

What is light?

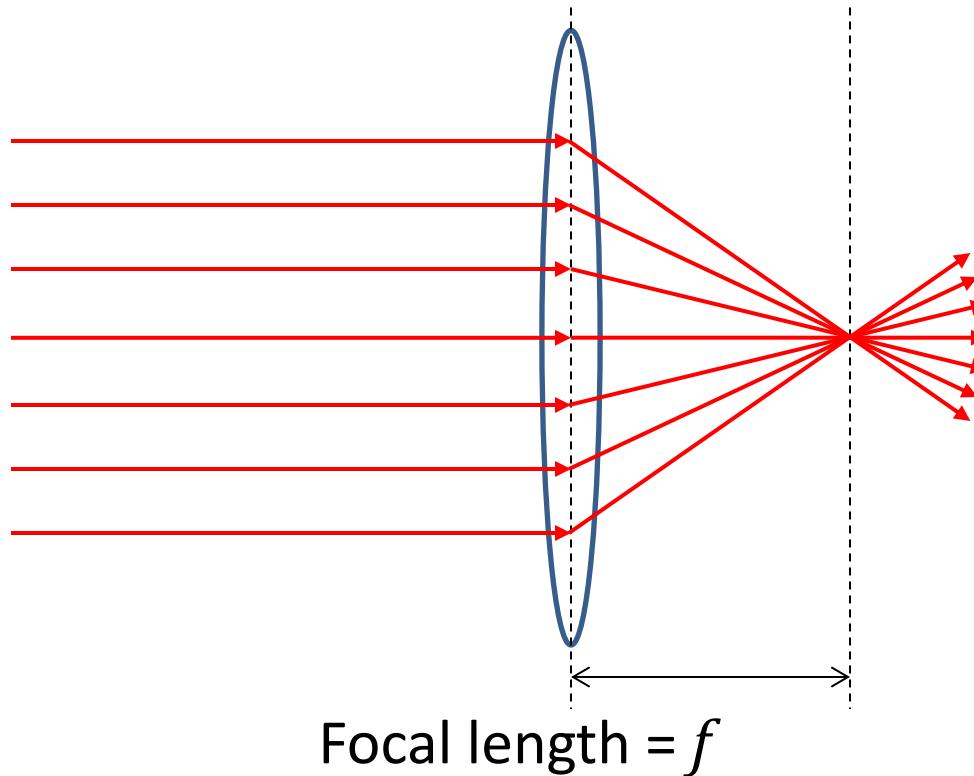
Bo Huang
Dept. Pharmaceutical Chemistry, UCSF



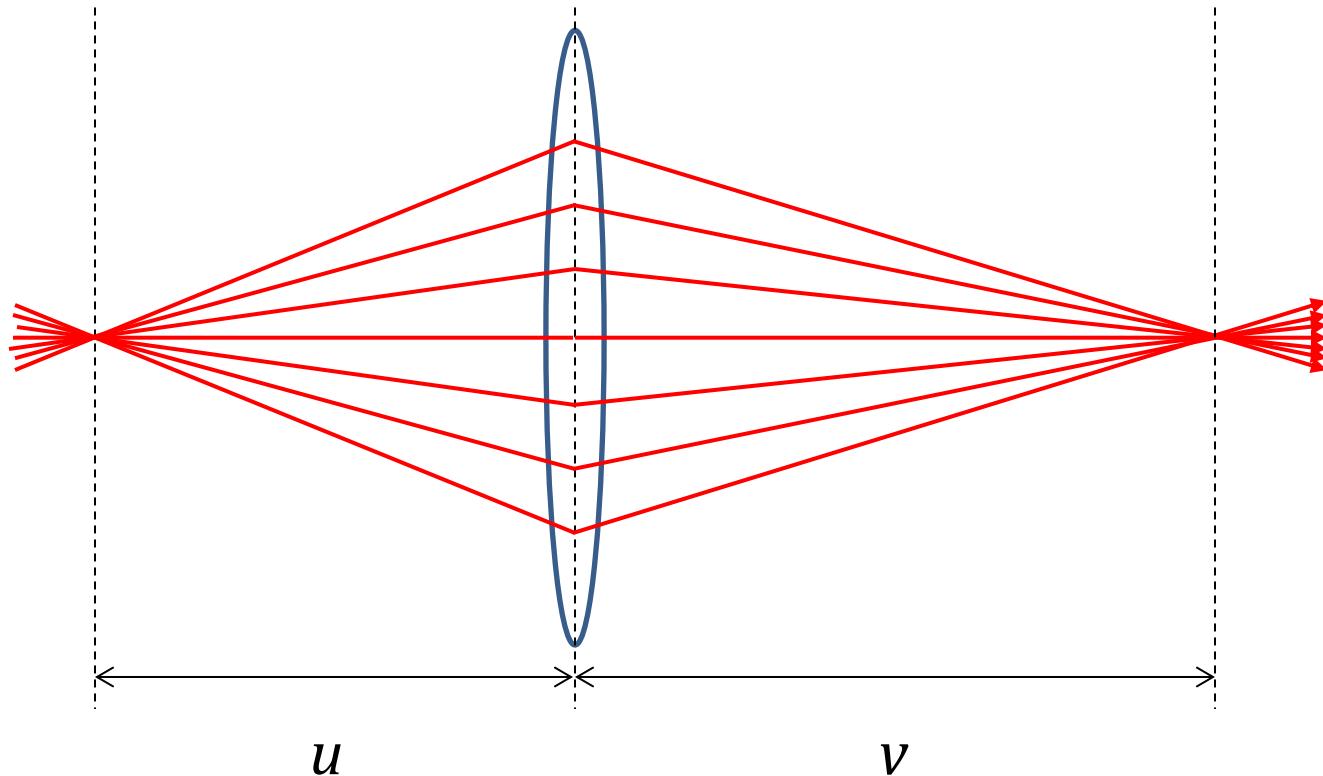
A photograph of a dense forest. Sunlight filters through the canopy of leaves, creating bright rays of light that illuminate the scene. The foreground is dark and shadowed, while the background is brighter where the sun's rays break through.

