Preparatory School to the Winter College on Optics: Advanced Optical Techniques for Bio-imaging

The Abdus Salam International Centre for Theoretical Physics

# Geometrical Optics I: refraction, reflection, lenses and image formation

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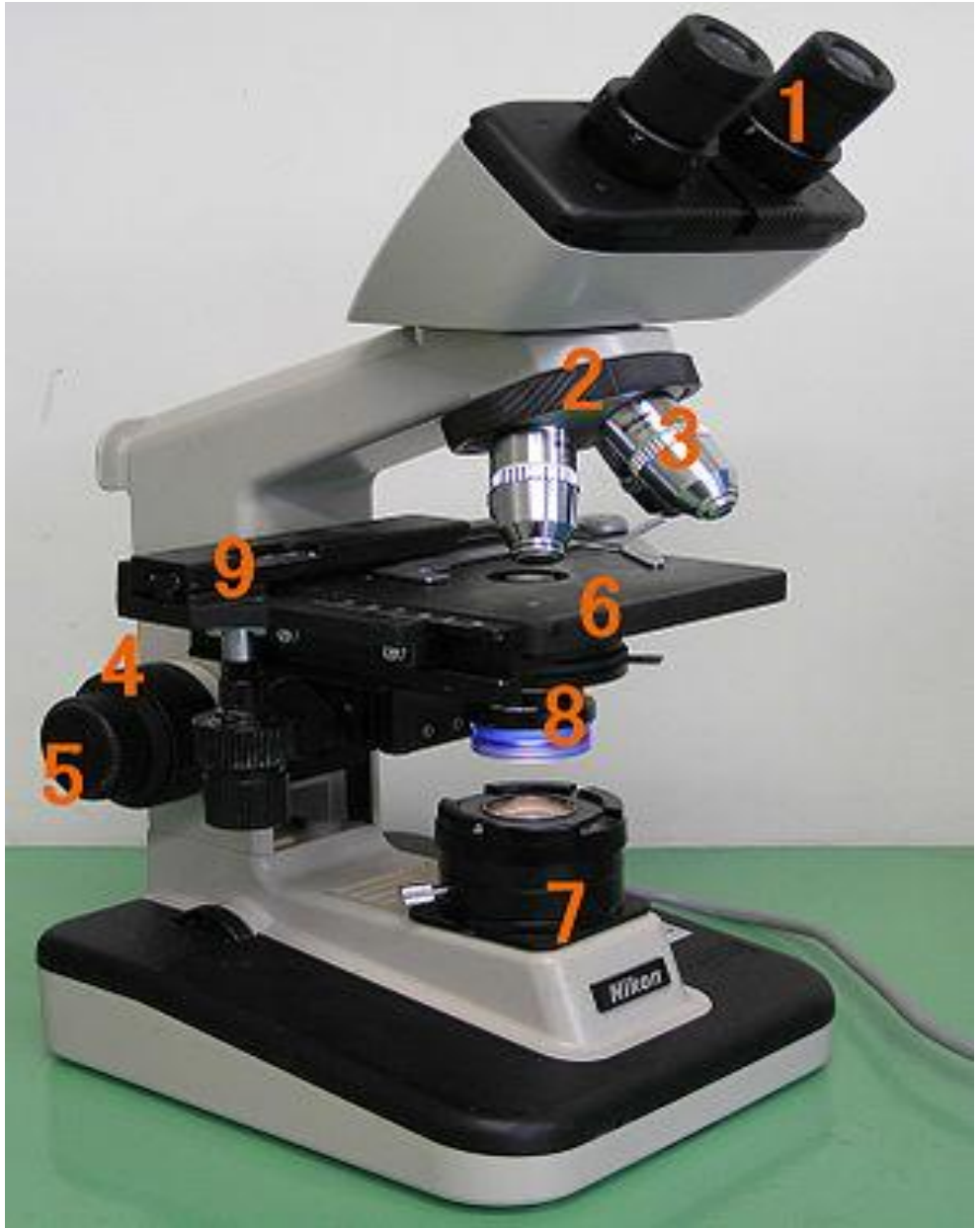
# Refraction, reflection, lenses, and image formation

Basic components
and their functions

What is inside?



