Introduction to Optics
Work in Y1Lab

Short Tutorial on Optics
Safety & Good working practices

A. Lens Imaging (Ray Optics)

B. Single-slit diffraction (Wave Optics)
Technological Revolution in Optics

Communication by photons

- Telephony/data/internet

Massive optical data storage

- CD/DVD
- Blu-ray disc (25GB)

Precision laser machining

- Laser cutting
- Laser writing on human hair
- Photolithography for manufacture of computer chips

Medical laser therapy & optical imaging

- Corrective laser eye surgery
- 3-D laser imaging of cell
Optics has an important place in history

Optics, light & vision has been vital for human survival

Telescope observations forged our understanding of the Universe

Microscopes revealed a micro-universe

Today, Optics remains a key scientific diagnostic technique (e.g. imaging).

A new revolution in Optics has emerged with the birth of the laser, fibre optics, integration of optics and electronics, etc..
Historical debate on nature of light

**Particles**

**Waves**

Light = EM waves

\[ c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \]
What is Light? - Revisited

- Wave-particle duality
- Quantum Optics
- Lasers

Paradoxes in physics (blackbody radiation / photoelectric effect)
Quantisation of light (photons) $E=nh\nu$
Bohr model of atom
Wavefunctions / Probability
Diffraction of electrons

Planck / Einstein
Michelson
Maiman (Laser)
…
**Fundamentals of Optics**

**Reflection**
\[ \theta_r = \theta_i \]

**Refraction**
Snell’s Law
\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

**Imaging**
\[ \frac{1}{s} + \frac{1}{s'} = \frac{1}{f} \]
\[ m = -\frac{s'}{s} \]

**Diffraction**
Aperture
beam spread
Continuum of waves

**Interference**
double-slit screen
Finite no. of waves

**Polarisation**
Linear polarised
Elliptically polarised

**EM-theory**
Safety

• Laser Safety: Lasers produce a highly collimated (parallel) beam of light that the eye could focus to a very small spot causing retinal damage. Therefore, **NEVER LOOK DIRECTLY INTO THE LASER OR POINT LASER AT OTHER PERSONS**

• Electrical Safety: Never tamper with mains-powered electrical equipment. Consult a demonstrator if in doubt or your equipment does not seem to be working properly.

• Trip Hazards: In Optics Lab, you are often working in darkened conditions, so it is especially important that bags and coats are stowed thoughtfully so that passageways around benches are kept clear.

Your Laboratory Notebook

• Start by writing the day and time, and title of the experiment.

• As you do each part of the lab, it is essential to keep a clear written record in your lab notebook. However, do not spend a long time engrossed in your lab book - remember this is a practical laboratory, not an exercise in writing.

• Write clearly, draw lots of clearly labelled sketches, write down any conclusions you have drawn or decisions you have made. It is vital that you describe or draw what you actually see. Don't draw what you think you might get from a perfect experiment: you might be throwing away important details.
CONSTRUCTING RAY DIAGRAMS

O object; I image
s object distance; s’ image distance; f focal length

PRINCIPLE RAYS: (Any 2 are sufficient to construct image)
• Ray passing through the centre of the lens is undeviated.
• Ray parallel to the optical axis passes through a focal point.
• Ray passing towards, or away from, a focal point emerges parallel to the axis.

LENS CALCULATIONS

Thin lens formula
\[
\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}
\]

Magnification formula
\[
m = -\frac{s'}{s}
\]

In later lab-work: you’ll explore issues of real lens (e.g. finite aperture; lens aberration)
Before we proceed to first experiment…..

• Find a lab-partner & sit at one of the optical set-ups

A.
1. Open your lab-book and write date and time
2. Write heading “Introduction to Experiments in Optics”
3. Write sub-heading: “A. Thin Lens Imaging”
Aligning an Optical Bench

A good rule of optical alignment is to:

• place one item at a time on bench (starting at light source)
• ensure light propagates parallel to bench (rotate post of light source if necessary)
• optical components are centred (by adjusting post height) and
• optical components are at right-angles to beam path (by rotating post).
Expt 1.1 Imaging with a Lens

1. Switch on light source (supply at ~ 5V preset, do not adjust)
2. As object place slide of letter \( L \), in slot-holder on light source
3. Place \( f = 100 \text{mm} \) lens at object distance \( s = 150 \text{mm} \). Measure \( s \) with ruler from object to lens centre
4. Adjust position of ground-glass screen for sharpest image. Measure \( s' \).
5. Measure a dimension of object (\( h_O \)) and corresponding size in image (\( h_I \)).