Light as rays

A simple thin lens

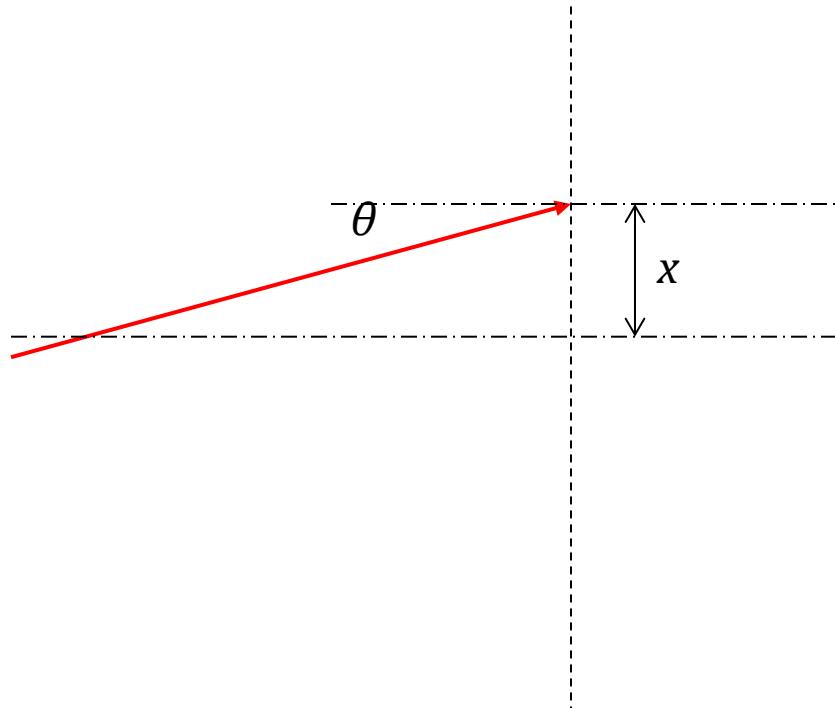


A simple thin lens

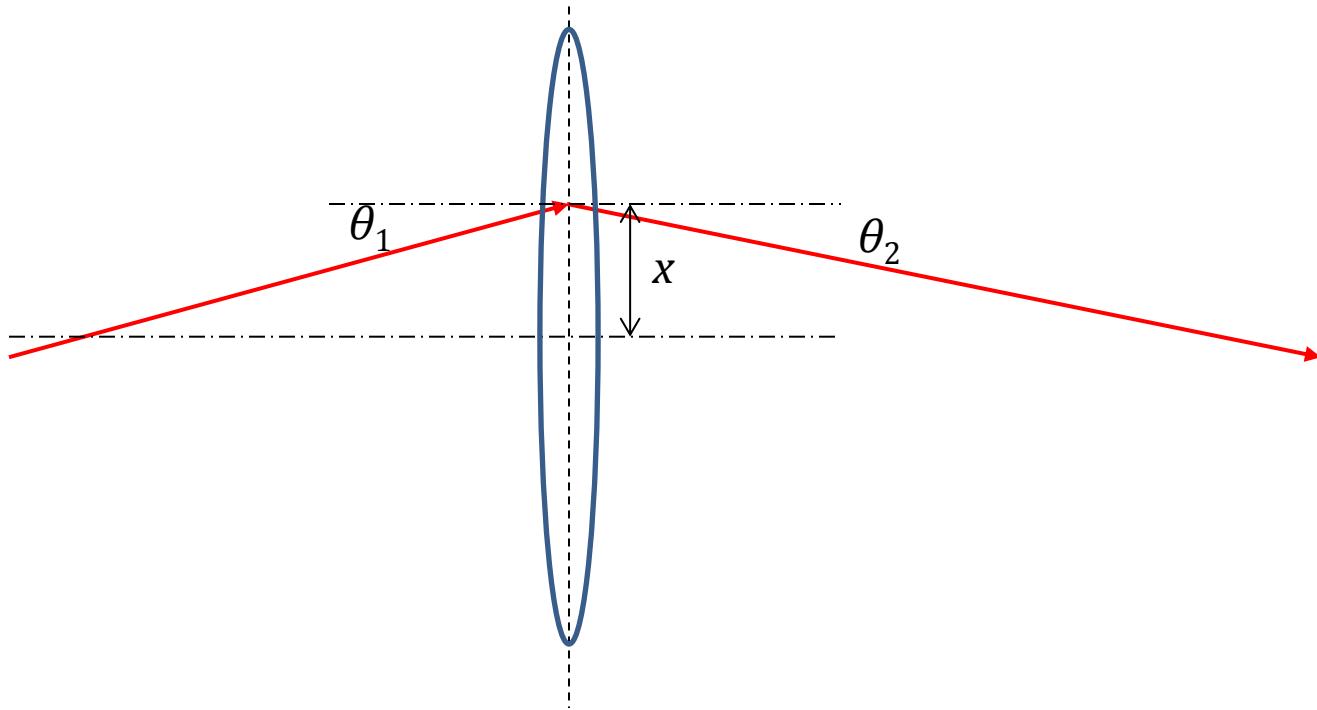


$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Describing a light ray

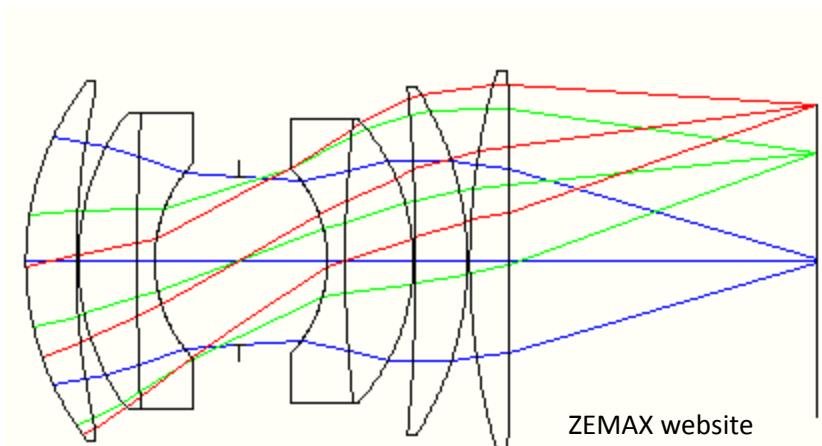


Describing a light ray



$$(x_1, \theta_1) \Rightarrow (x_2, \theta_2)$$

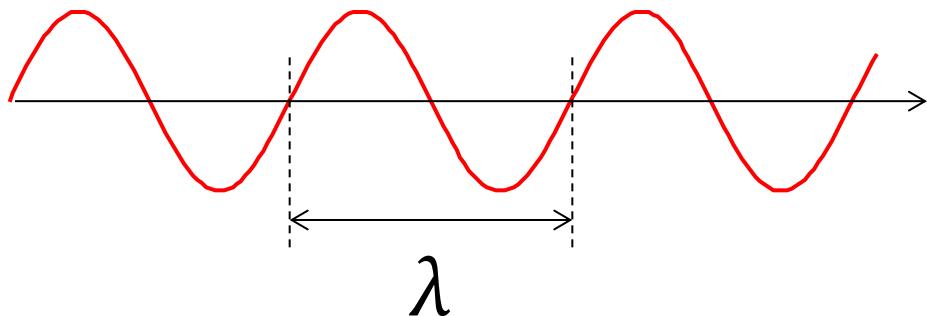
Geometric optics and ray tracing



A photograph of a large, translucent white cylinder floating in dark blue water. The cylinder is positioned horizontally across the frame, casting a prominent, distorted shadow onto the water's surface below. The shadow is wavy and multi-layered, creating a complex pattern of light and dark bands. The water itself has small ripples and reflections, particularly around the base of the cylinder. The overall composition emphasizes the interaction between light, shadow, and physical form.

