Computer Vision

Image Formation

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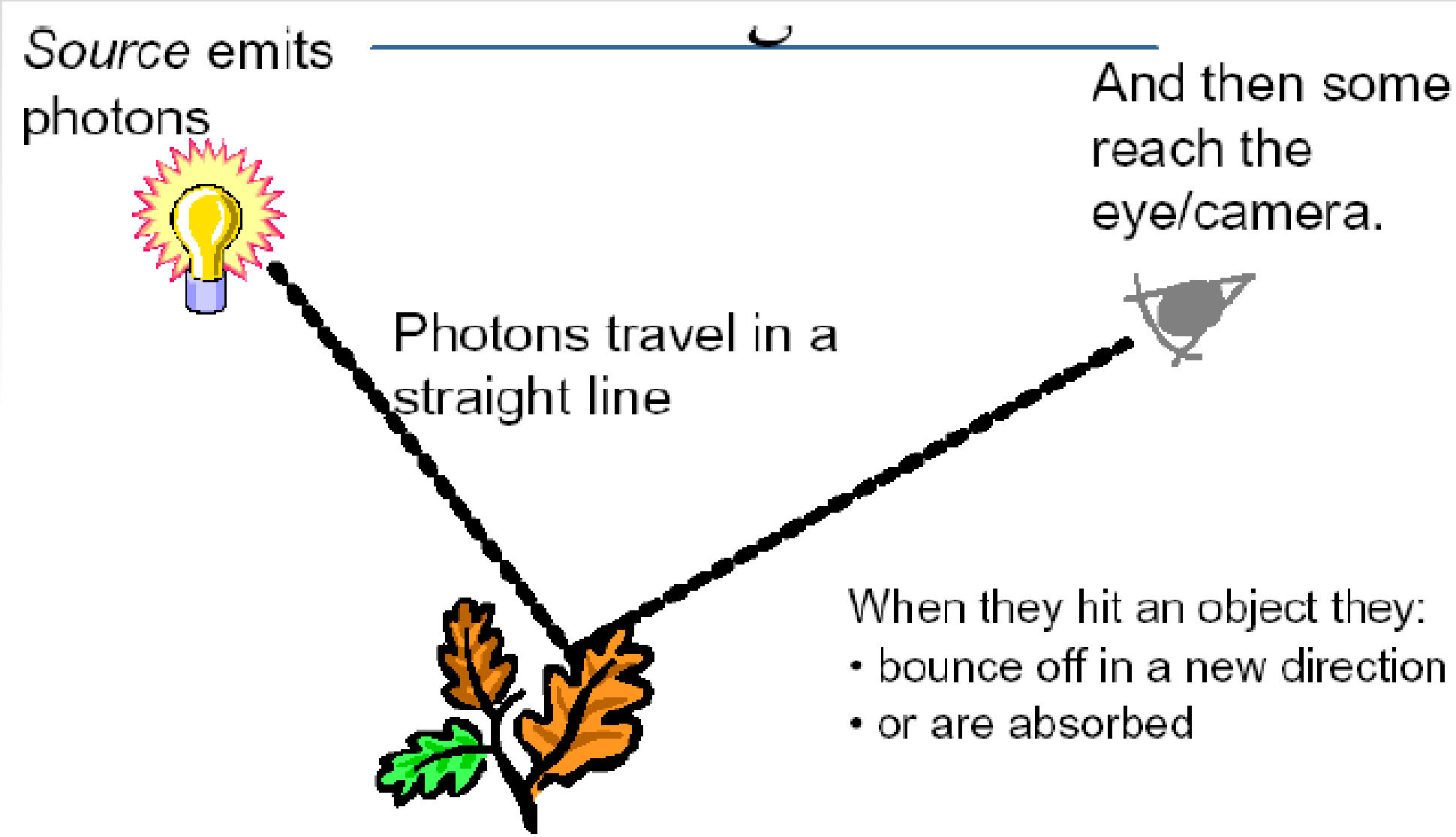
