Transmission Hologram:



Feb 7, 2019:

Goal of the Day: Perform the first set-up and test it out with different gratings to gain a good understanding of how to position the different lenses and mirrors.

- Began initial setup of fourier transform
- Was able to get all but the camera set up

- CAREFUL to make sure the microscope lens is in the good way - resulting beam should not look like a tiny dot!

Feb 11, 2019:

Goal: Figure out how to take good photos of the diffraction pattern and being image analysis process.

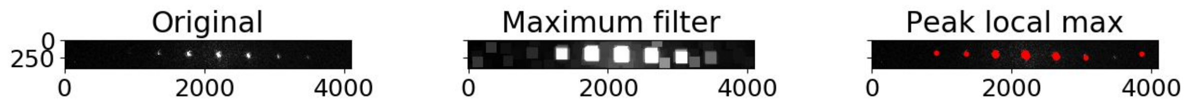
- Played with camera settings to get best photos
- EQ1409 (grating?)
    - Found best results with 1s shutter speed, F13, ISO800 (100-0670, 100-0669)

EQ1408:
- 0.8s, F13, ISO800 (100-0675)

EQ1415:
- 0.8s, F13, ISO800 (100-0680)

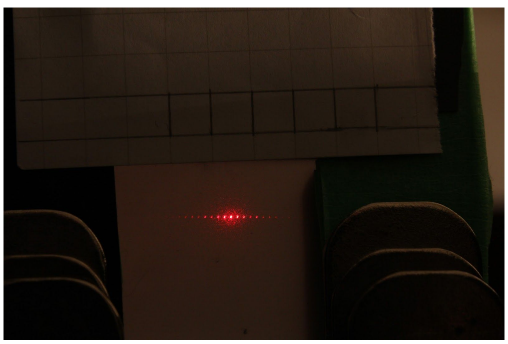
Began initial image processing:

- able to identify dot position and trying find line which they all lie on
- plan to then get brightness value along that line which we can then fit with gaussian

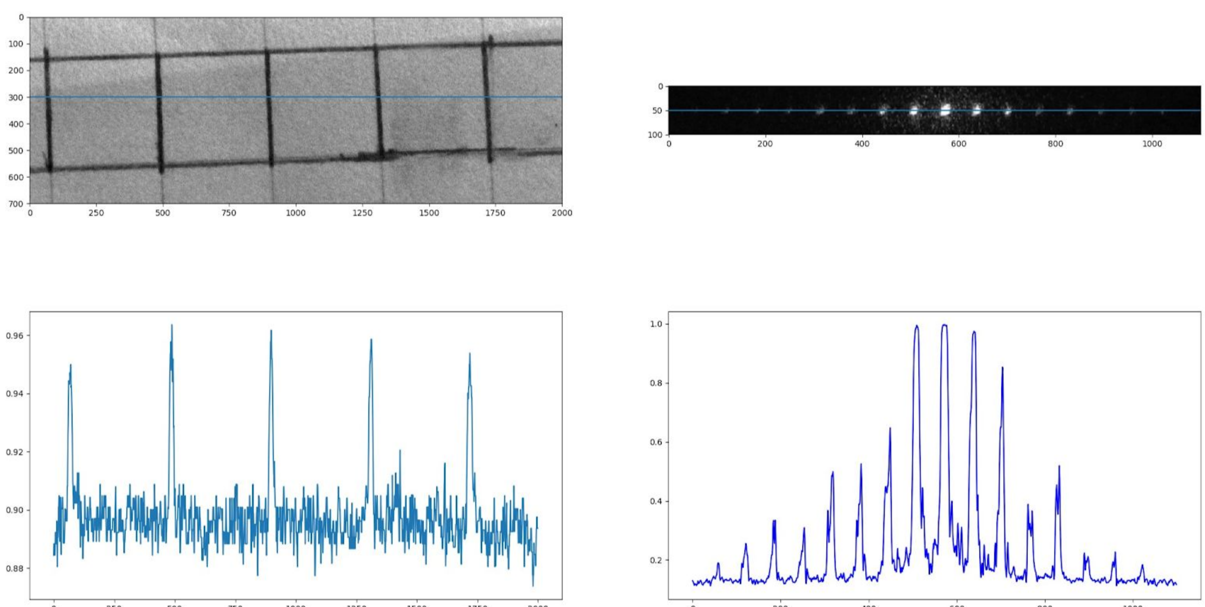


Feb 13, 2019:

