

# Experimental Physics 3 - Em-Waves, Optics, Quantum mechanics

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## Lecture 1

fcichos.github.io/exp3

Experimental Physics 3

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# Experimental Physics 3

## Welcome to the Experimental Physik 3 Course!

In this Experimental Physics 3 course, we will dive into to basic experiments and mathematical descriptions related to light propagation, electromagnetic waves and its material counter part of matter waves. In particular we will have a look at

- Geometrical Optics
- Wave Optics
- Electromagnetic Waves
- Matter waves and Quantum Mechanics

The fields of optics and quantum mechanics are nowadays very active research areas with a dynamically developing areas of optical technologies, high resolution microscopy and quantum information. All this builds on the foundations that are tackled in this course.

### Course Information:

# 1. Geometrical Optics

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Geometrical optics is an approximate description of light propagation in the limit of infinitely small wavelength, where all wave phenomena like diffraction can be neglected.

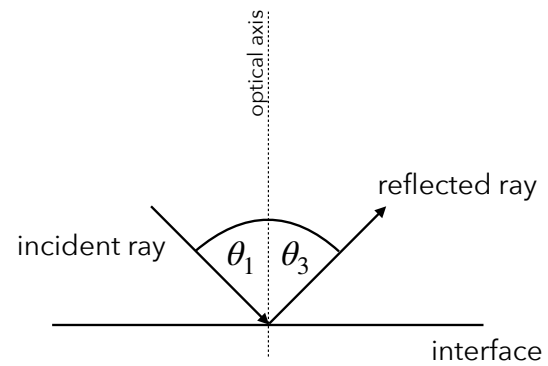
# Geometrical Optics - Assumptions

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- light rays emerge from a light source
- light rays are detected by a detector
- light matter interaction is characterized by a refractive index  $n$
- rays may be reflected and refracted at interfaces between media
- light propagates in straight line path (rays) in a homogeneous medium
- light bends to a curved path in inhomogeneous media  $n(\vec{r})$
- the speed of light is  $c = c_0/n$

# 1.1 Reflection

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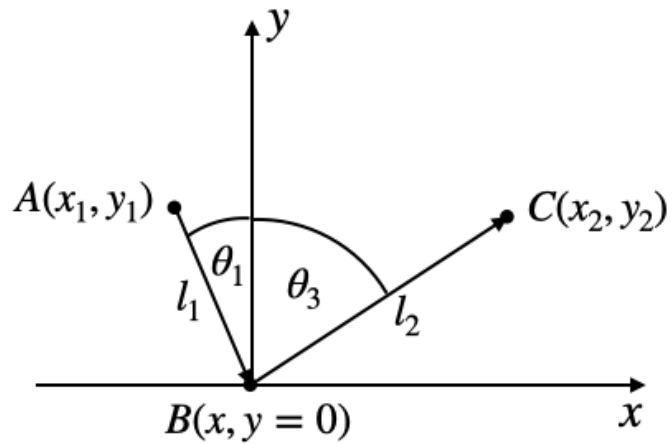


- light is reflected at interfaces

$$\theta_1 = \theta_3$$

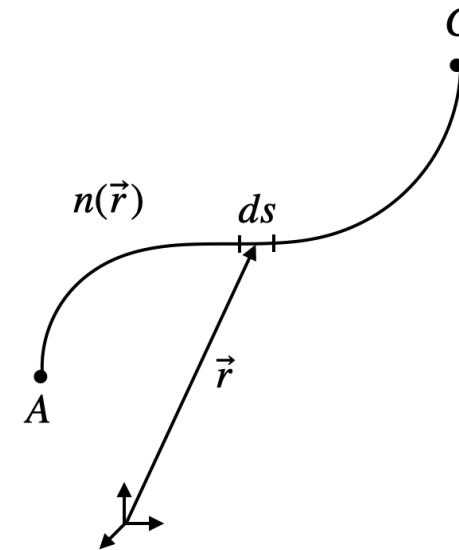
# Fermat's principle

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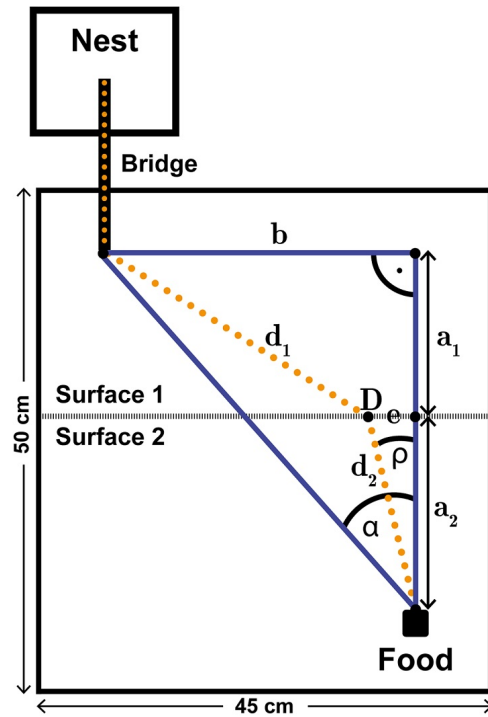
Light takes the path of shortest time.