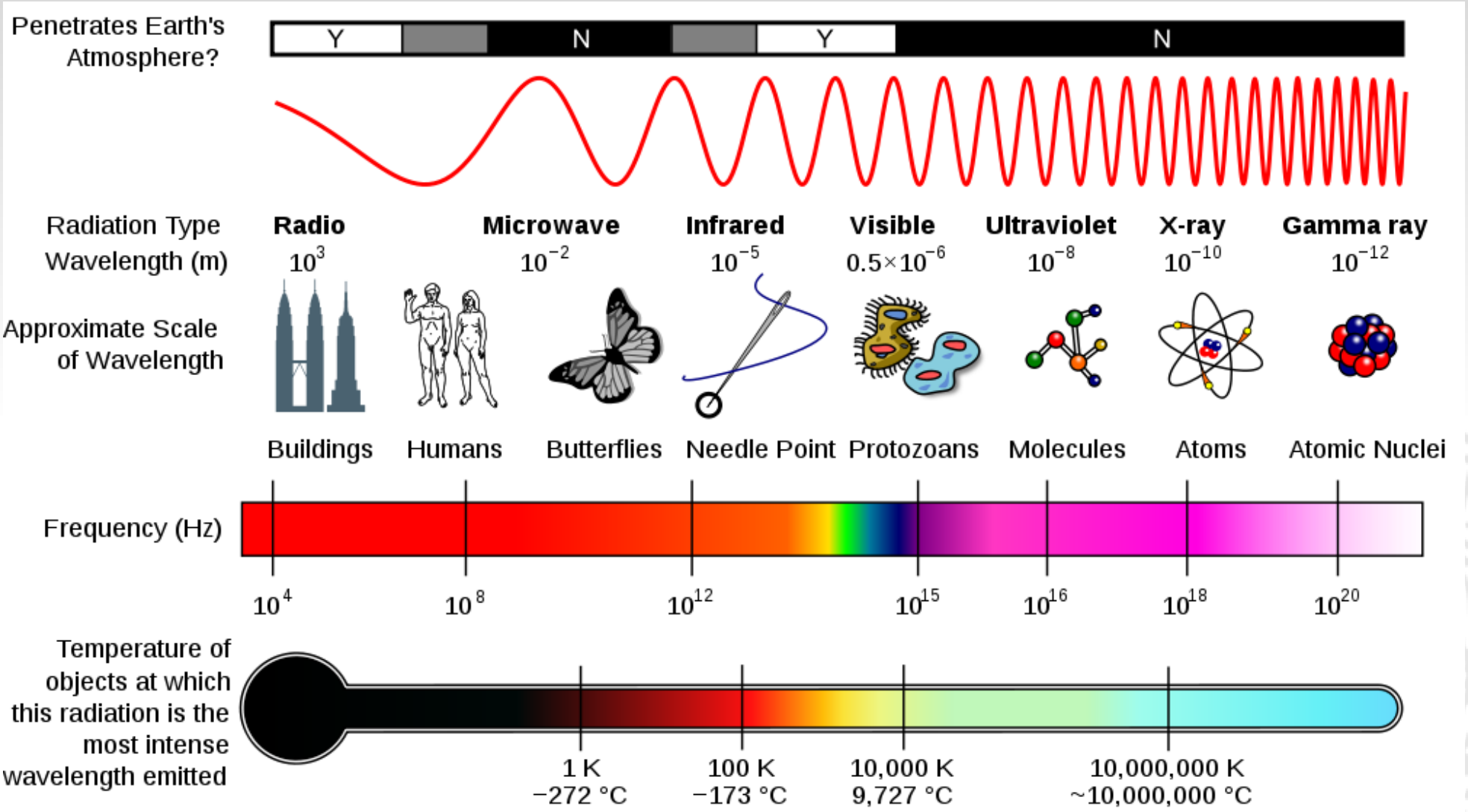
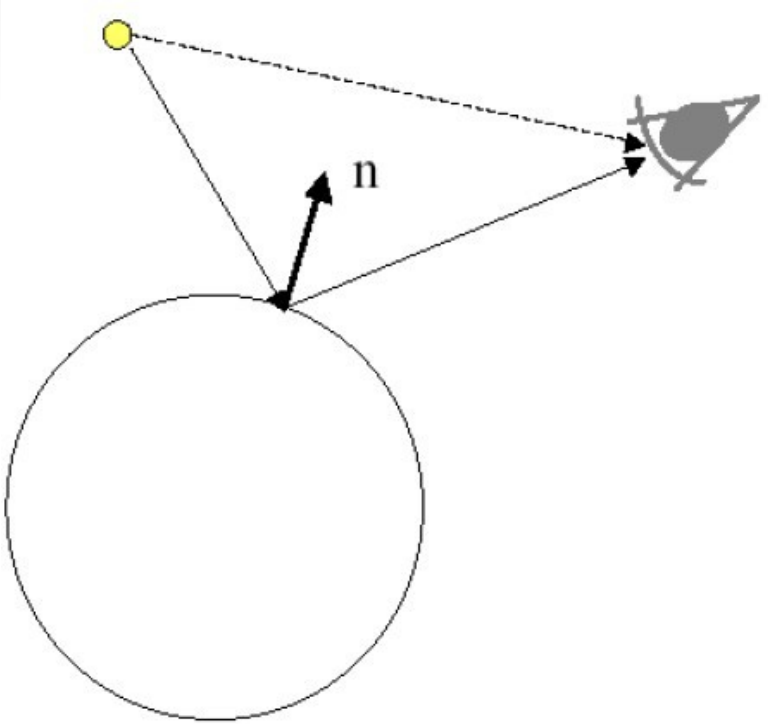
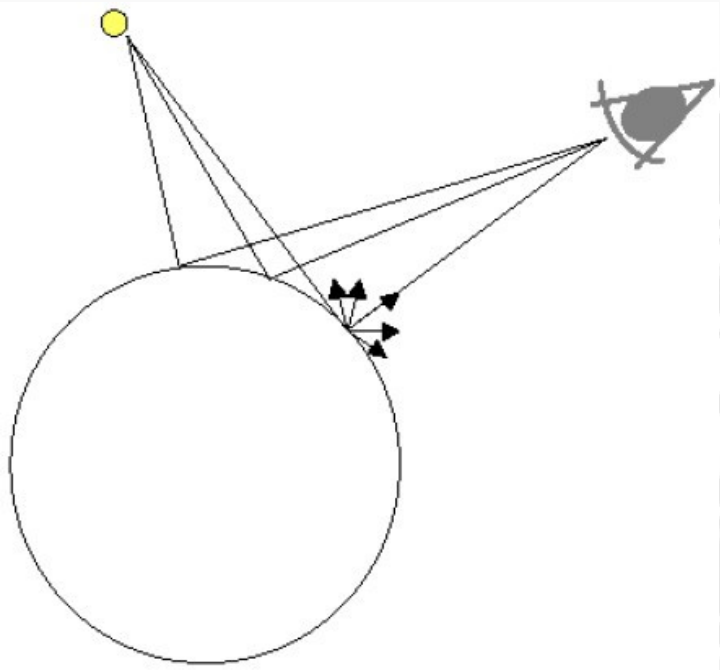