-needed to retake photos to have graph paper in view to get scale for analysis
-was able to get proper lighting to see both graph paper and the diffraction pattern



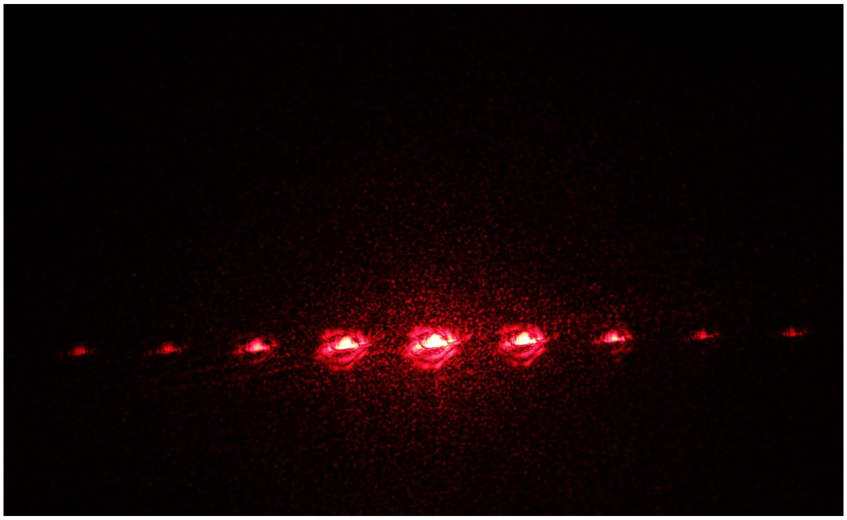
-was able to create histogram like plot to show pixel brightness along certain line



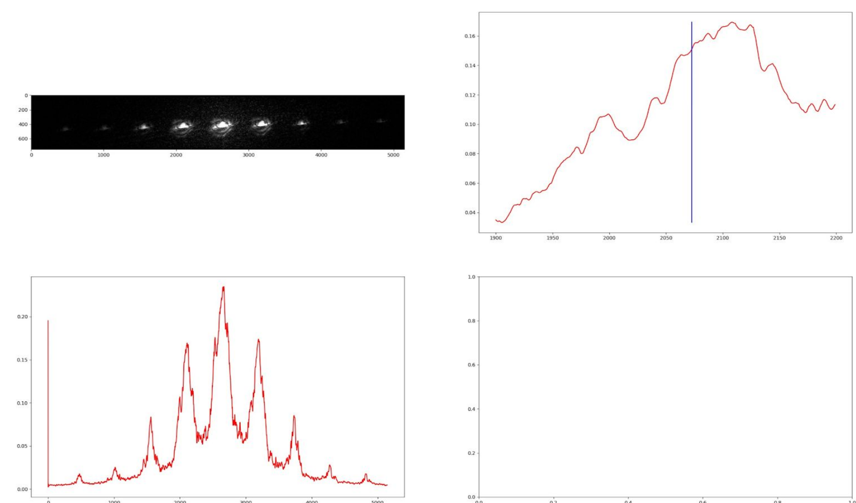
-made plots for both the graph paper and the diffraction pattern with the goal to get a scale from the graph paper then to fit the peaks to get coordinates of the diffraction pattern peaks

Feb 18, 2019:

-talked to Professor Sankey and he recommended to realign our setup to reduce systematic noise



-we got new photos of the diffraction batter by aligning the camera with the optical axis and placing it at the focal point instead of taking photos of the pattern on the screen