# Topics:

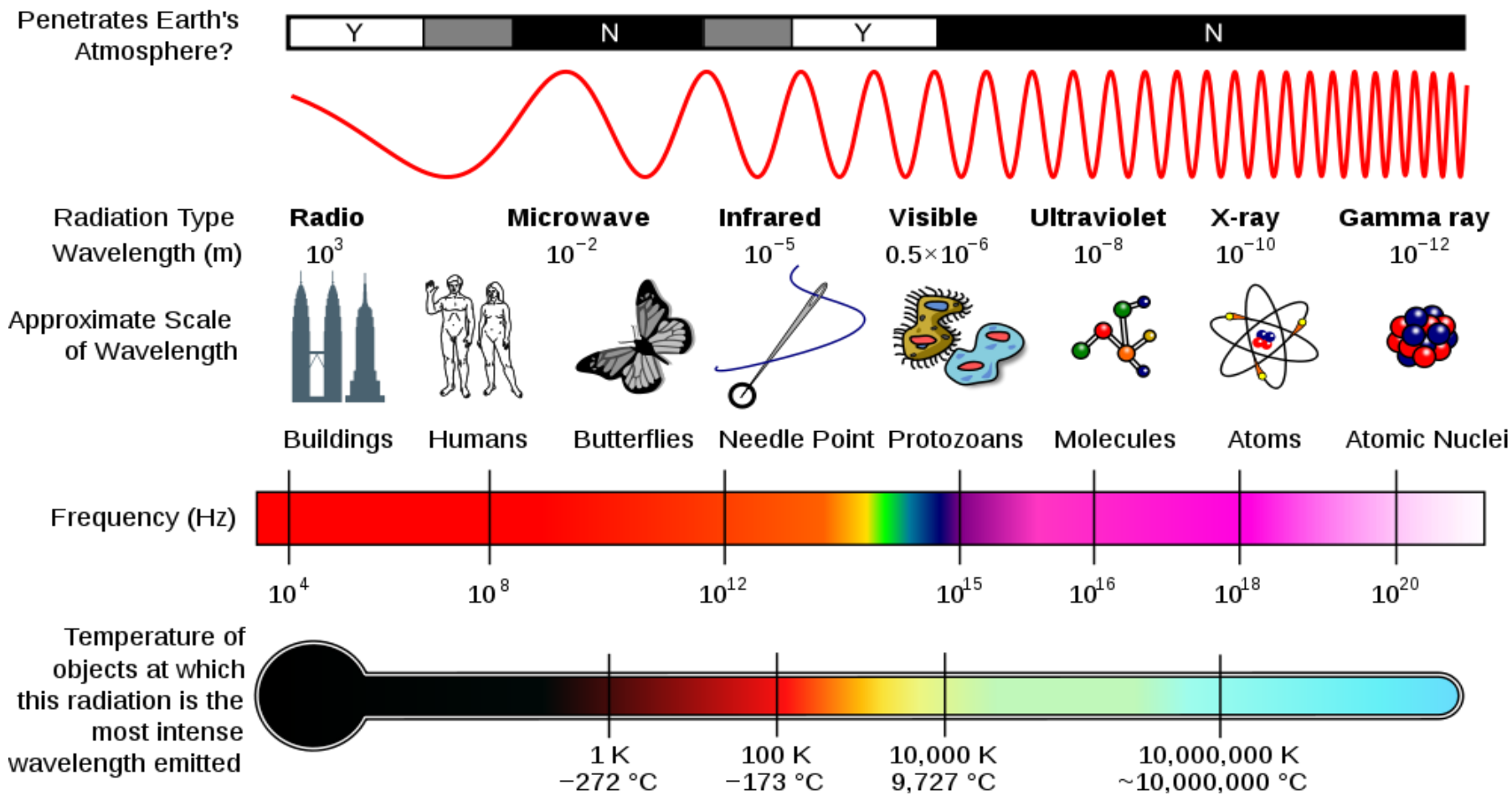
1. Properties o light

2. Light matter interaction

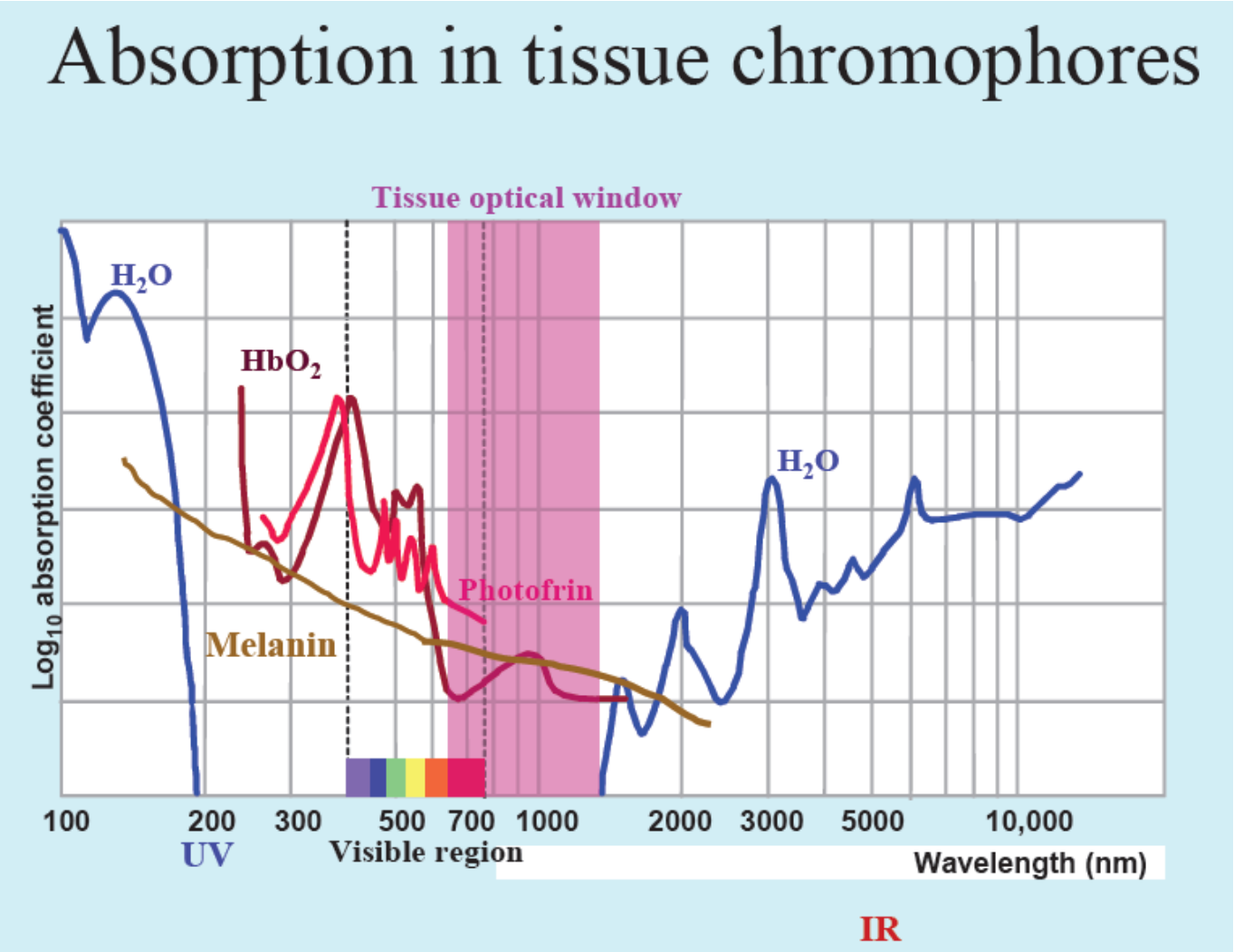
3. Refraction and reflection. Refractive lenses