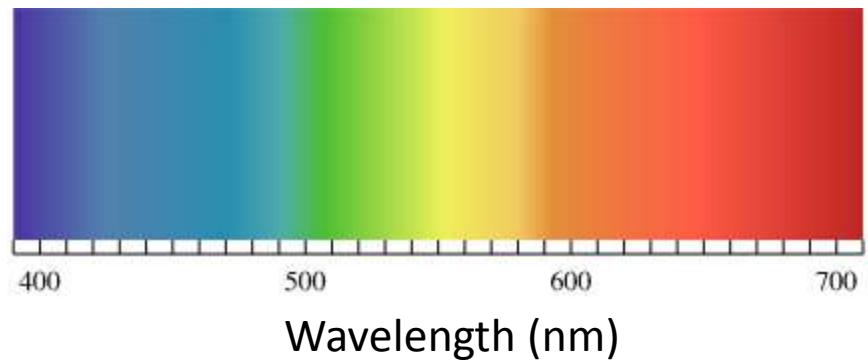
Light as waves

Wavelength and frequency

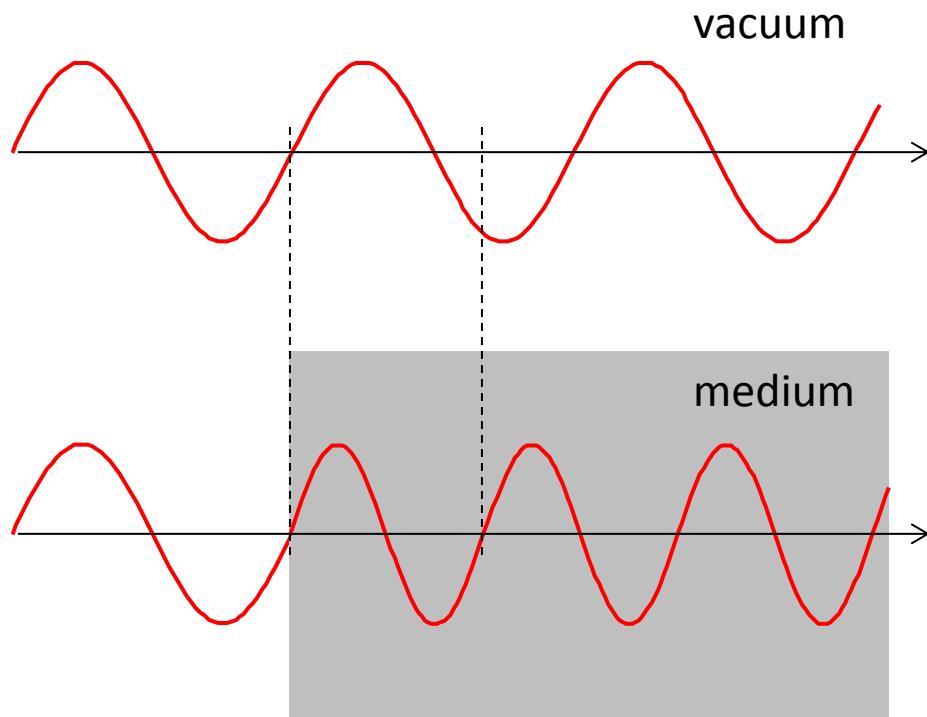


$$c = \lambda\nu$$

= 299,792,458 m/s in vacuum

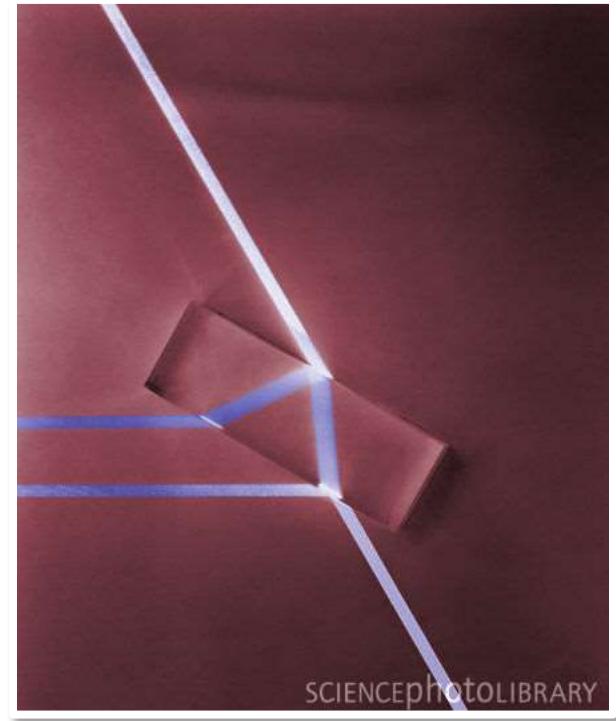
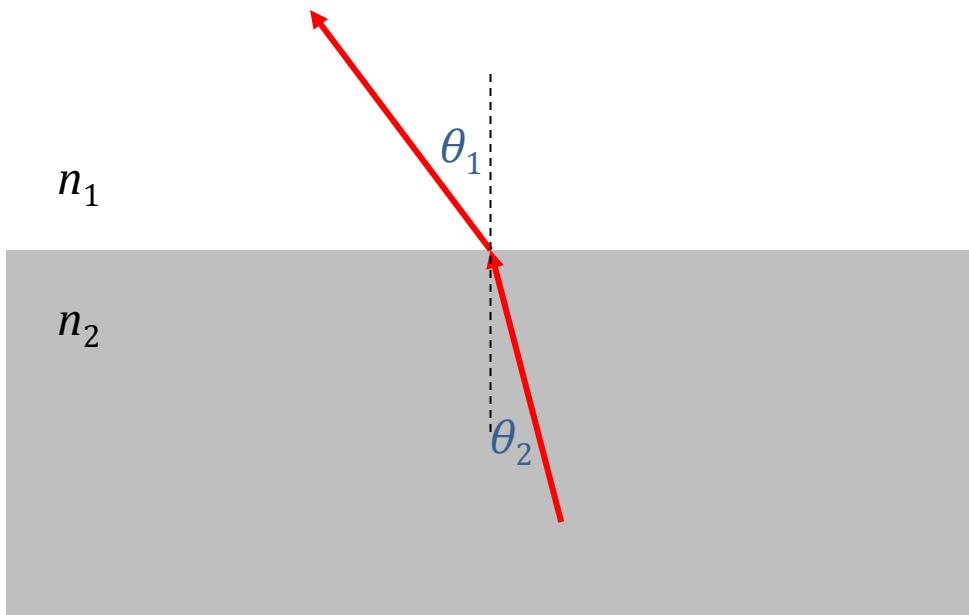


Refractive index



$$n = \frac{c}{\text{speed in medium}} = \frac{\lambda_{\text{vacuum}}}{\lambda_{\text{medium}}}$$

