INTRODUCTORY GEOMETRIC OPTICS

EXPERIMENTS WITH LIGHT RAYS

Material:

1) Light ray box with five vertical slits.
2) Plane-, concave and convex-mirrors (metal), right-angle plane mirror combination.
3) Double-convex, double-concave and plano-convex cylindrical lenses, plane –parallel, circular and semicircular plastic elements.
4) Set of color filters, ruler, protractor.

General Procedure and Hints for Experiments:

Place light ray box between the positioners on the board, plug it in and switch it on, and observe the five diverging light beams emerging from the five slits on paper placed on the board. The small masonite plates allow you to block out beams to choose the number of light rays you want to use, while the multiple color filter allows marking and discriminating the light rays. In order to produce collimated parallel beams of light, needed in all experiments, place plano-convex lens into the holder in front of exit slits (flat side towards the lamp) and adjust its position carefully for optimum parallel beams (check on graph paper). Leave this lens in this position for all experiments. When inserting lenses for measurements, place them into the parallel beam symmetrically, such that the center beam is not refracted and can serve as an "optical axis" of your setup.

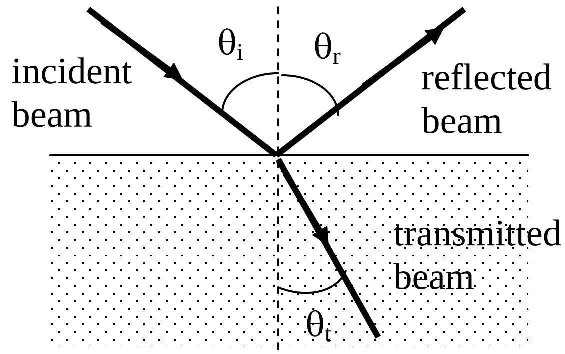
All experiments can be observed, mapped out and evaluated directly on ruled engineering paper. Map out on the paper the actual positions of the used optical elements and the traces of the light rays (starting with the incident parallel ones), and make the required evaluations of lengths with a ruler and angles with a protractor directly from the graphical record. Always place the transparent optical elements with the rough surface on the paper and observe through the opposite polished surface how the beams propagate inside the elements. (Only exception: Experiment I.D)

Week I:
LIGHT REFLECTION AND REFRACTION AT PLANE SURFACES

BACKGROUND PHYSICS:

a) Reflection Law: $\theta_i = \theta_r$

b) Snell's Law for Refraction: $n_i \sin\theta_i = n_t \sin\theta_t$



I.A Reflection from Plane Mirror ✍ *(Report errors in measured quantities only)*

Experiment: Reflect a single light beam from the plane mirror.

☛ Verify the relation between the angle of incidence θ_i and the angle of reflection θ_r for one angular position ($0° < \theta_i < 90°$) of the mirror.

Experiment: Reflect a beam of several rays (marked by color)

☛ Observe and understand the fact that the left and right side of the light beam becomes exchanged under reflection by a mirror.

I.B Reflection from Two Plane Mirrors Forming an α=90° Angle

Experiment: Observe the light reflection from the 90° Plane-Mirror Combination.

☛ How does the reflection depend on the angular position of the mirror combination? What is changing under rotation of the mirror combination?

☛ What is the general relation between the angle α formed by the two mirror and the angle δ formed by the incident and reflected beam?

I.C Light Refraction, Refractive Index n and Snell's Law

Experiment: Let a single light beam fall on the flat surface of the semicircular plastic element and observe the reflected and transmitted beam.

☛ Observe and note qualitatively how the relative intensity of reflected and transmitted beam varies under variation of the angle of incidence θ_i.

Experiment: Observe that if your light beam is incident exactly on the midpoint of the flat surface, the transmitted beam is not bent again when leaving through the circular surface.

☛ Why? Explain it with simple geometry.

Experiment: Use this latter geometry to measure θ_i and θ_t for one angle of incidence ($0° < \theta_i < 90°$). *(Report errors in measured quantities and do error propagation)*

☛ Determine the refractive index n of the plastic using Snell's law.