Source emits photons
And then some reach the eye/camera.
Photons travel in a straight line
When they hit an object they:
• bounce off in a new direction
• or are absorbed

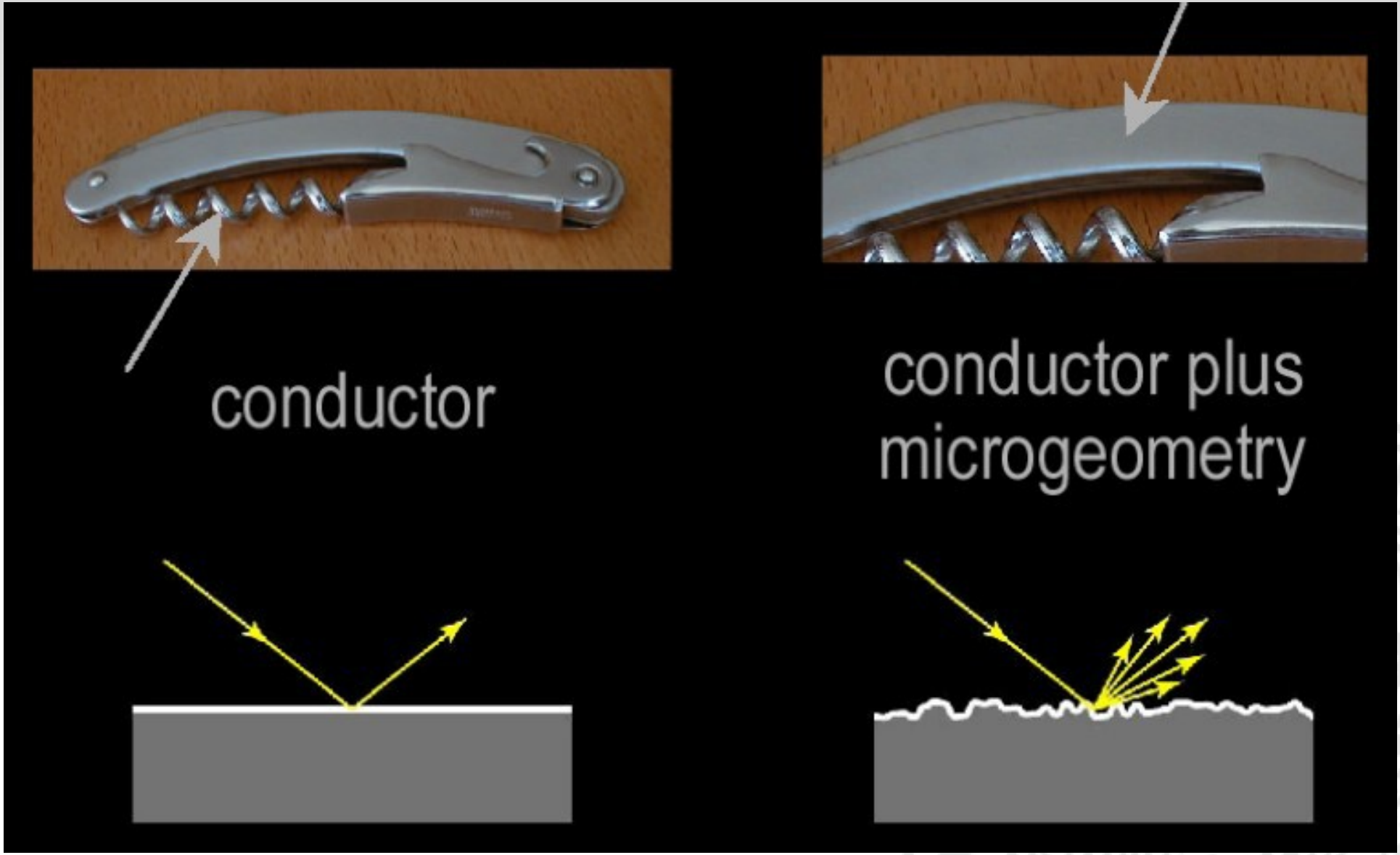

Penetrates Earth's Atmosphere?
Y
N
Y
N
Radiation Type
Wavelength (m)
Approximate Scale of Wavelength
Radio
10^{3}
Microwave
10^{-2}
Infrared
10^{-5}
Visible
0.5×10^{-6}
Ultraviolet
10^{-8}
X-ray
10^{-10}
Gamma ray
10^{-12}
Buildings
Humans
Butterflies
Needle Point
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of objects at which this radiation is the most intense wavelength emitted
1 K
−272 °C
100 K
−173 °C
10,000 K
9,727 °C
10,000,000 K
~10,000,000 °C

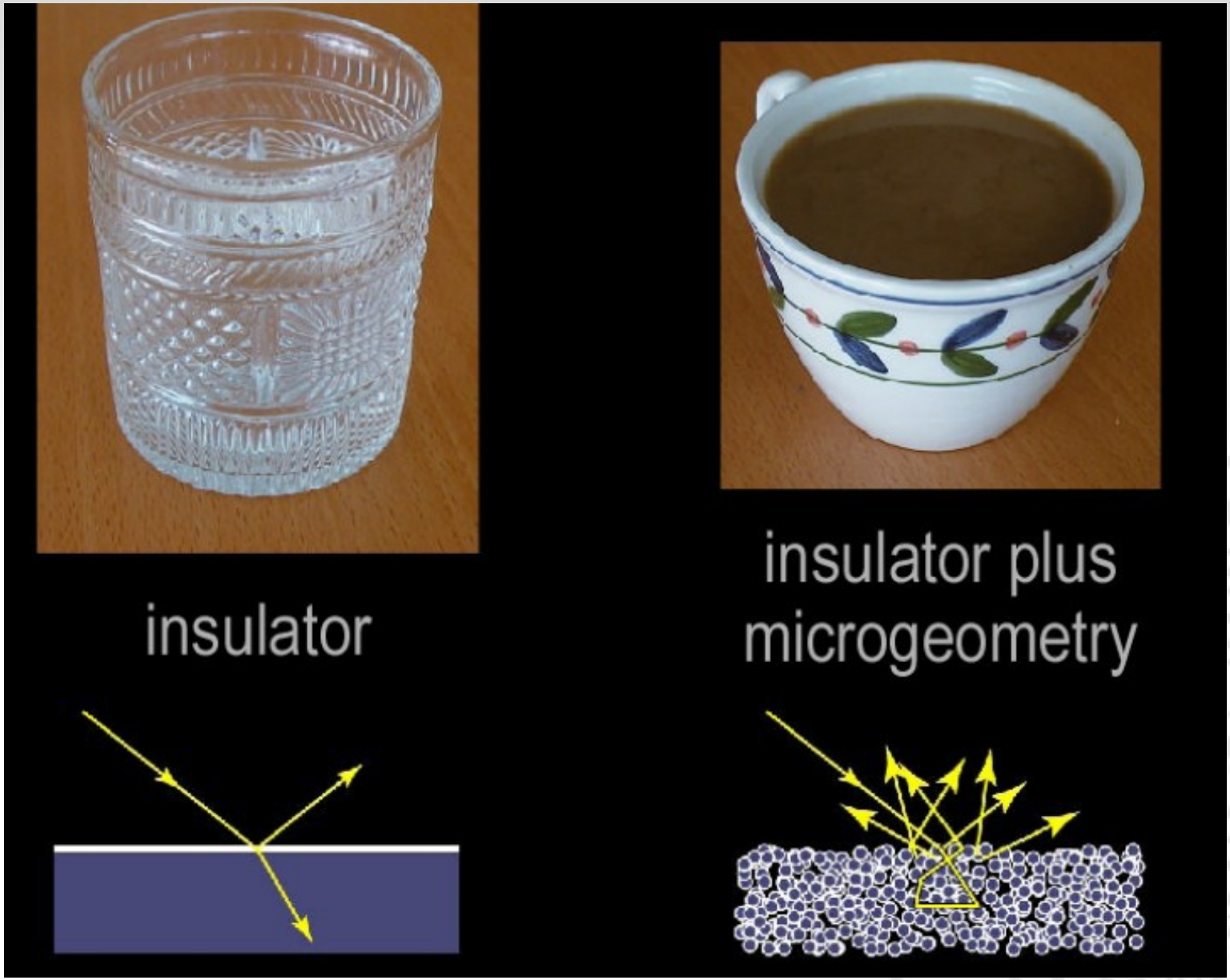
- What would you see looking at a perfectly specular sphere in a perfectly dark room?
(completely absorbing)



- What would you see if the sphere was painted white?




conductor
conductor plus
microgeometry


insulator
insulator plus
microgeometry

Radiometry

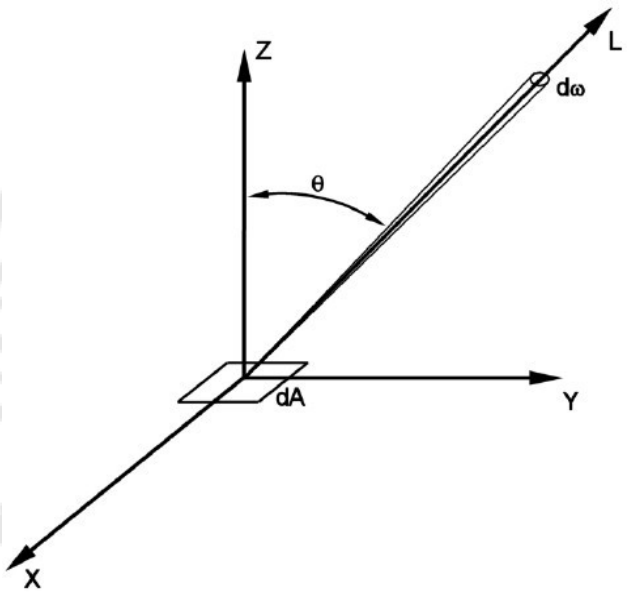
Radiometry: set of techniques for measuring electromagnetic radiation, including visible light