4. Image formation

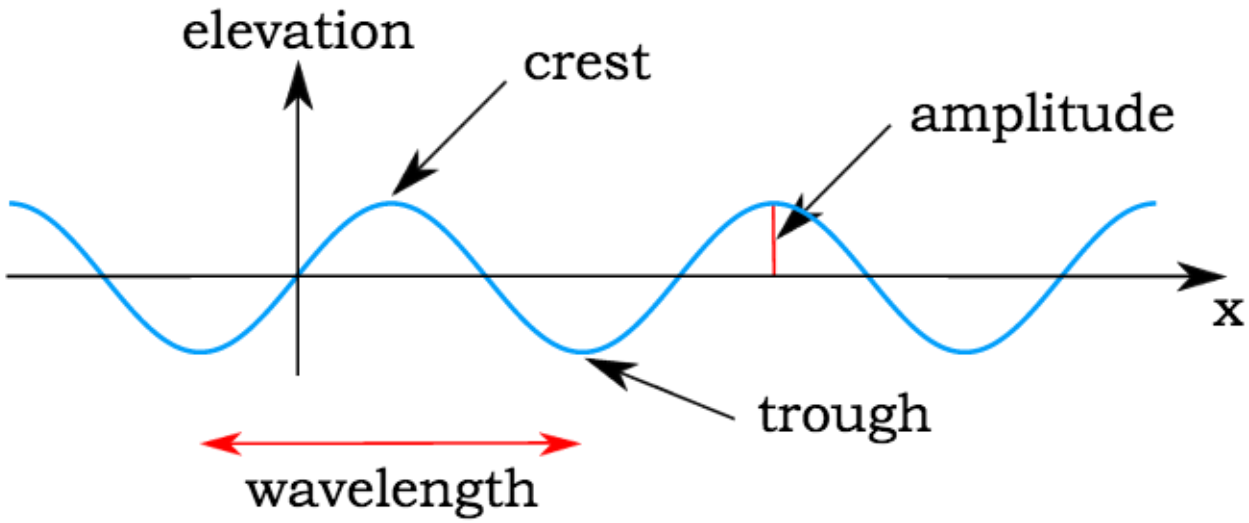
# Properties of light. Electromagnetic spectrum



# Electromagnetic spectrum and tissue absorption



# Properties of light. Waves




amplitude E

wavelength (λ)

frequency (ν)

speed (c)

phase (ϕ)

polarization intensity (I)