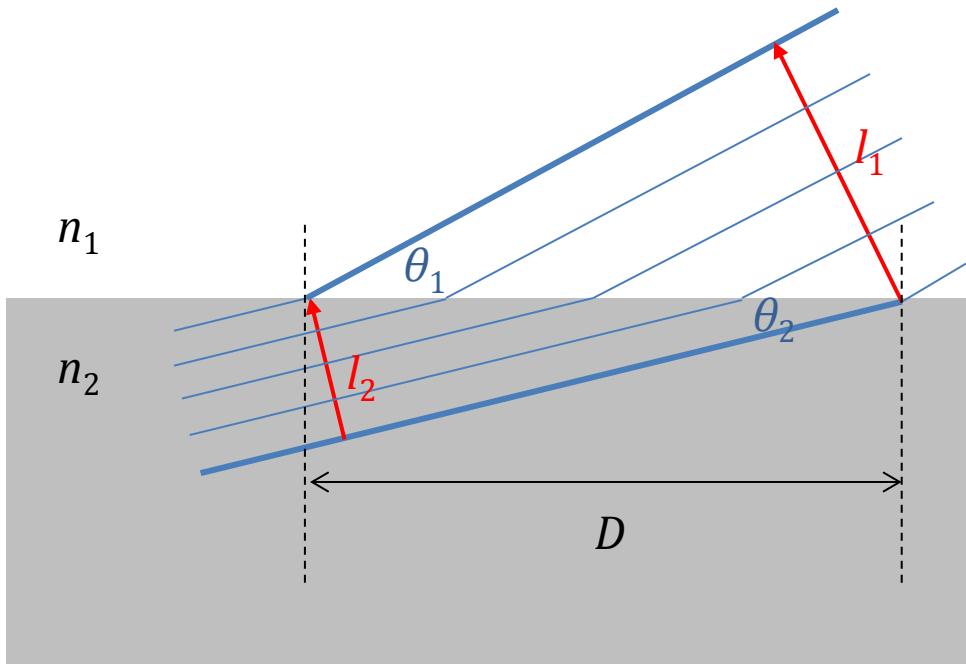
Refraction



Snell's law:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

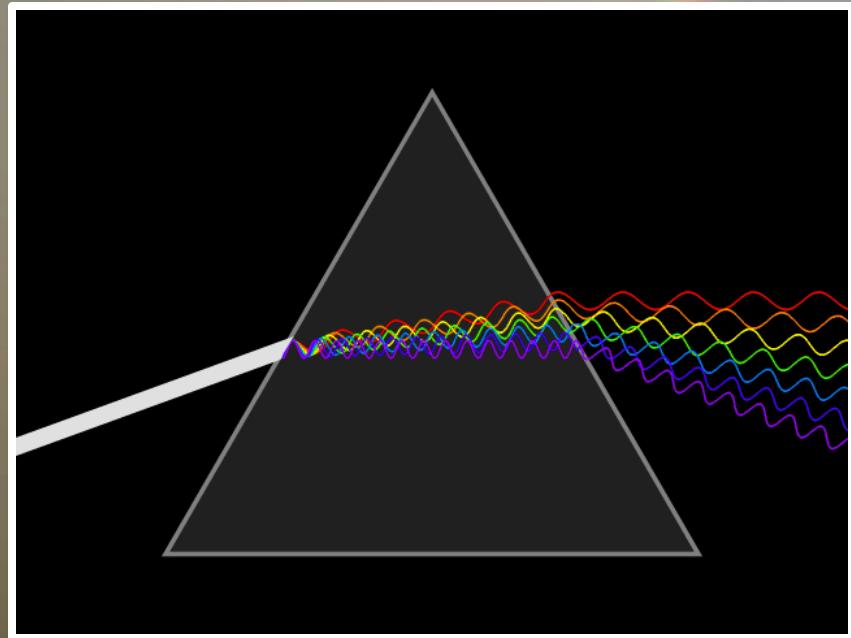
Explaining refraction