Experiment: Reverse the beam direction, (so that it is incident perpendicular to the circular surface), and observe refraction and internal reflection at the flat surface. *(Report errors in measured quantities and do error propagation)*

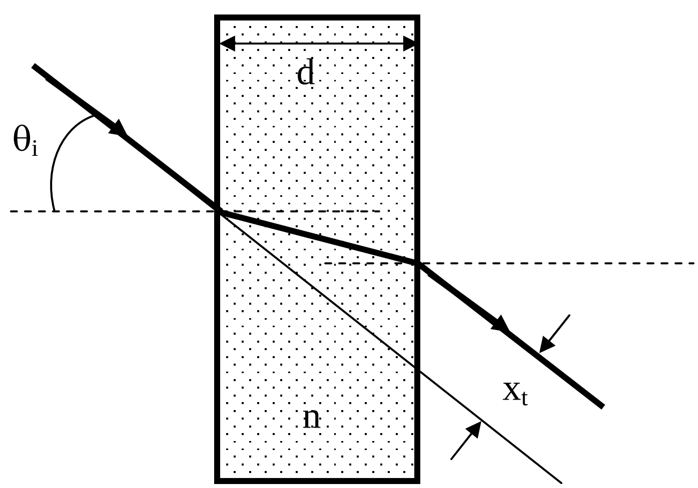
☛ Find and measure the critical angle for the onset of total internal reflection, and determine from it the refractive index n again.

I.D Light Beam Displacement by Plane-Parallel Plate *(Report errors in measured quantities only)*

Experiment: Let a single light beam fall – under different angles – on the plane-parallel plate, and observe how the beam, emerging on the other side, is displaced parallel to the incident one.

☛ Measure this displacement for one angle of incidence θ_i. ($0° < \theta_i < 90°$) and compare your measured result to the predicted relation (use n from activity I.C.)

$$x_t = d \cdot \sin\theta_i \cdot \left(1 - \frac{\cos\theta_i}{\sqrt{n^2 - \sin^2\theta_i}}\right)$$



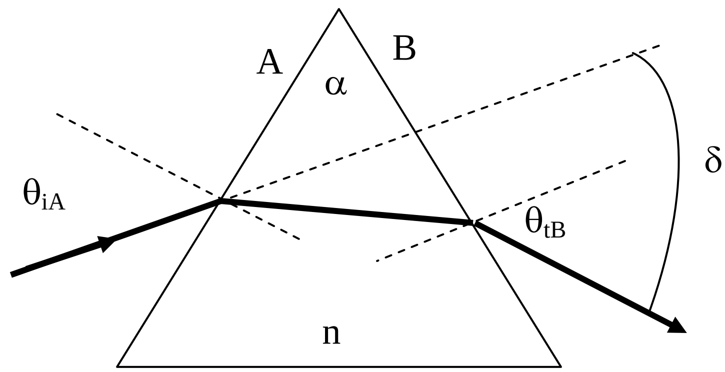
Experiment: Use a plane-parallel plate <u>polished on all sides</u>. Observe that the refracted light rays inside the optical element seem to disappear and are completely invisible, but reappear and become visible when the light leaves the plate.

☛ Think about and explain this "Mystery of the Disappearing Light Rays".

I.E Refraction and Reflection by a Prism

BACKGROUND PHYSICS:

Any optical element of transparent material with planar exterior surfaces is called a prism. Depending upon the geometry of the prism and the angle of incidence of the impinging beam, refraction and reflection within the prism will invert, reverse and/or displace the incident beam. Normally, interactions at two or more prism surfaces are required to produce the desired effect.



The simplest prisms have a symmetric triangular shape and are defined by the prism angle α. Application of Snell's Law for the light refraction at both interfaces A and B leads to the following general relation between the angle of incidence θ_{iA} ,the angle of transmission θ_{tB} ,the prism angle α, and the refractive index n:

$$\sin\theta_{tB} = (\sin\alpha)\sqrt{(n^2 - \sin^2\theta_{iA})} - \sin\theta_{iA}\cos\alpha \qquad (1)$$

The angle δ between the incident and transmitted beam defines the angular deviation of the light produced by the prism: it varies strongly under variation of the angle of incidence θ_{iA}.

For the minimum of δ, a very simple relation holds

$$n = \frac{\sin\left[\frac{1}{2}(\delta_{\min} + \alpha)\right]}{\sin\alpha/2} \qquad (2)$$

because $\theta_{iA} = \theta_{tB}$ and the prism can be split into two identical parts.

Experiment: Use the α=60° prism, and minimize δ.

Observe that $\theta_{iA} = \theta_{tB}$ for the minimum condition and that the light beam goes through the prism in a symmetric way.

☛ Determine n with the above equation (2). *(Report errors in measured quantities and do error propagation)*

Experiment: Applying total internal reflection of the light beam at the second (third….) interfaces, prisms are often used as devices to deflect or invert the incoming light. Set up the ***<u>90° prism</u>*** to obtain by total internal reflection

a) a 90° beam deflector
b) a 180° beam deflector
c) an image inverter (which inverts the order of two color-marked parallel beams as they appear when looking against the direction of propagation.