Radiant flux (Φ, Watt): radiant energy passing through a surface per unit of time

Irradiance ($\frac{d\Phi}{dA}$, Watt/m²): radiant flux per surface element

Radiance ($\frac{d^2\Phi}{\cos\theta d\omega dA}$, Watt/m²sr): Irradiance per emission angle

- Measures the electromagnetic flux going through the infinitesimal area dA in the infinitesimal range of directions dw
- Physical quantity related to luminosity

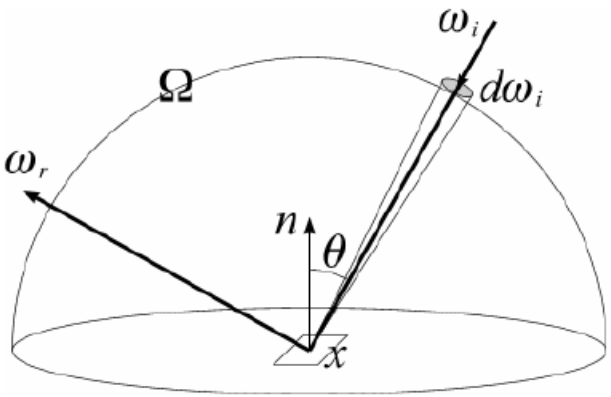


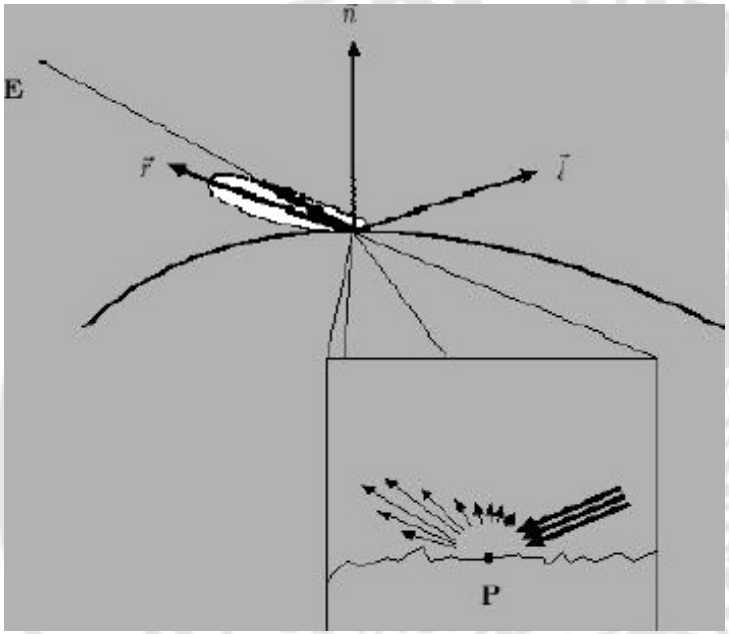
BSSRDF and BRDF

- Bidirectional Scattering Surface Reflectance Distribution Function (BSSRDF)
  - Functions that characterizes the local interaction between light and a surface

$$S(x_i, \omega_i, x_r, \omega_r) = \frac{dL(x_r, \omega_r)}{d\Phi(x_i, \omega_i)}$$

- Bidirectional Reflectance Distribution Function (BRDF)
  - No internal scattering → $x_r = x_i = x$



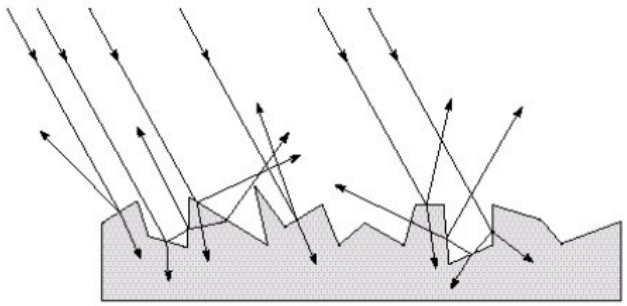


Lambertian Surfaces

Radiance depends on incident and observation angles

For some materials (e.g., chalk) the dependency to the viewing direction is weak or inexistent

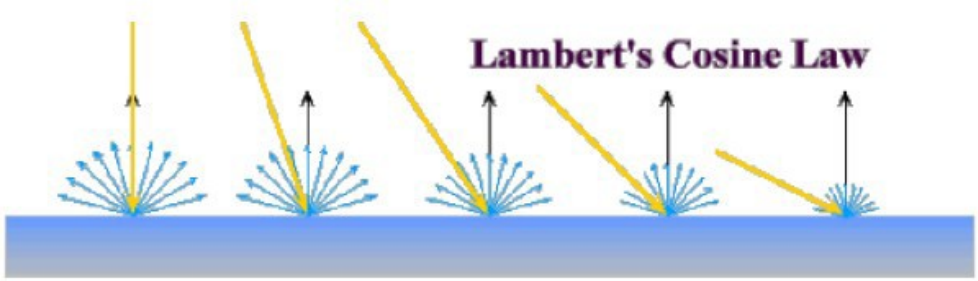
- Micro facets diffuse light randomly → radiance is uniform in all directions