-this is the histogram of this new diffraction pattern
-tried out a few techniques to get a rough peak position
    -local max
    -weighted average of x-values
-we can then use these rough estimations to get an error on our data, which we can use to fit the theoretical model

Feb 22, 2019:

-goal today is to get photos of more images
-we will then have them on record for further analysis

EQ1408:
- Narrow grating horizontal
- 1/320s, F13, ISO800 (100-0700)

EQ1402: (edit feb 27th: I dont think we should use this since we are unsure which aperture the light went through)
- 1/200s, F13, ISO800 (100-0675)
- Thin slit (multiple slits with different widths)

EQ1407:
- Narrow grating horizontal (larger spaces than EQ1408
- 1/1250s, F13, ISO800 (100-0711)

EQ1413:
- Grid
- 1/1250s, F13, ISO800 (100-0712)

EQ1418: Single slit
- Large horizontal slit (turned vertical)
- 1/1250s, F13, ISO800 (100-0718)

EQ 1405:
- Square aperture approx. 2mm
- 1/160s , F13, ISO800 (100-0725)

EQ 1424:
- Lines of variable spacing
- 1/500s , F13, ISO800 (100-0727)

EQ 1405 (square) & EQ 1408 (thin multiple slit, lines horizontal):
- 1/250s, F13, ISO800 (100-0729)

EQ 1418 (single slit - horizontal) & EQ 1413 (mesh/grid): not giving anything really

EQ 1408 (multiple slits, vertical) & EQ 1407 (multiple slits horizontal):
- 1/800s , F13, ISO800 (100-0731)

UPDATED OUTLINE OF REPORT:

1. **Showing that set-up is indeed FT**: With unidimensional periodic functions test out the fourier transform properties of our optical set up:
    a. A periodic grating will only (or should only) have 1 frequency in fourrier space
    b. Measure this frequency using a traveling microscope as a lines/m measure
    c. Using the optical set-up take photos of the grating. Analyse them to obtain a measure of the frequency of the grating (nu = x' / lambda * f) . This will test the theory.
    d. If possible, compute the FT of the aperture function and try to fit it to the resulting intensity data from the image. ***MAYBE NOT NECESSARY
    e. For this we can take 3 different gratings:
        i. EQ 1408 (mulitple slit)
        ii. EQ 1407 (multiple slit) larger spaced slits
        iii. EQ 1413 (mesh pattern - 2 frequencies 1 for x and 1 for y which should be the same)

2. **Bandwidth Theorem:** Use non-periodic functions. Determining bandwidth theorem that relates spatial frequency (nu) to spacial distance (x) on aperture.
    a. Example of non-periodic function is: single slit, any non-symmetric slide
    b. For this we need also 3 gratings (so we can compare the results amongst different)
        i. EQ1402 (single slit)
        ii. EQ1424 (varying spaces with mountain pattern)
        iii. EQ1405 (Square)

3. **Convolution Theorem**:
    a. To convolve 2 different gratings we need to make the light pass through both of them.
    b. Convolution theorem: conv. In real space = multiplication in FS
    c. To show the convolution theorem, we can:
        i. Calculate the FT of the aperture functions of the two gratings in question
        ii. Mulitiply the two FT and square them (call this function F(v))
        iii. Observe on our equipment the diffraction pattern of light going through the two different gratings
        iv. Fit F(v) to the intensity curve from our experiment - should be a good fit!
        v. For this take 2 different "convolutions":
            1. EQ 1405 (square) & EQ 1408 (thin multiple slit)
            2. EQ 1408 (multiple slits, vertical) & EQ 1407 (multiple slits horizontal)

d. OR: take into account the pinhole as another grating (single slit) and improve our fits by convolving them.