A ray going in a certain particular path has the property that if we make a small change in the ray in any manner whatever, say in the location at which it comes to the mirror, or the shape of the curve, or anything, there will be no first-order change in the time; there will be only a second-order change in the time



$$\delta \int_A^C n(\vec{r}) ds = 0$$

# Funny Fact



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PLOS ONE

## Fermat's Principle of Least Time Predicts Refraction of Ant Trails at Substrate Borders

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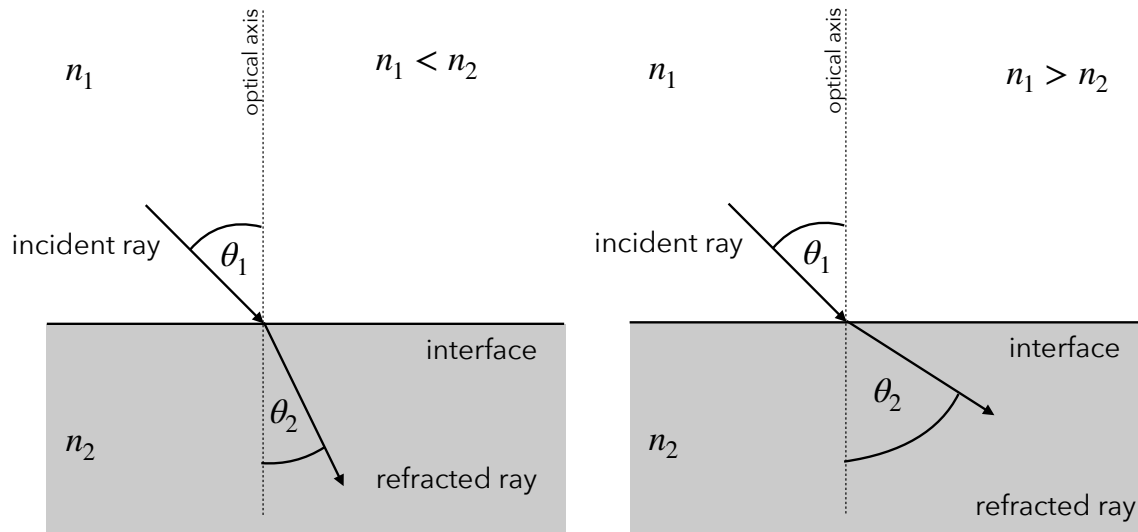


## 1.2 Refraction

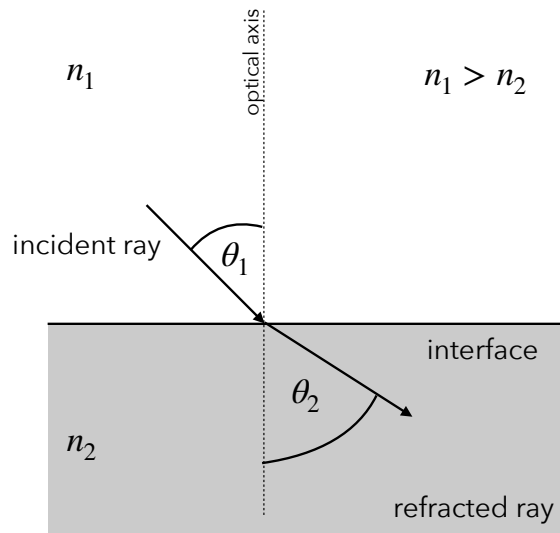
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- light is refracted at interfaces