- Diffuse reflection follows Lambert's law

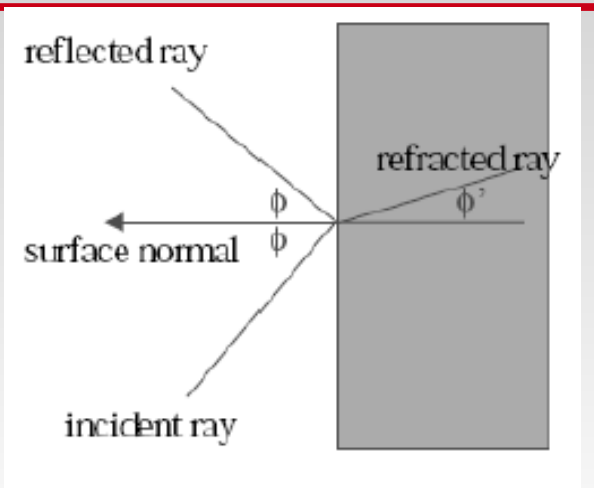
$$L_r = k_x L_i \cos\theta_i$$

- k_x is called **albedo**



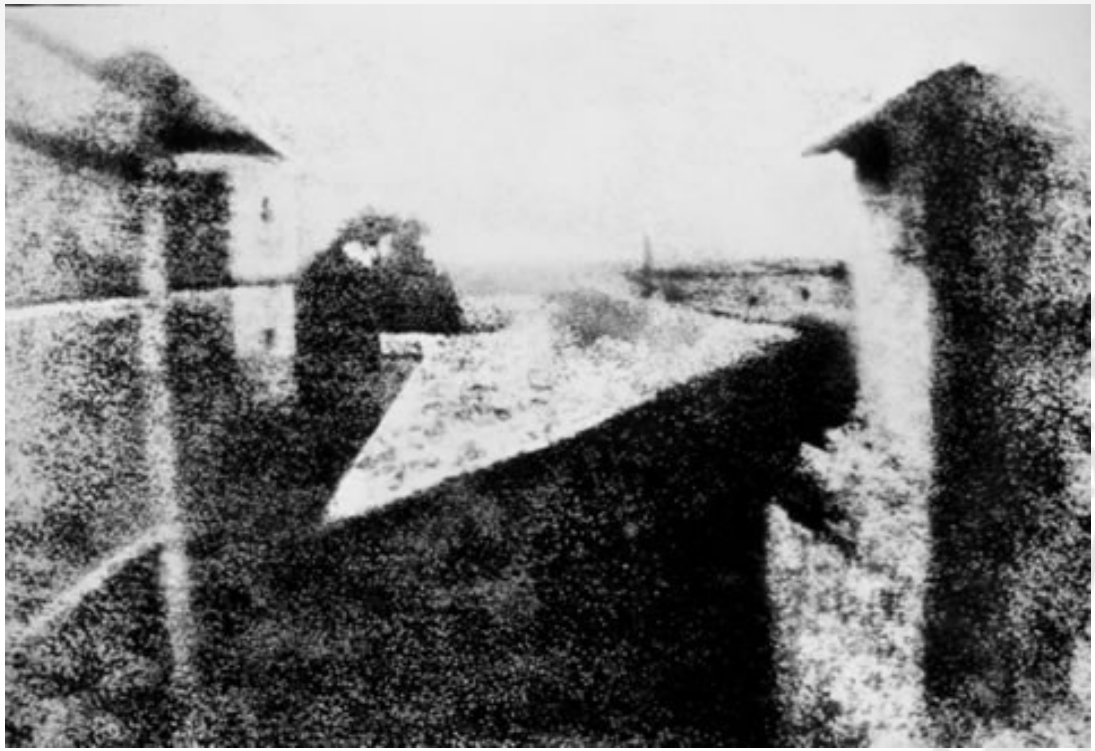
- There are other effects and complex interactions between light and matter
  - Refraction
  - Scattering
  - Fluorescence
  - Color bleeding

- We will (mostly) ingore them!

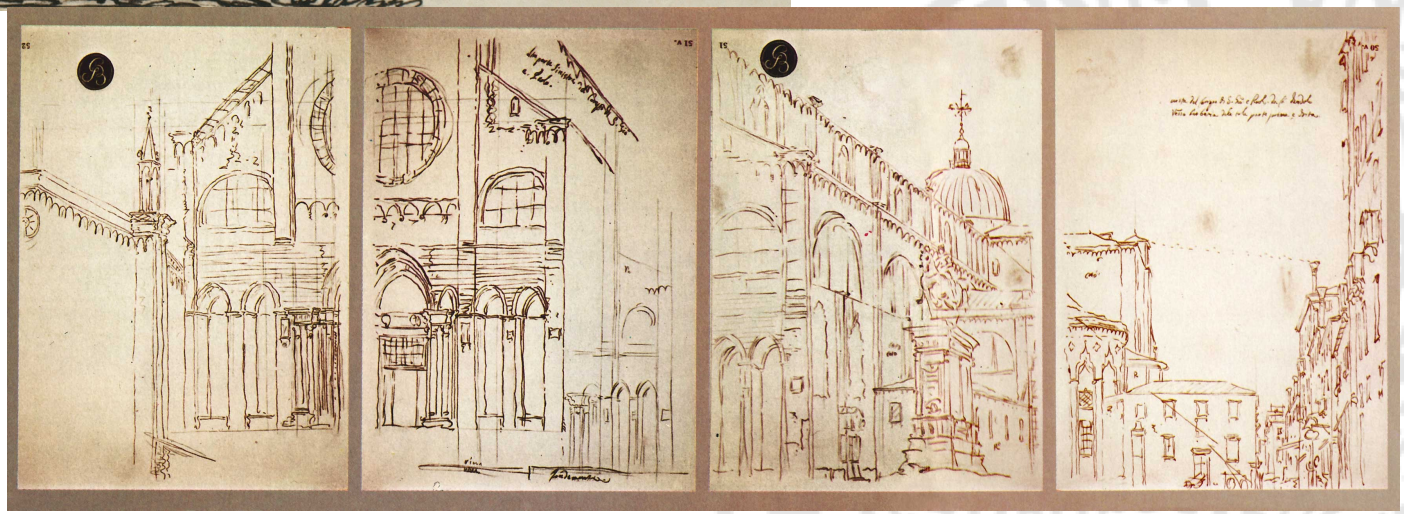


Photography

- 1826 Niepce made first photograph
  - Exposed paper covered with silver cloride in a camera obscura and then fixed the image with nitric acid

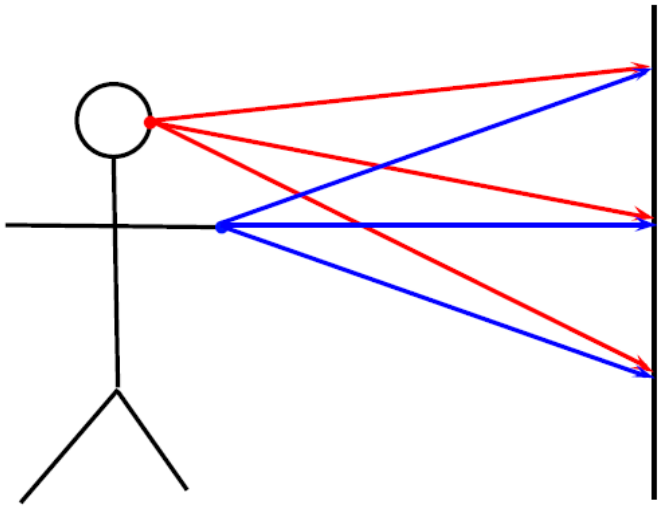


Camera Obscura

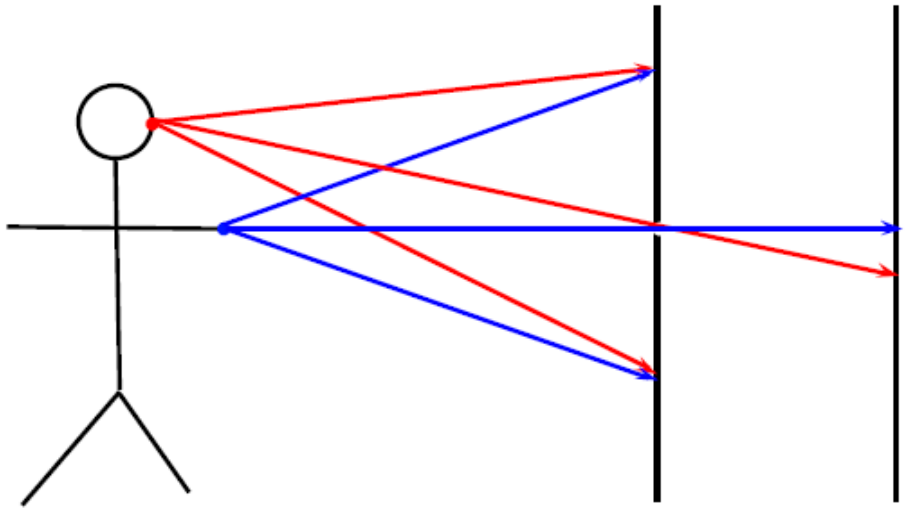


Canaletto
Campo San Giovanni
e Paolo
Accademia

- What happens if you place the film in front of an object?