Feb 25, 2019:

Re-thinking the experiment and analysis methods = more research and understanding of what is going on. New plan:

- Our ideas on how to prove convolution theorem are wrong.
    - The convolution happens on the diffraction grating itself where the aperture function is a convolution between delta functions and square functions (width of the slits). -> cite textbook!
        - All the images taken last time where we superimposed gratings are not good for use.
    - The envelope we see over the interference pattern of our gratings in the data should be coming from this convolution. How to test this hypothesis?
        - Measure the grating parameters using traveling microscope
        - <u>Find an error estimate on the data</u> and fit a theoretical model (*theoretical model:* we can represent the aperture function as a general mathematical expression. Then, if we take the fourier transform of this function and square it we should get the intensity function to fit to our data). See if we can retrieve the same parameters (ie compare the fit parameters to the real grating parameters)
        - This will show that :
            1. the intensity pattern we observe is the square of the FT of the aperture function.
        - To show that the convolution theorem holds we know that:
            1. The aperture function for a simple grating is a convolution of delta functions and square functions. In Fourier Space this should be a multiplication of the FT of the delta function and the FT of the square function (by the convolution theorem). Then if we divide our data by the FT of the square function, we should get back the FT of a sum of delta functions - this will simply be the interference pattern of the multi-slit diffraction grating!
    - With this, we can show that both the convolution theorem holds AND that the experimental set up we have does indeed allow us to measure the Fourier Transform of the aperture function.
- Bandwidth Theorem:
    - We have 2 different non-periodic gratings (single slit and square aperture) that we can use. We will use the single slit grating to derive a bandwidth theorem relating x and nu_x and verify it with the square aperture data.

Feb 27, 2019:

Measuring the parameters on our gratings: using microscope EQ1553
** All slides have dimension:

EQ1418: (Single Slit)
- Width of the slit: [**13.10** +/- 0.05 cm] - [**13.00** cm +/- 0.05 cm] = 0.1 +/- E cm

error estimate to be done for report for the sum of two measurements check textbook!*
*** will be the same for all the measurements made in this section. Error calculation will be done later.*

EQ1408: (Multiple Slits Grating thin lines)
- Width of the slits: [**13.10** +/- 0.05 cm] - [**13.075** +/- 0.05 cm] = 0.025 +/- E cm
- Width of the dark lines: too thin to measure with the microscope

EQ1407: (Multiple Slit Grating with thicker lines)
- Width of the slits: [**13.10** +/- 0.025 cm] - [**13.0375** +/- 0.052 cm] = 0.0625 +/- E cm
- Width of the dark lines: [**13.0375** +/- 0.025 cm] - [**13.00** +/- 0.025 cm] = 0.0375 +/- E cm

EQ1405: (Square Aperture)
- Side of square: [**13.20** +/- 0.025 cm] - [**13.00** +/- 0.025 cm] = 0.20 cm +/- E cm

EQ1413: (Grid)
- Width of the slits: [**13.2** +/- 0.025 cm] - [**13.15** +/- 0.025 cm] = 0.05 cm +/- E
- Width of the dark lines: [**13.15** +/- 0.025 cm] - [**13.10** +/- 0.025 cm] = 0.05 cm +/- E

Error estimation:
- Statistical error in our measurements come from the lenses:
    - The amount of dust collected on them, minor scratches etc.
    - Take 10 photos of the same grating pattern with minor modifications to set-up (such as wiping down lenses or shifting mirrors slightly)
    - Measure the deviation between all these photos. This should be a good approximation for the error on all of our data.
        - The maximum intensity of each photo when analysed should be the same (since all 10 photos will be taken with the same exact settings). The only difference between the maximum intensity would thus be due to the statistical errors of our experiments.
        - To estimate the uncertainty, we can then take the maximum intensity value of each photo and plot it. We can fit this plot with a horizontal line and force the error bars on intensity until we get a reduced Chi^2 ~ 1 (like in the tutorial). This uncertainty should be the standard deviation of the maximum intensity.

- Grating used: Single Slit EQ 1418
- **EQ1418 error estimation picture numbers:**
  - Picture #: 0739 ; 0741 ; 0742 ; 0743 ; 0744 ; 0745 ; 0747 ; 0748 ; 0749 ; 0750
  - Settings on camera: 1/1250s, F13, ISO800