**λν = c**

$$I = \frac{cn\epsilon_0}{2}|E|^2$$

# Properties of light. Waves

Wavelength: $\lambda$=635 nm

Power: P=2 mW

Spot (area): A=8 mm

Speed: c=3.00×$10^8$ m/s

Area: A=8 $mm^2$

$\varepsilon_0$ = 8.854 187 817... × $10^{-12}$ F·m

I=P/A=250 W/$m^2$

E=430 V/m

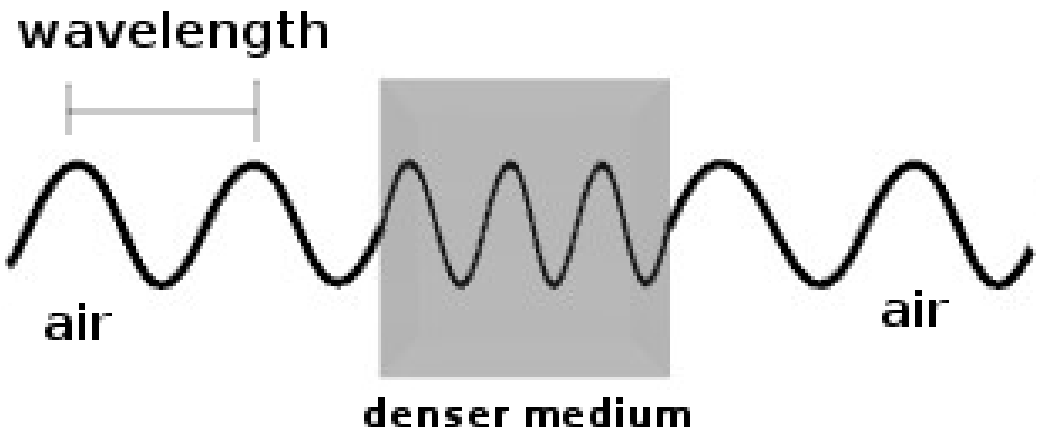
Spot (area) =8 mm

Speed (c)=3.00×$10^8$ m/s

$\nu$ =5x$10^{14}$ Hz

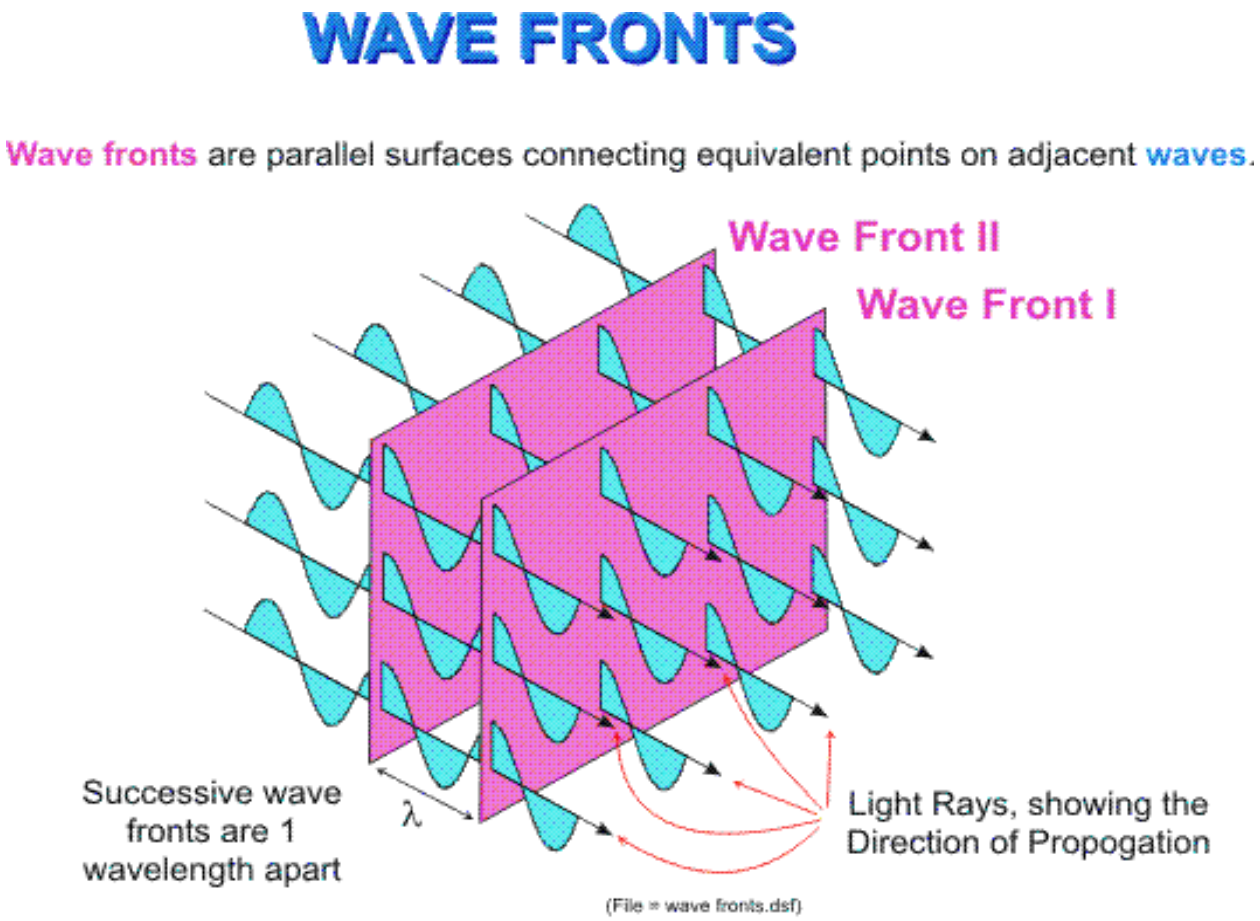
# Properties of light. Speed

n=1 n>1 n=1



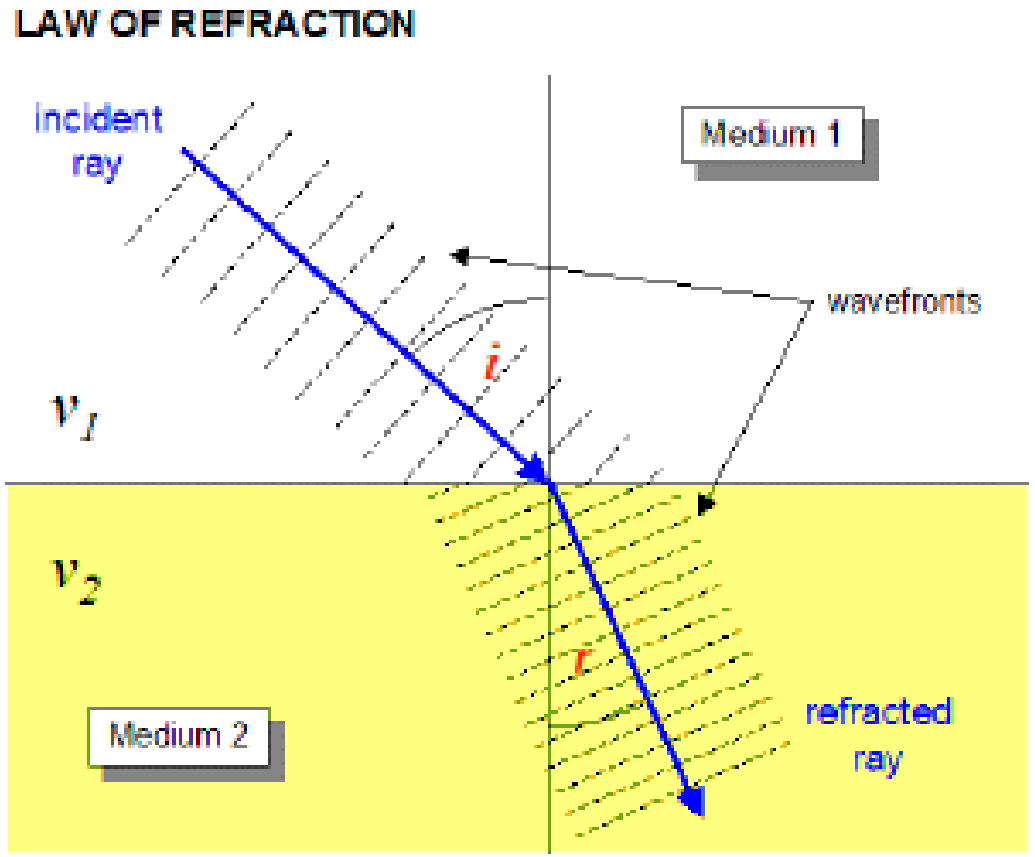

$$n_{material} = \frac{3.00 \times 10^{8}\ m/s}{v_{material}}$$

# Properties of light. Rays and wavefronts



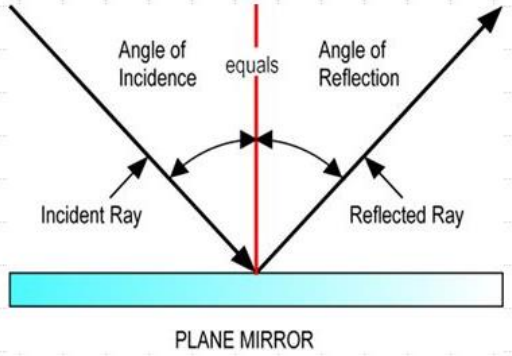

(To simplify drawing light, rays and wavefronts are used instead)