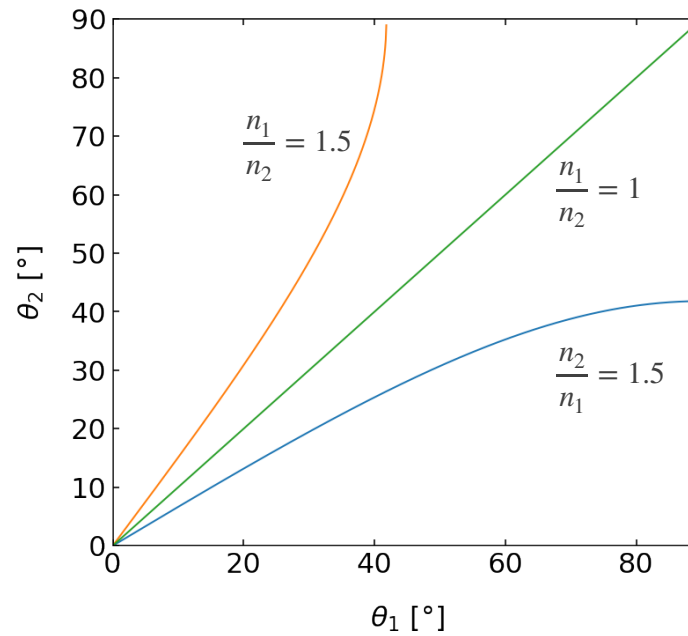
Snell's law  $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$



## 1.2 Refraction - Total Internal Reflection (TIR)



$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \quad \theta_2 = \frac{\pi}{2}$$

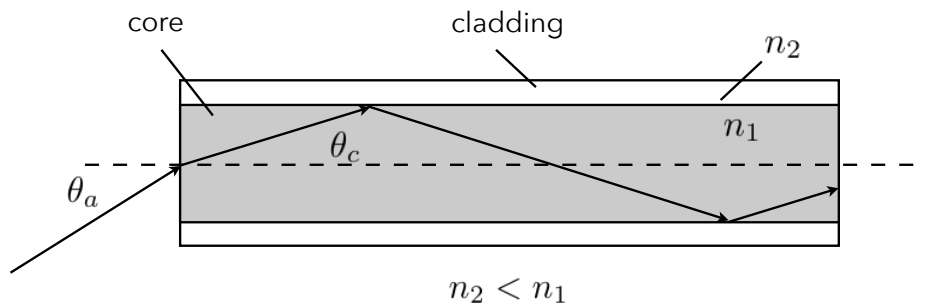


When going from an optical thick to and optical thin medium, total internal reflection occurs for