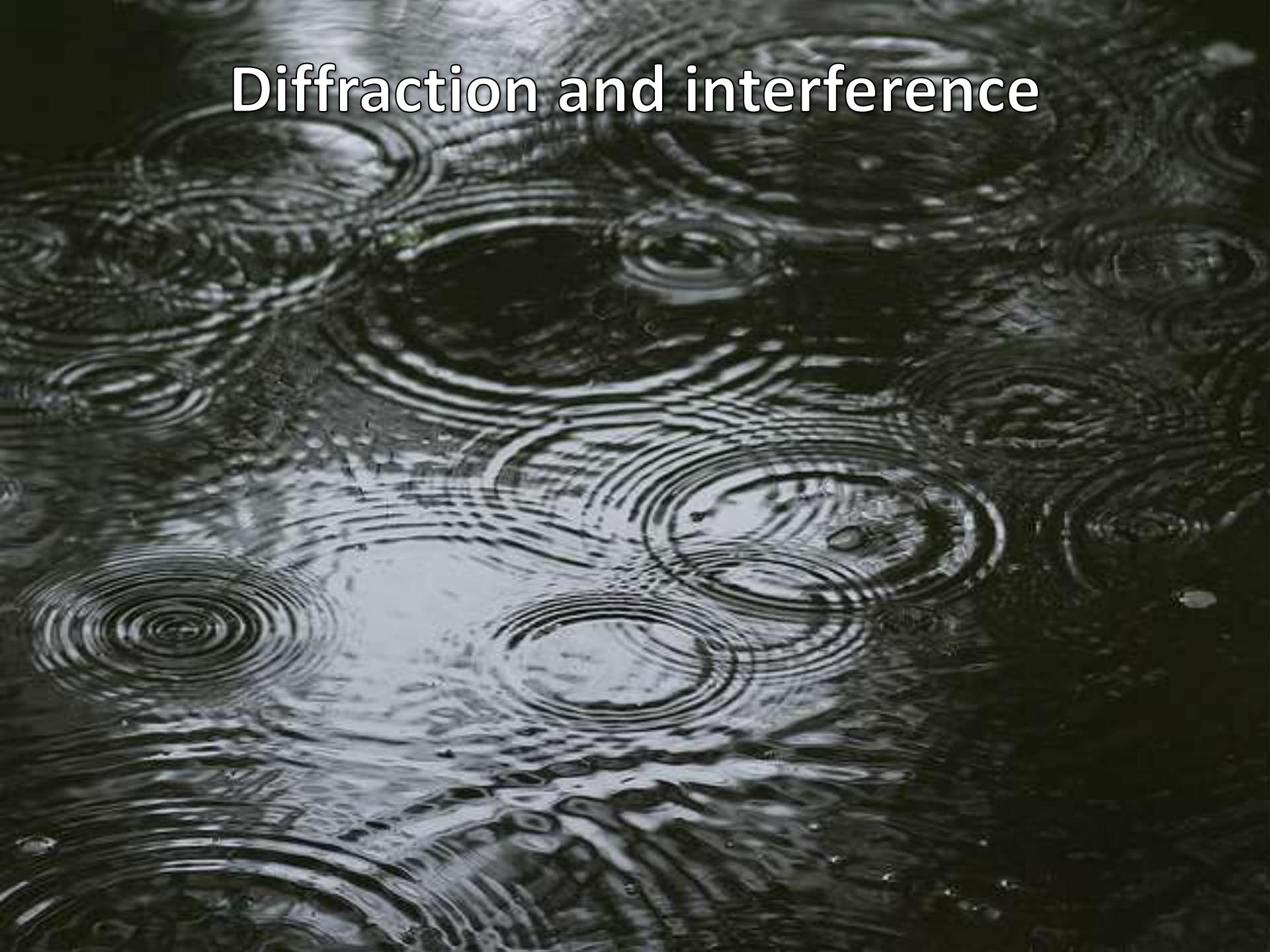
$$\Delta t = \frac{l_1}{c/n_1} = \frac{l_2}{c/n_2} \quad \Rightarrow \quad n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$l_1 = D \sin\theta_1 \quad l_2 = D \sin\theta_2$$