# Light matter interaction. Refraction and reflection

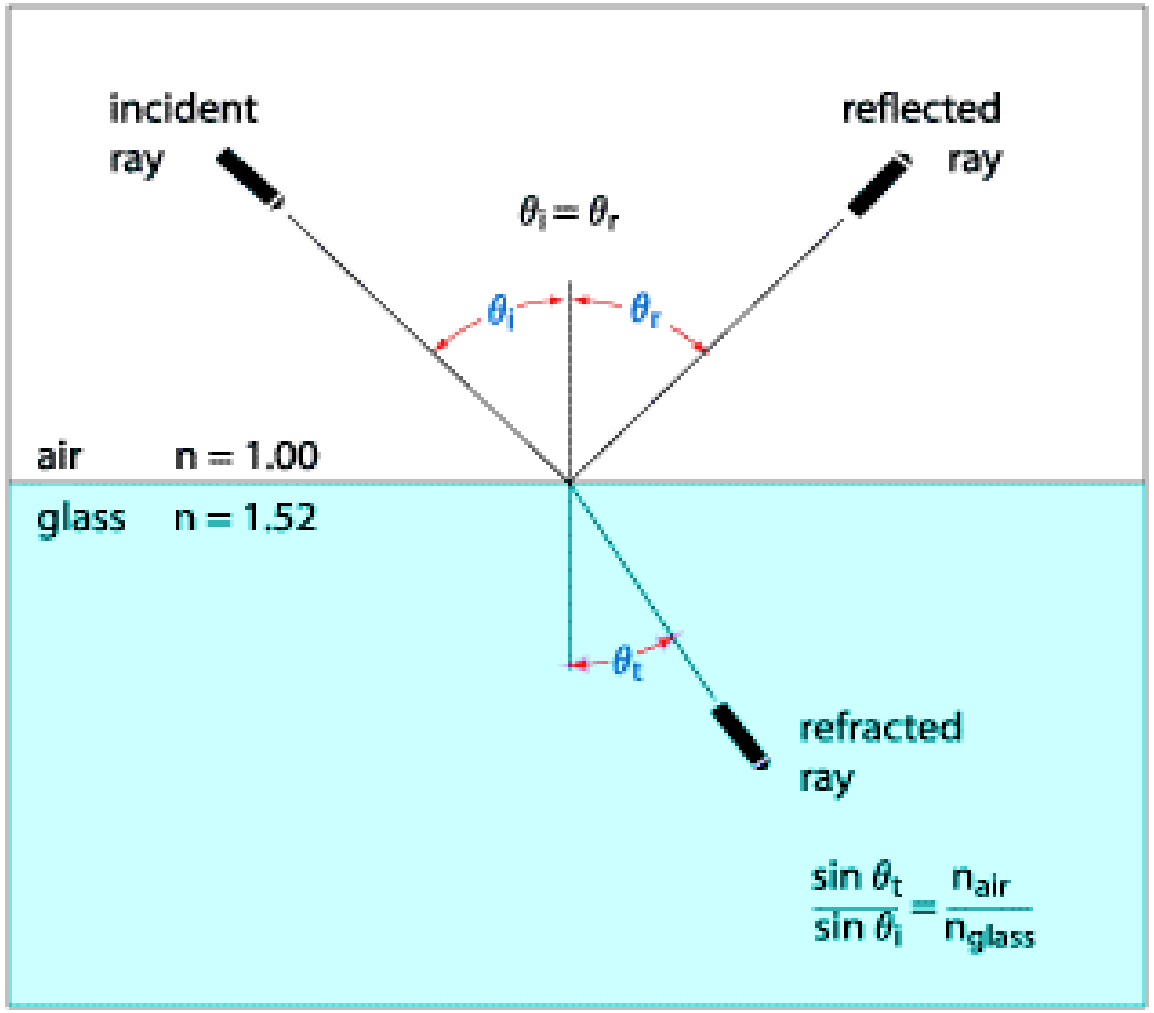



## Reflection

- The Law of Reflection states that the angle of incidence is equal to the angle of reflection.
- Angles are measured with respect to the 'normal' line.
- $\theta_i = \theta_r$ Law of Reflection



# Light matter interaction. Snell´s law



# Light matter interaction. Fresnel equations for normal incidence

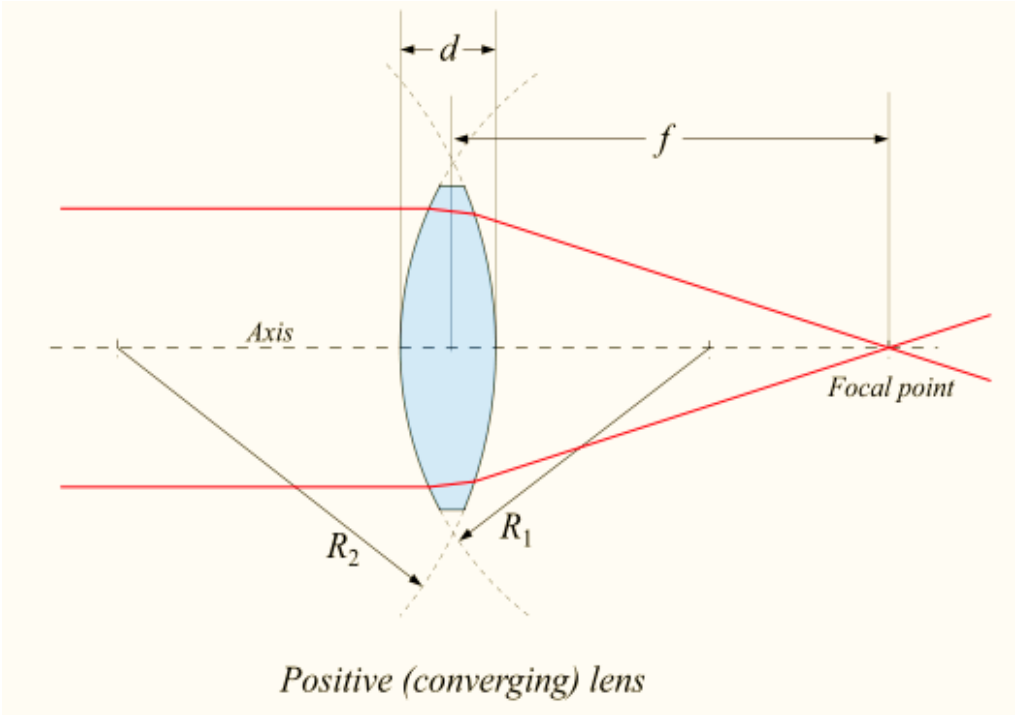
$$R_{\perp} = (n_1 - n_2)^2 / (n_1 + n_2)^2$$