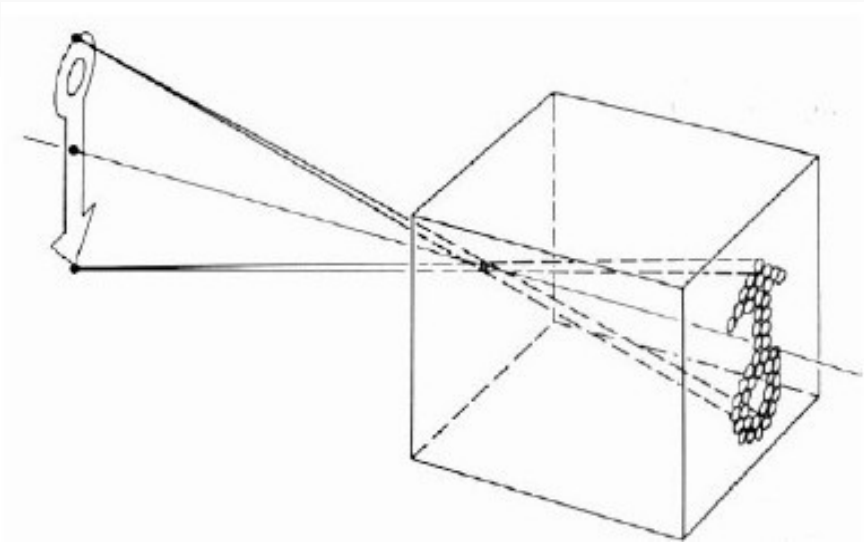


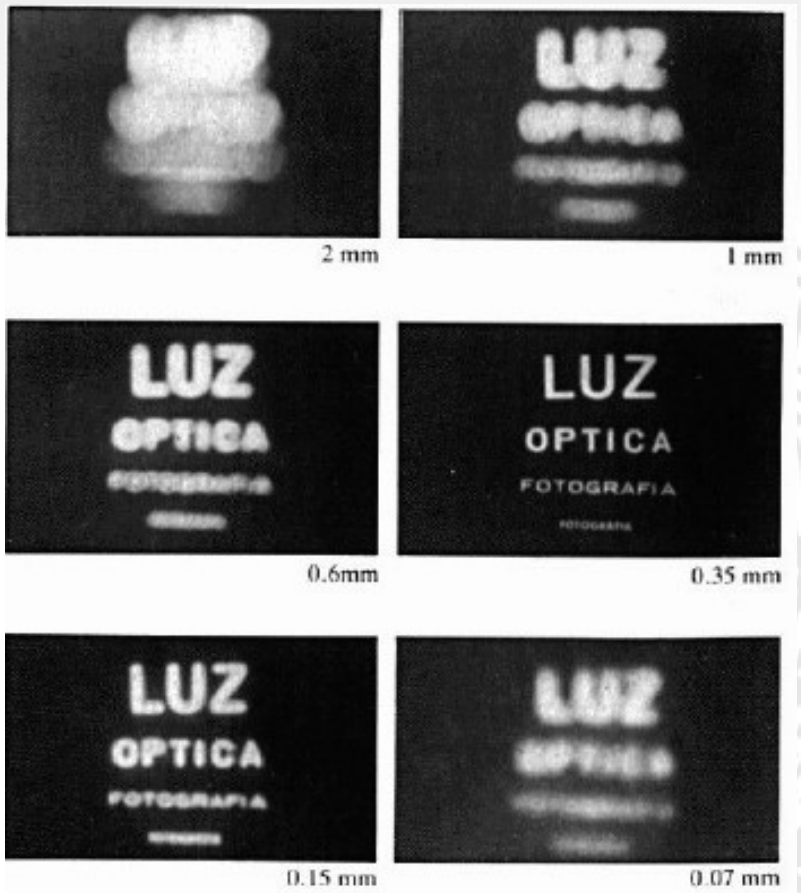
- What happens if you put a barrier with a small hole in front of it?



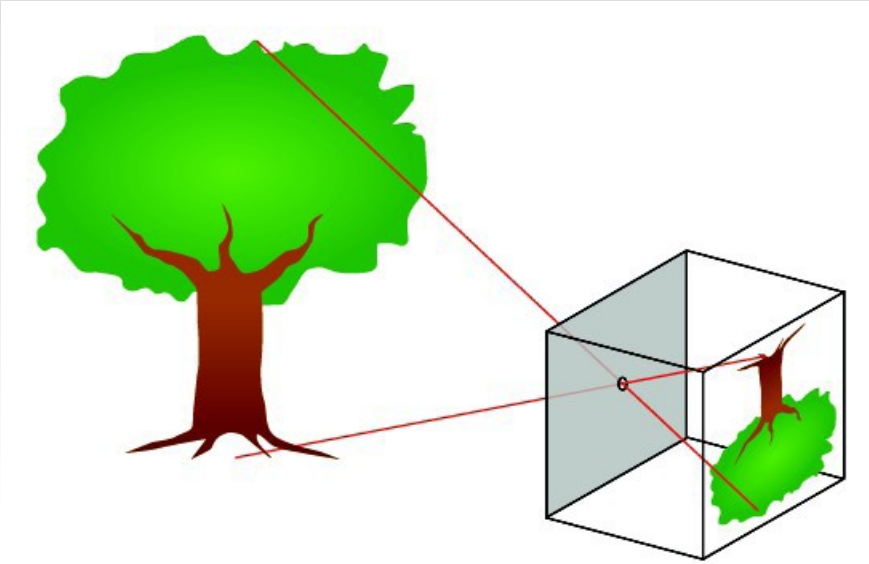
Problems with camera obscura

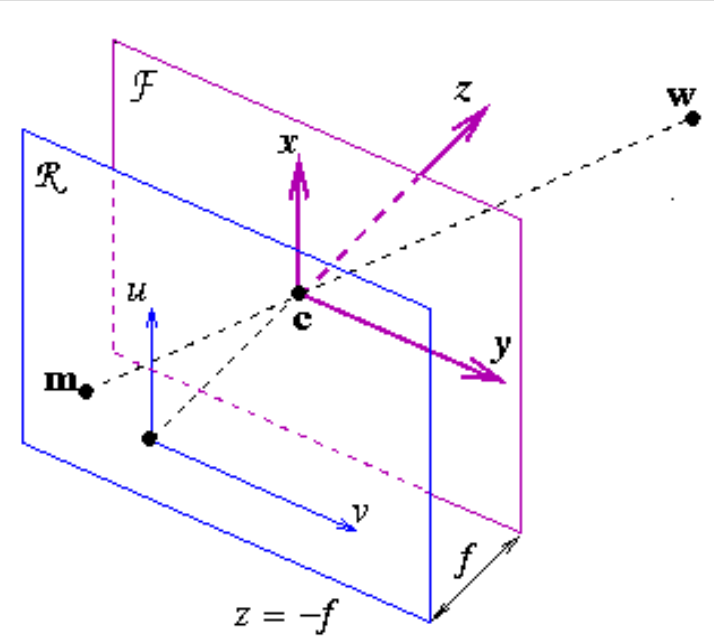
- Hole too large → out of focus
- Hole too small → image too dark
  - Hole size comparable to wave length → out of focus