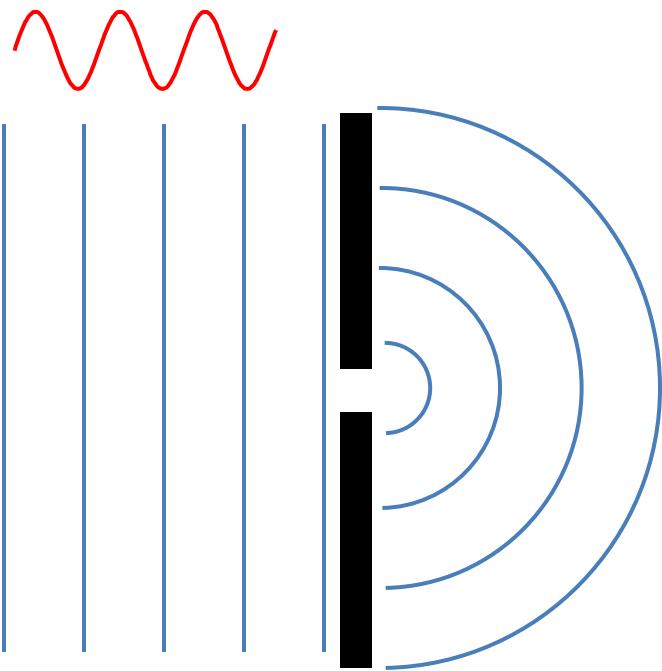
Dispersion



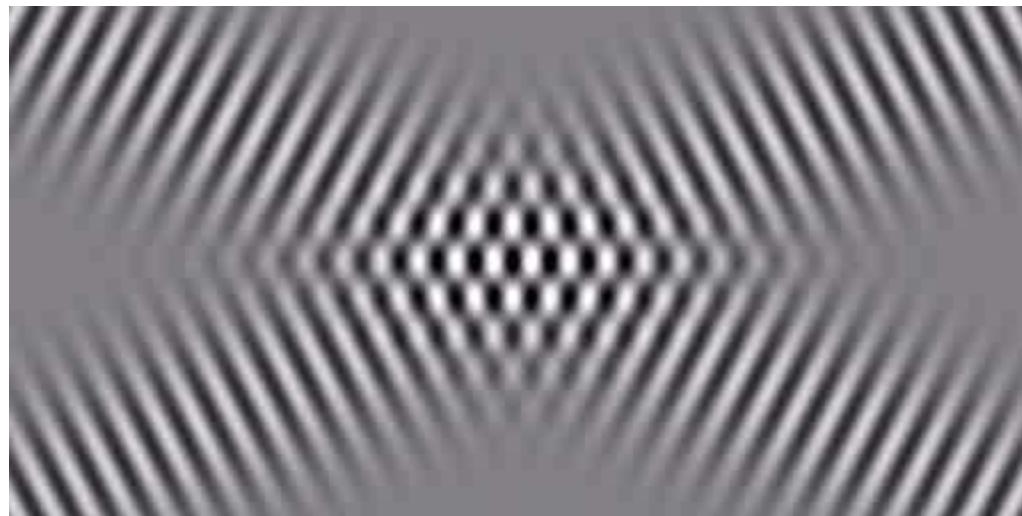
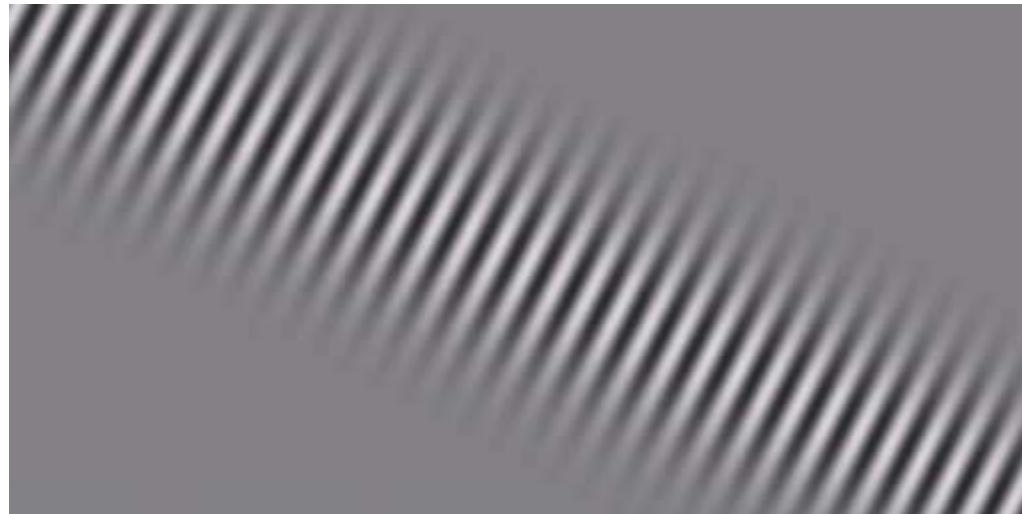
Diffraction and interference