~4% for air-glass

$$T_{\perp} = 4\, n_1 n_2 / (n_1 + n_2)^2$$

~96% for air-glass

# Refractive lenses. Focusing



Positive (converging) lens

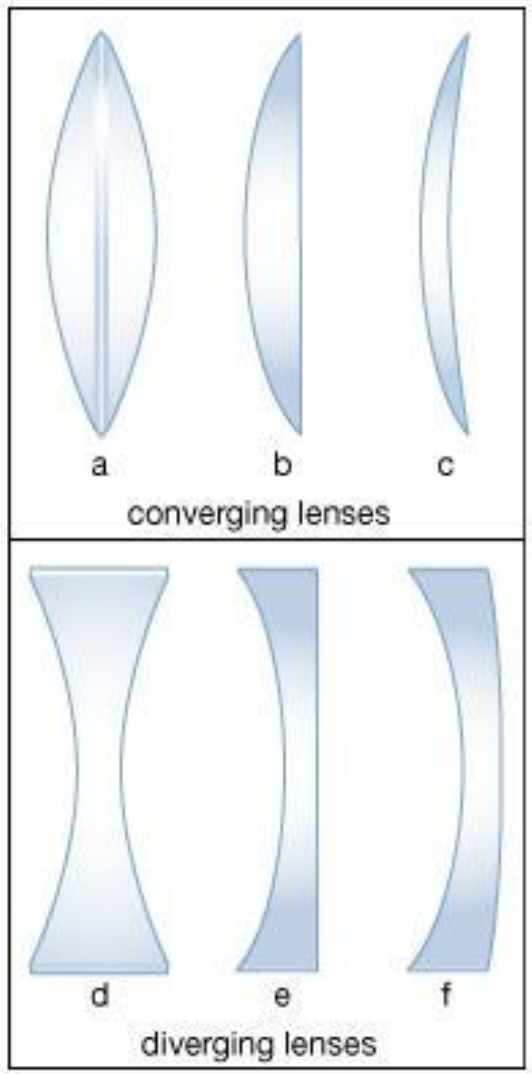
Lens maker´s equation:

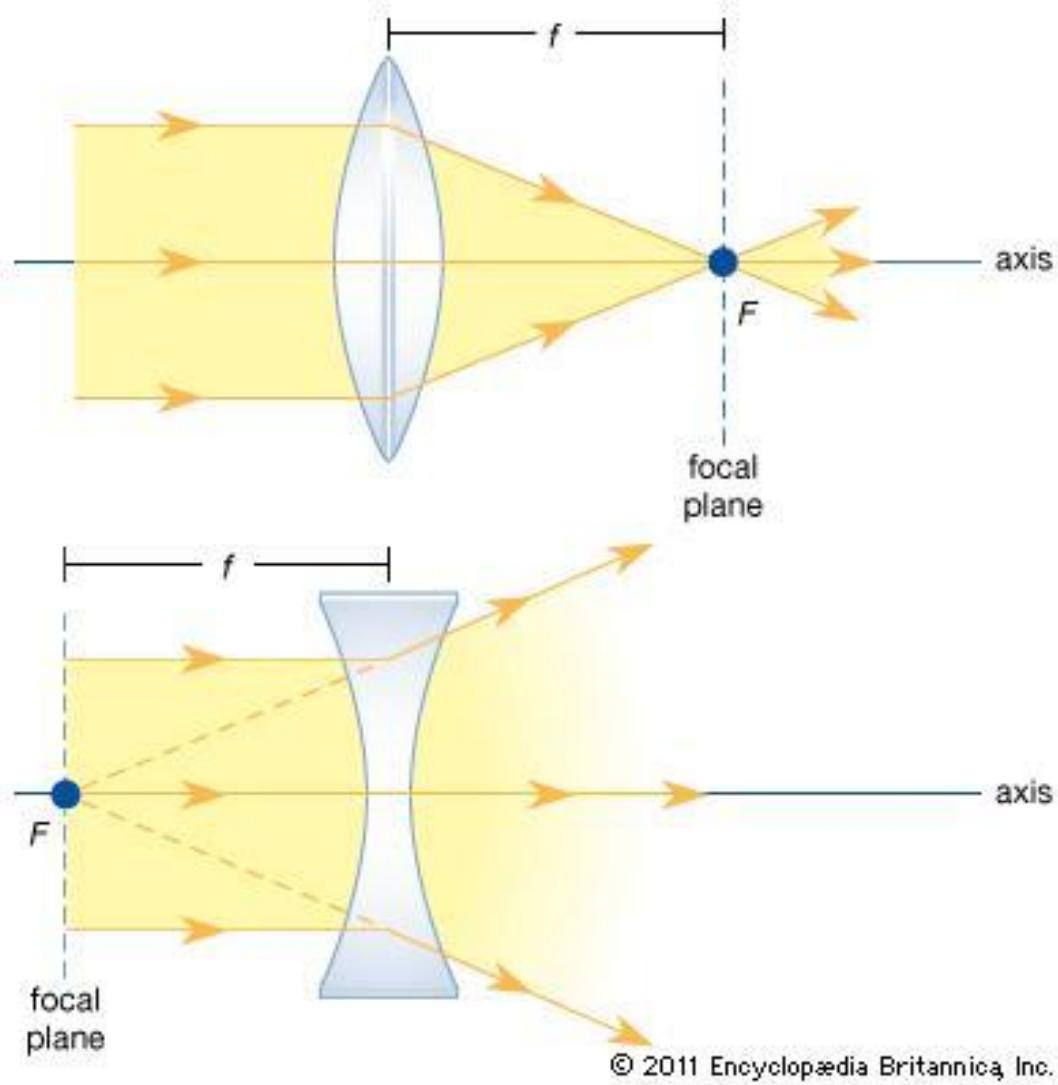
$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}\right],$$

where $n$ is the index of refraction of the lens material, and $R_1$ and $R_2$ are the radii of curvature of the two surfaces. For a thin lens, $d$ is much smaller than one of the radii of curvature (either $R_1$ or $R_2$)

$$\frac{1}{f} \approx (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right].$$