Pinhole Camera Model



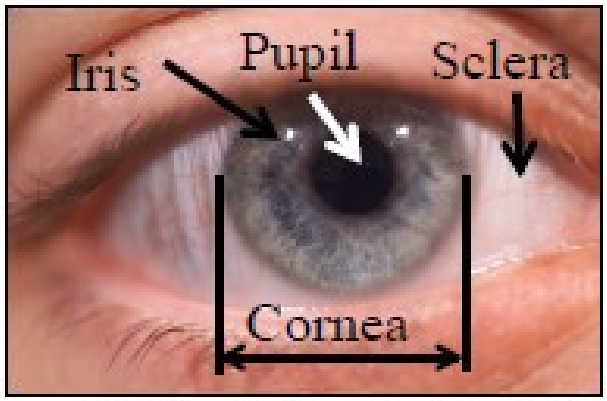


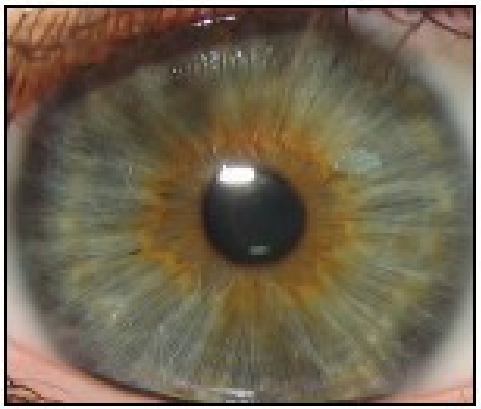
$$\mathbf{w} = (x, y, z)^T$$

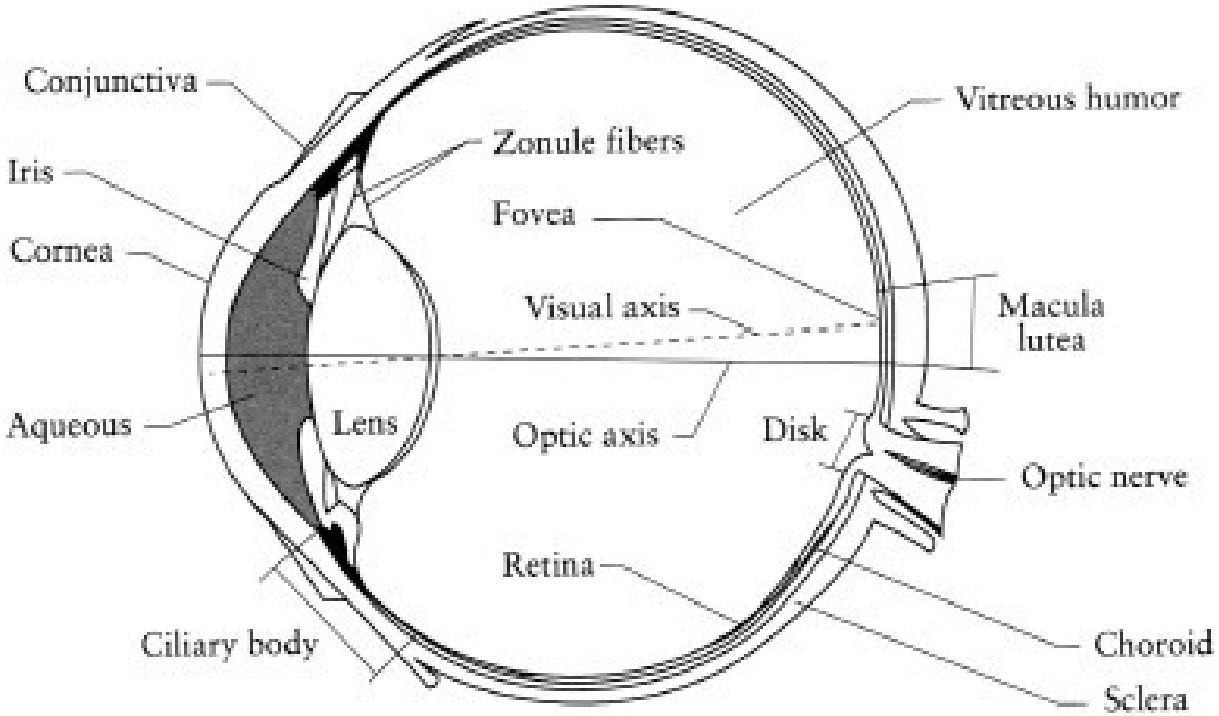
$$\mathbf{m} = (u, v)^T \begin{cases} u = -f\frac{x}{z} \\ v = -f\frac{y}{z} \end{cases}$$

