Week VI:
INTERFERENCE EXPERIMENTS

Part 1 (October 23rd – October 26th 2012): VI.A, VI.B
Note: Please submit part 1 and part 2 together as one single lab report after part 2 is completed

VI.A  Young’s Double Slit Experiment with Laser Light (Report errors in measured quantities and do error propagation)

If light from a single source illuminates a double slit, the light emerging from the two slits can form an interference pattern provided that the difference in optical path length $\Delta$ for the two beams is smaller than the coherence length $\Delta x$ of the used light. For the highly coherent laser light this is an easy experiment, in which interference patterns up to very high order (= large optical path difference $\Delta$) can be readily observed. A maximum of intensity can be observed whenever

$$\Delta = m\lambda = a \cdot \sin \theta_m$$

Experiment: Place the laser at one end of the bench and place the component with the four double slit apertures directly in front of it. Observe the interference pattern on the screen at the other end of the bench. When you shift a double slit aperture into the laser beam, you will see an interference pattern consisting of equally and narrowly spaced fringes with a superimposed coarse pattern of periodic intensity variations.

☛ Observe and describe qualitatively the interference pattern changes under variation of the double slit spacing (ignore the variation of slit width).

Neglect at this stage the coarse pattern (i.e. the diffraction pattern of the individual slits which will be treated later) and concentrate on the observation of the narrowly spaced pattern produced by the interference of light emerging from the two slits.

☛ For a double slit aperture with the smallest separation of the two slits (0.25 mm), measure the spacing of the fringes in the interference pattern on the screen. Together with the measured distance from the double slit to the screen, determine the wavelength of the laser light, using the relation for Young’s double slit interference.
VI.B  Young’s Double Slit Experiment with White Light (*Report errors in measured quantities only*)

In this experiment you will observe that even very incoherent white light gives rise to interference fringes within the range of its very small coherence length.

Experiment: Set up the incandescent lamp at the left end of the optical bench and the frosted glass diffuser at the right end as an observation screen. Position a carrier with the double-slits as close as possible on the left side of the diffuser and observe the pattern on the diffuser by looking at it from the right side against the direction of light propagation. You should see sharp geometrical images of the double slit. Shift the carrier with the double slits gradually away from the diffuser towards the incandescent lamp.

☛ Observe the emerging patterns and describe your observation with simple sketches.

☛ What is the difference in the interference pattern produced by the double slit with small and large slit separations. Can you explain it?

Experiment: At a good condition for observing the interference pattern of the narrow spaced double slit, count the number (order) of observable interference fringes and estimate their separation.

☛ Estimate the coherence length of the light from your observations and the measured distance between double slits and diffuser (observation screen).

Experiment: By placing on the same holder, carrying the double slits, the photometer apertures try to cover with the edge of the wide (1 mm) aperture one of the double slits so that light is passing through only one slit.

☛ Observe the change in the interference pattern when light is passing through either one or both slits.
VI.C Interference by Plane-Parallel Plates and Measurements of their Thickness (Report errors in measured quantities and do error propagation)

When an exactly parallel beam of light falls on a plane-parallel plate, the optical path length difference \( \Delta \) between the two reflected beams (i.e., one reflected on the upper surface, and the other reflected on the bottom surface) is

\[
\Delta = 2d\sqrt{n^2 - \sin^2 \Theta_i}
\]

The two reflected beams will interfere destructively for \( \Delta = m\lambda \), while they will interfere constructively for \( \Delta = (m+1/2)\lambda \).

If the beam is slightly diverging, there is some variation \( \Delta \Theta_i \) around \( \Theta_i \) (i.e., \( \Theta_t \approx \Theta_i \approx 0^\circ \)), producing interference fringes. In order to find the angular separation of fringes, we differentiate the above equation by \( \Theta_i \):

\[
\frac{\Delta \Theta}{\Delta \Theta_i} \approx \frac{\partial m}{\partial \Theta_i} = \frac{2d \sin \Theta_r \cos \Theta_r}{\lambda \sqrt{n^2 - \sin^2 \Theta_r}}
\]

And we can get

\[
d = \frac{\lambda (\Delta m)}{2 (\Delta \Theta_i)} \sqrt{n^2 - \sin^2 \Theta_r} \frac{\sin \Theta_r \cos \Theta_r}{\sin \Theta_r \cos \Theta_r}
\]

Use this relation and the measured value of \( \Delta m/\Delta \Theta_i \) as shown in the left figure to determine the thickness of the plate.

Before you start to examine this interference problem experimentally, try to answer the following questions and confirm your prediction afterwards in the experiment:

- How does the interference pattern look like for (a) very small angles (\( \Theta_i = \Theta_t \approx 0^\circ \)), (b) larger angles? What kind of overall symmetry does the pattern have?
Experiment: Make the laser beam slightly divergent with an appropriate lens or lens combination. The thickness of the plates may vary slightly over the component, therefore it is best to produce a small spot on the plate, otherwise the interference pattern may be averaged out by some thickness variation of the plate. Three different plates will be studied:
Start with the thick glass plate. Reflect the laser beam under a very small angle.
☛ Study the symmetry of the pattern, especially close to $\Theta_i = \Theta_r \approx 0^\circ$. Confirm your predictions above.
☛ Try to determine the thickness using the interference pattern by measuring the number of fringes $\Delta m$ (for small angles $\approx 10^\circ$) within a certain angular range $\Delta \Theta$. Compare this thickness result to the one you obtain with a caliper.

Experiment: Observe the interference pattern of the microscope slide and make sure you observe the right pattern by checking the symmetry.
☛ What is the optimum condition to determine the thickness of the plate (measure over a spatial extent of about 10 fringes, if they are narrowly spaced)? Measure its thickness by using the interference pattern.

Experiment: Repeat the procedure for the very thin glass plate (microscope cover slide).
☛ Determine the thickness.
☛ Discuss the advantages of this method to measure thickness compared to direct measurements with a caliper.

VI.D Interferometer Experiments *(Report errors in measured quantities only)*

<table>
<thead>
<tr>
<th>In an interferometer the initial incoming light is split in two or more components with the help of semi-reflective elements and an interference pattern can be observed where the light components overlap again. The pattern depends on the path length difference.</th>
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<tbody>
<tr>
<td>☛ Make a sketch of a Michelson- and a Fabry-Perot Interferometer.</td>
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<td>☛ Determine for both by how much the mirror has to be moved to go from one interference maximum to the next.</td>
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Use the demonstration set-ups. You do not need to adjust their optical alignments.

**Caution:** Do not touch the mirrors or beam splitters – they are front surface and difficult to clean without damaging them.

Experiment: Observe the center fringe on the screen. Turn very slowly and carefully the micrometer as you count the cycles of the center fringe change (e.g., one cycle is from bright to bright). Move the movable mirror for at least 10 cycles of changes, and then measure the moving distance of the mirror by using the micrometer scale.
☛ Determine the wavelength of the laser with both interferometers.