# Refractive lenses. Lens shapes

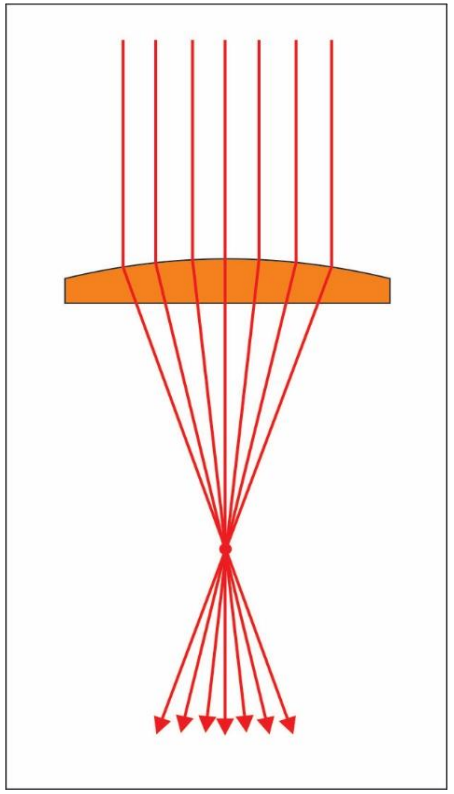


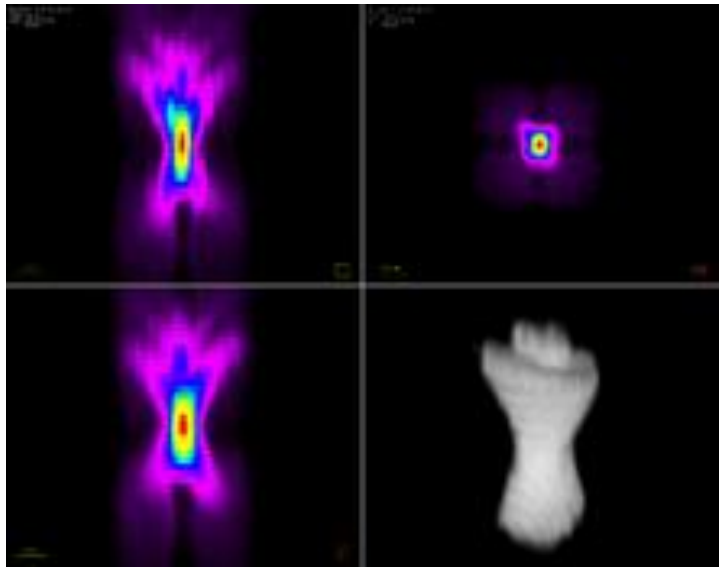



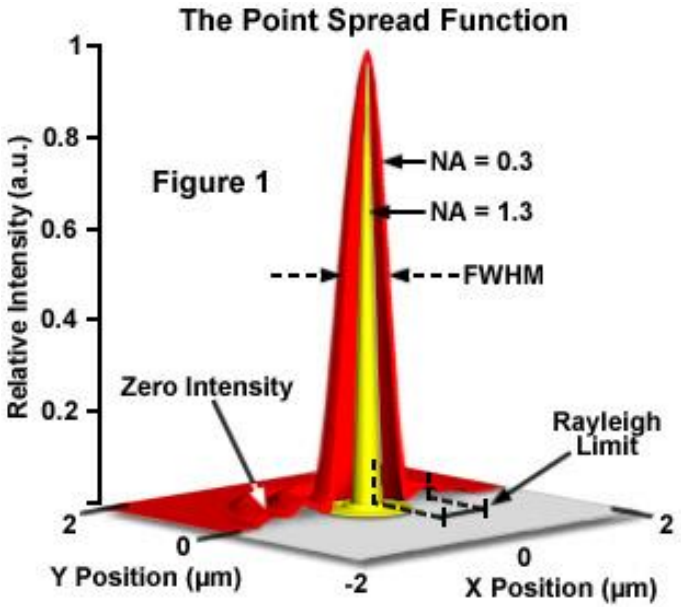
# Refractive lenses. Focus size

**Is the focus really a point?,**

No, the focus has a size proportional to the wavelength

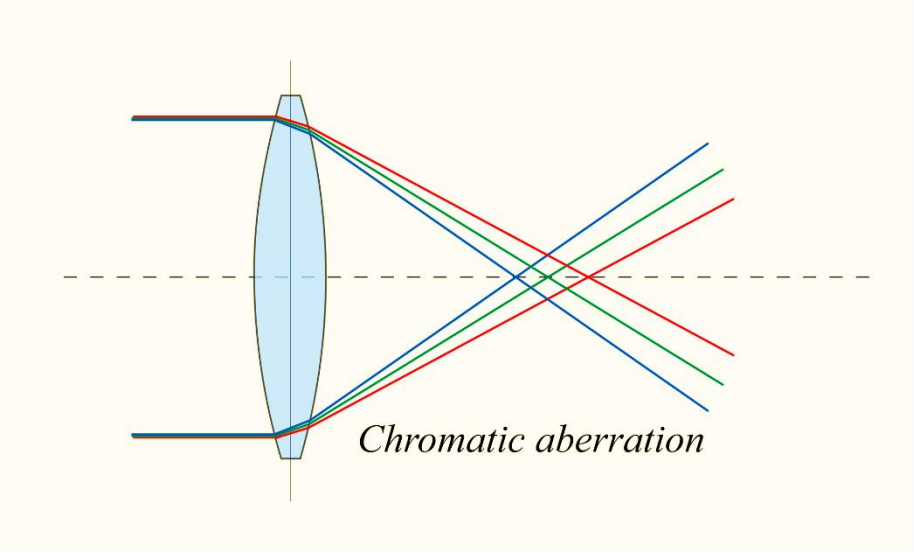


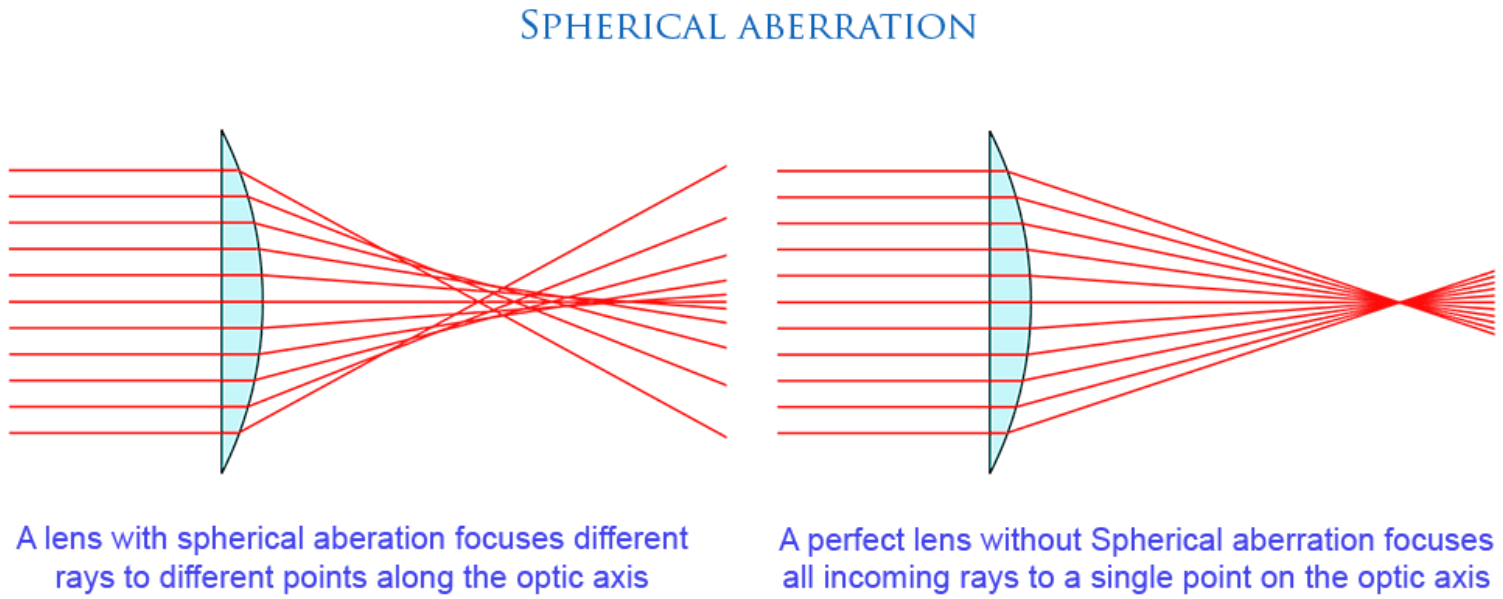





Airy disk

# Refractive lenses. Aberrations



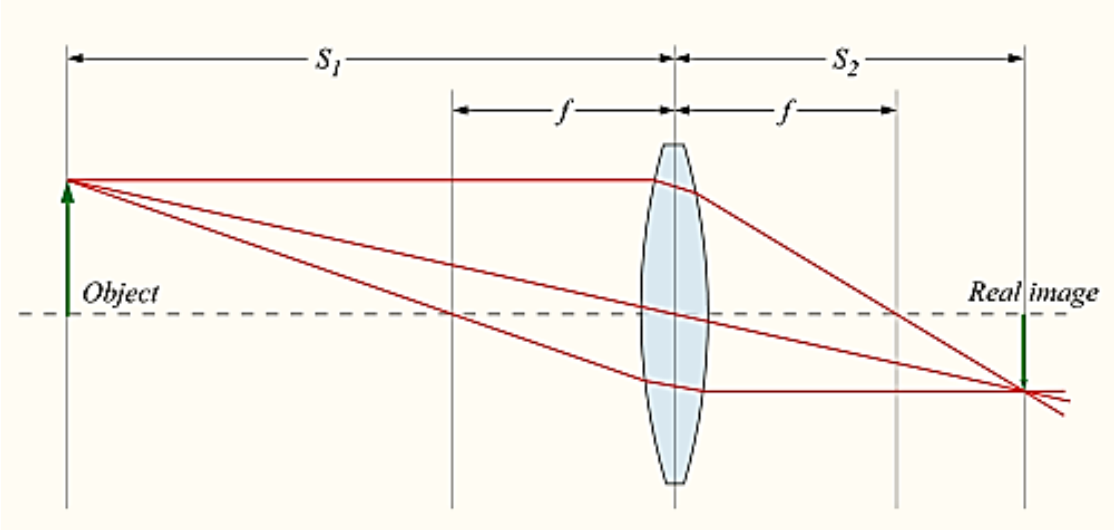



# Refractive lenses. Ray tracing

1. Any ray that enters parallel to the axis on one side of the lens proceeds towards the focal point f on the other side

2. Any ray that arrives at the lens after passing through the focal point on the front side, comes out parallel to the axis on the other side

3. Any ray that passes through the center of the lens will not change its direction



# Refractive lenses. Ray tracing

- With ray tracing rules 1, 2 and 3, the position and size of an image can be determined from the position and size of an object

- By tracing these rays, the relationship between the object distance and the image distance can be shown to be (thin lens equation):

$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$

- And the magnification of the image:

$$M = -\frac{S_2}{S_1} = \frac{h_2}{h_1}$$

# Image Formation by Lenses

https://www.youtube.com/watch?v=OSUGRvYwxw8

# Image formation: Real and virtual images

https://www.youtube.com/watch?v=mfytZxM8lho