Deduce magnification \(|m| = h_I / h_O\)

- Estimate an error for all experimental values measured \( s, s', h_O, h_I \).
Errors?

Four measured quantities

\[ h_O = \overline{h}_O \pm \sigma_O \]
\[ h_I = \overline{h}_I \pm \sigma_I \]
\[ s = \overline{s} \pm \sigma_s \]
\[ s' = \overline{s}' \pm \sigma_{s'} \]

Experimental measurement

\[ |m| = \frac{h_I}{h_O} \quad m = \overline{m} \pm \sigma_m \]

Theoretical prediction

\[ |m| = \frac{s'}{s} \quad m = \overline{m} \pm \sigma_m \]

Why is \( \sigma_{s'} > \sigma_s \)?

Error Propagation:

\[ z = \frac{x}{y} \quad \overline{z} = \frac{\overline{x}}{\overline{y}} \]

\[ \sigma_z = \overline{z} \cdot \sqrt{\left( \frac{\sigma_x}{x} \right)^2 + \left( \frac{\sigma_y}{y} \right)^2} \]

How might you estimate \( \sigma_{s'} \)?

Calculate the magnification (inc. standard error) for the two method.

Do they agree / are they consistent given the errors?
Experiment 1.2 Measuring focal length of lens

1. Use pin-hole slide as object

2. Angle mirror so you can see reflected spot of light on object slide. (You may not be able to see this until lens is near its focal length position)

3. Measure focal length $f$ by finding the position for minimum reflected spot size

Is focal length $f = 100$ mm?

Figure 3: Simple method for estimating focal length of a positive lens.
B. Wave-Optics: Single-slit Diffraction

Aperture (width $a$) causes light to spread (diffraction)

Near-field ($z < a^2/\lambda$): Fresnel diffraction
(complex mathematical form)

Far-field ($z \gg a^2/\lambda$): Fraunhofer diffraction
(simpler mathematical form; Fourier Transform)

Light pattern at any plane $z$ is the sum of secondary wavelets of the unobstructed aperture (including phases)
Problem: Far-field ($z \gg a^2/\lambda$) may not be convenient for lab bench. Solution: Use lens.

The far-field diffracted pattern can be visualised in the focal plane of a lens.

\[ \theta = \frac{x}{f} \]
Expt.2 Visual Observation of Single-Slit Diffraction Pattern

1. Replace white light source by 
Diode Laser

2. Visually observe diffraction pattern of variable slit on white screen placed at focal length of lens

- Note in your lab-book the effect of changing the slit width.
- With the central maximum peak of width ~10 mm sketch the diffraction pattern (to scale)
Far-field Single-Slit Diffraction Pattern

\[ I(x) = I_0 = \left[ \sin \left( \frac{\pi ax}{\lambda f} \right) \right]^2 \]

Positions of zeroes
\[ x_m = m(\lambda f / a) \]
\[ m = \pm 1, \pm 2, \pm 3 \ldots \]

Is this what you see?
Logarithmic Response of the Eye
Measurements with a Photo-detector

Measurements:
1. Quickly scan photodiode across diffraction pattern to get feel of its scale.
2. Note the voltage value of the central maximum and the first secondary maximum.
3. Locate the positions of the first zeroes \( (m=\pm 1) \). Hence calculate the slit width \( a \)

Instructions:
1. Switch on photodiode power supply and set voltmeter to 200mV setting.
2. Position central maximum of diffraction pattern to coincide with photodiode slit at centre of translation stage (~12.5mm on micrometer). You may need to rotate laser and move diffracting slit sideways to achieve this.

Diagram:
- **LASER**
- **bi-convex lens** \( f=500\text{mm} \)
- **Photodiode/slit assembly on translation stage**
- **Voltmeter**
- **diffracting object = single slit slide**

Formula:
\[ \theta = \frac{x}{f} \]
Final Comments

It is hoped that this introductory Optics session has given you:

• some useful practice in laboratory work (inc. lab notebook and errors)

• provided some groundwork for more advanced Optics you will perform in the lab later in the year.

• confidence in working in the UG laboratory