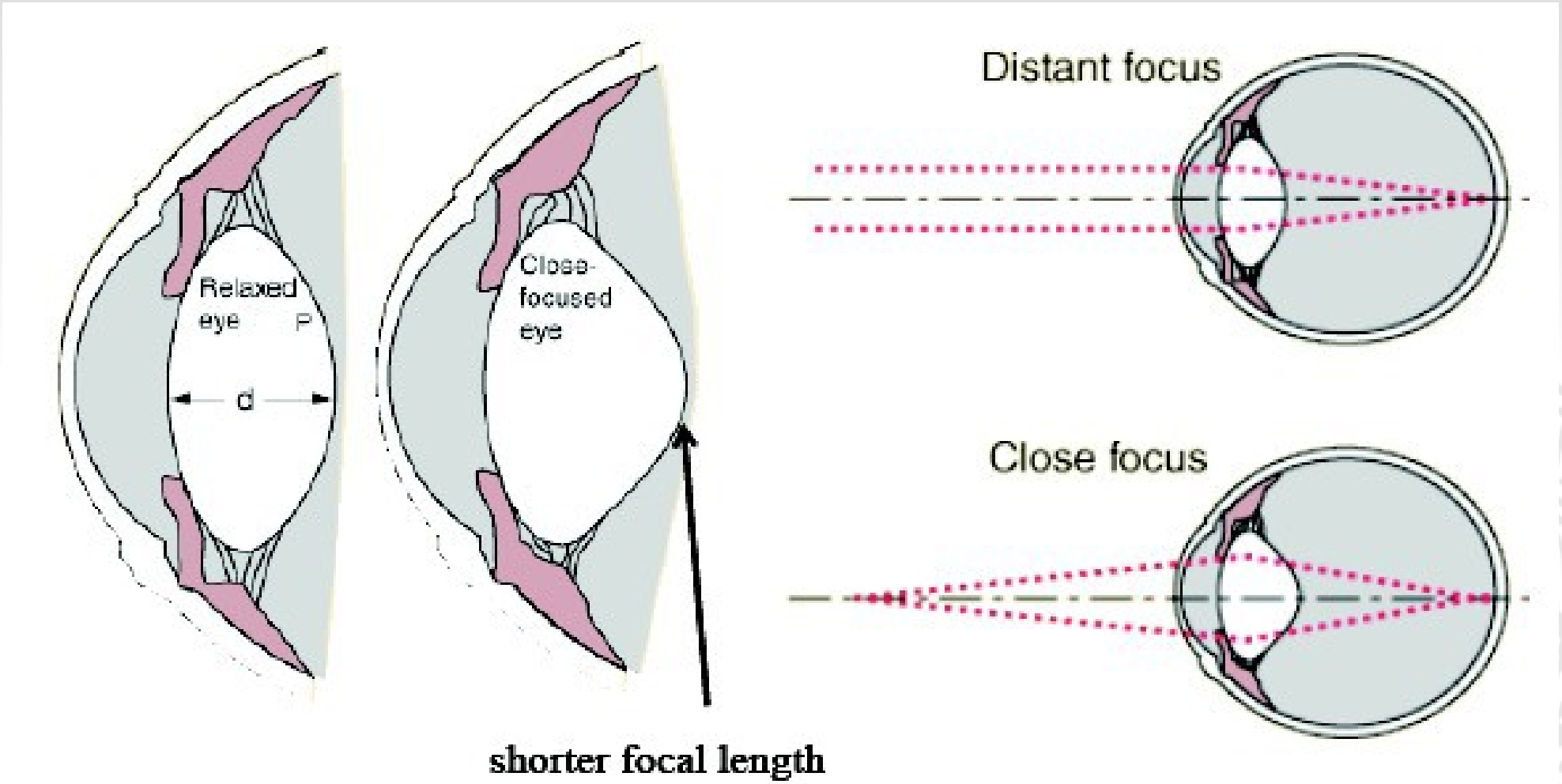
$$z\mathbf{m} = \mathbf{K}\mathbf{w}$$

$$\mathbf{K} = \begin{bmatrix} -f & 0 & 0 \\ 0 & -f & 0 \\ 0 & 0 & 1 \end{bmatrix}$$


Iris
Pupil
Sclera
Cornea




Conjunctiva
Iris
Cornea
Aqueous
Lens
Ciliary body
Zonule fibers
Fovea
Visual axis
Optic axis
Retina
Vitreous humor
Macula lutea
Disk
Optic nerve
Choroid
Sclera


Relaxed
eye
F
d
Close-
focused
eye
Distant focus
Close focus
shorter focal length

Sensor matrix

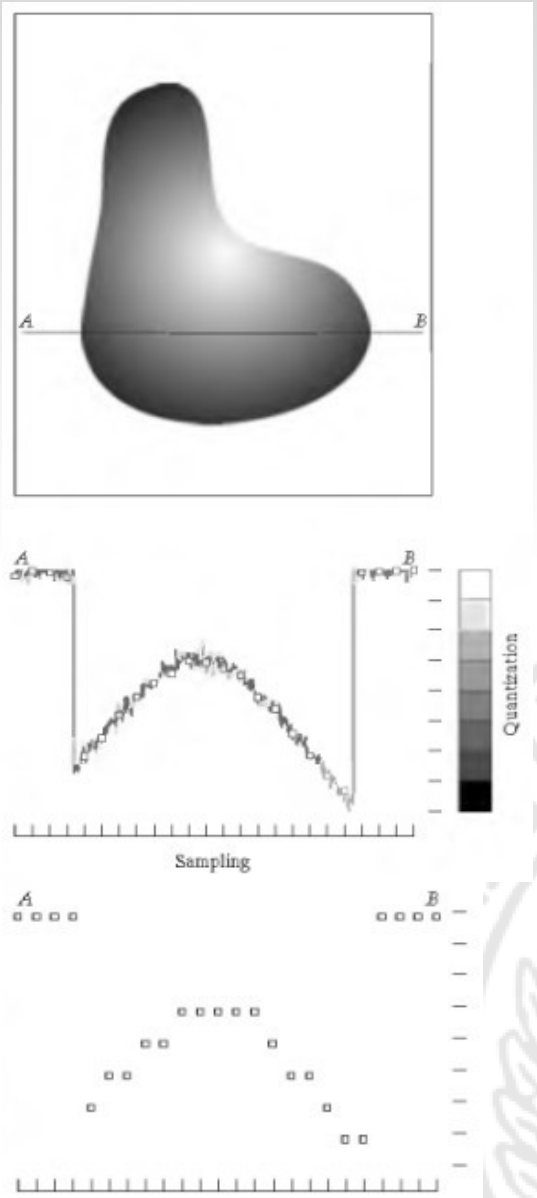
- An image can be modelled a sa function

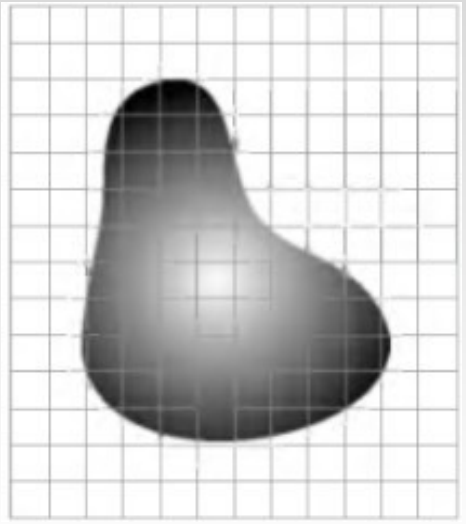
$$I : \Omega \subset \mathbb{R}^2 \rightarrow \mathbb{R}$$

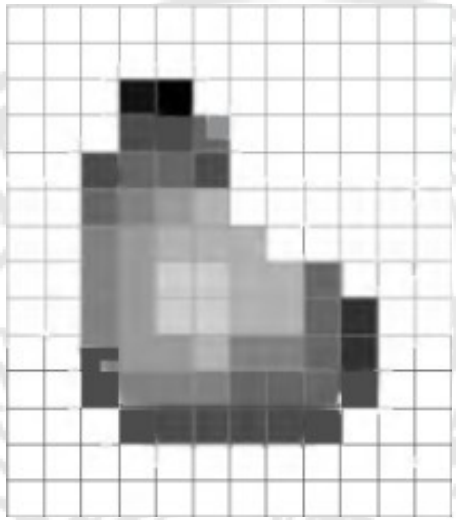
  - The domain is a (usully rectangular) subset of the real plane

- A continuous image is converted into a digital one through a process of sampling and quantization

  - **Sampling** reduces the image to a finite set of spatial coordinates
  - **Quantization** reduces the sensor response (function value) to a finite set of values







- The result of the sampling process is a MxN matrix
  - Each cell is called **pixel**