$$\theta_1 > \arcsin\left(\frac{n_2}{n_1}\right)$$

## 1.2 Refraction - Applications of TIR

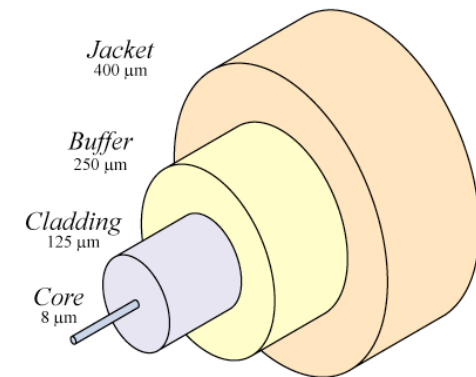
glass fiber for optical communications



$\theta_a$  acceptance angle

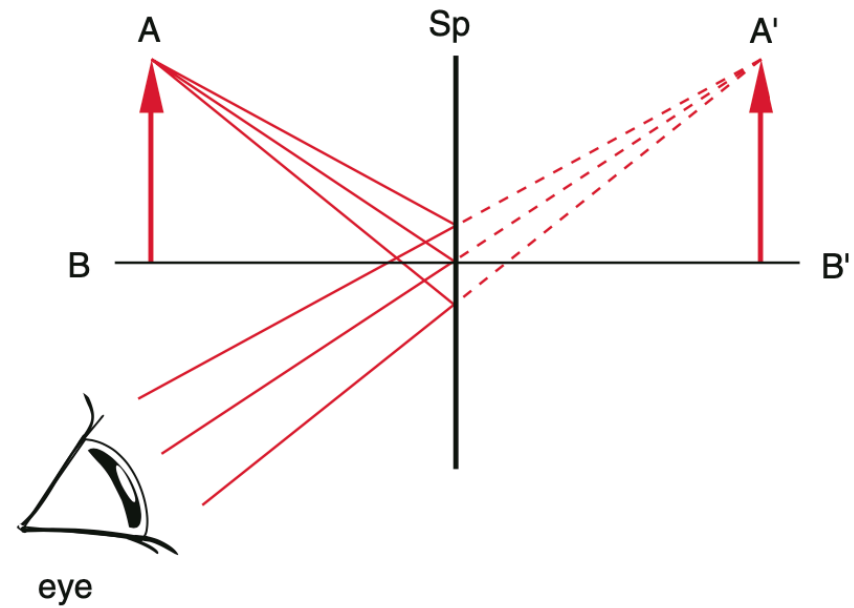
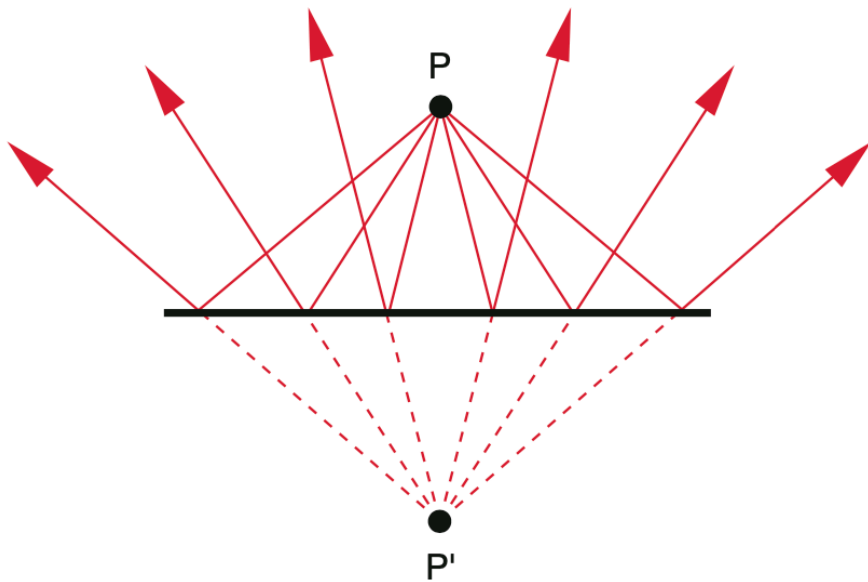
numerical aperture:  $NA = \sin \theta_a = \sqrt{(n_1^2 - n_2^2)}$

typical value:  $NA \approx 0.2$   $n_1 = 1.475$ ,  $n_2 = 1.46$



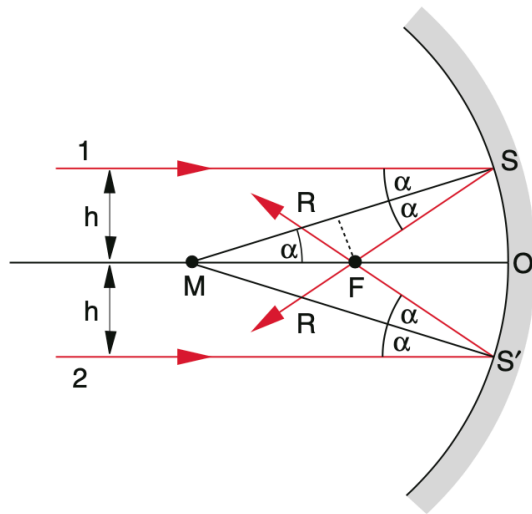
# 1.3 Mirrors, Prisms, Lenses - Mirrors

## Plane Mirrors



# 1.3 Mirrors, Prisms, Lenses - Mirrors

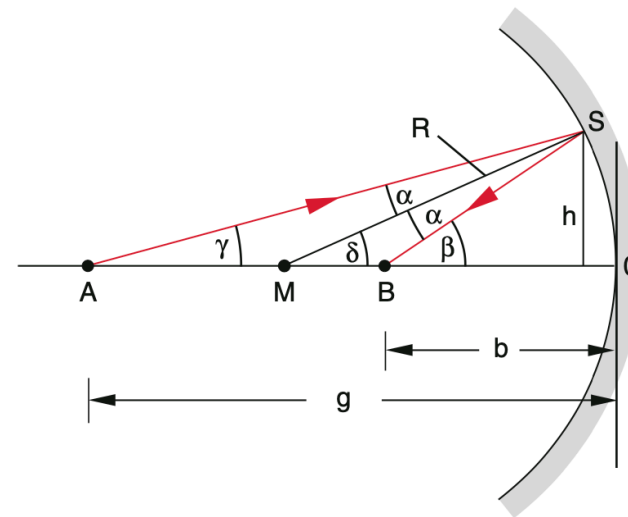
## Concave (spherical) Mirrors



### Focal distance

$$f = OF = R(1 - 1/(2 \cos(\alpha)))$$

$$f = R \left( 1 - \frac{R}{2\sqrt{R^2 - h^2}} \right)$$



### Imaging equation

$$\frac{1}{g} + \frac{1}{b} \approx \frac{2}{R} \approx \frac{1}{f}$$