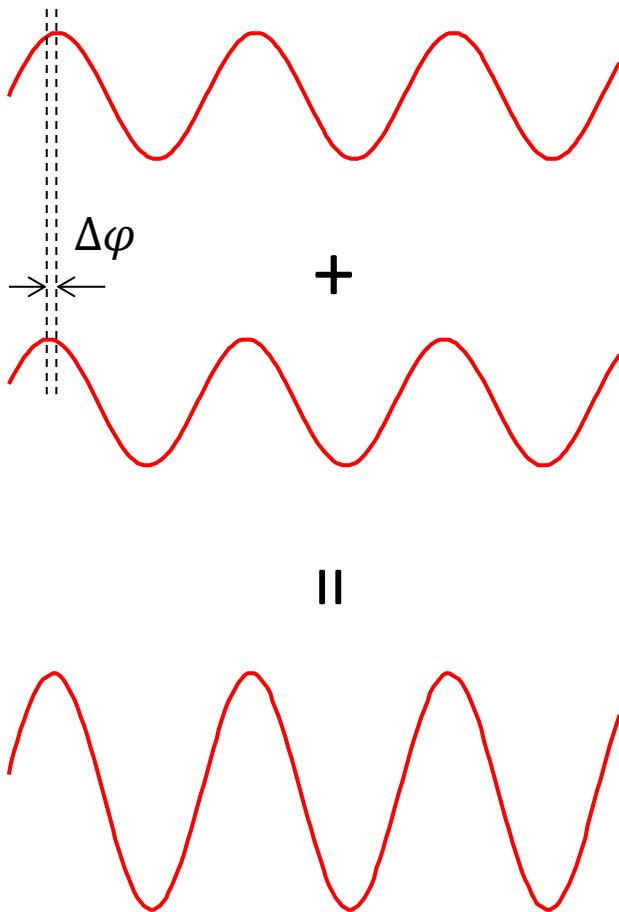
Diffraction



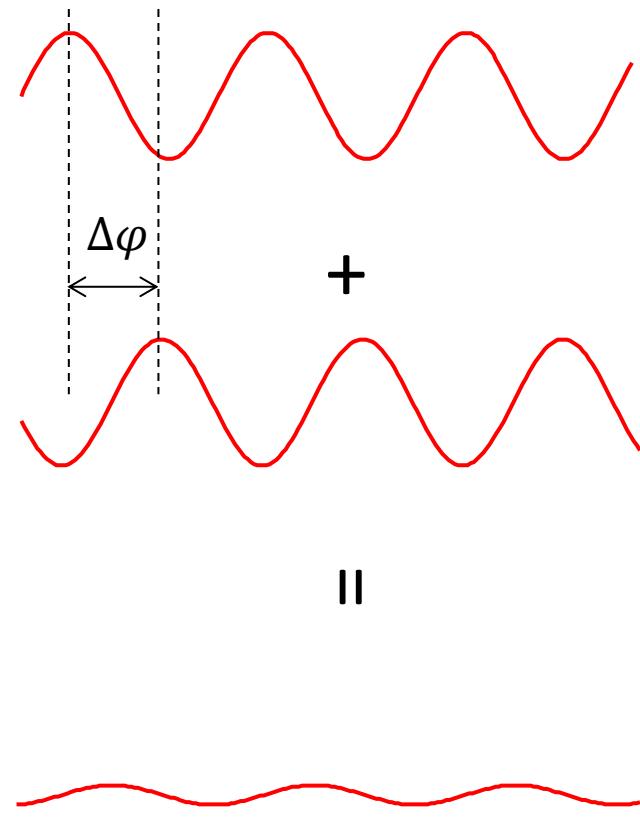
Interference



Interference

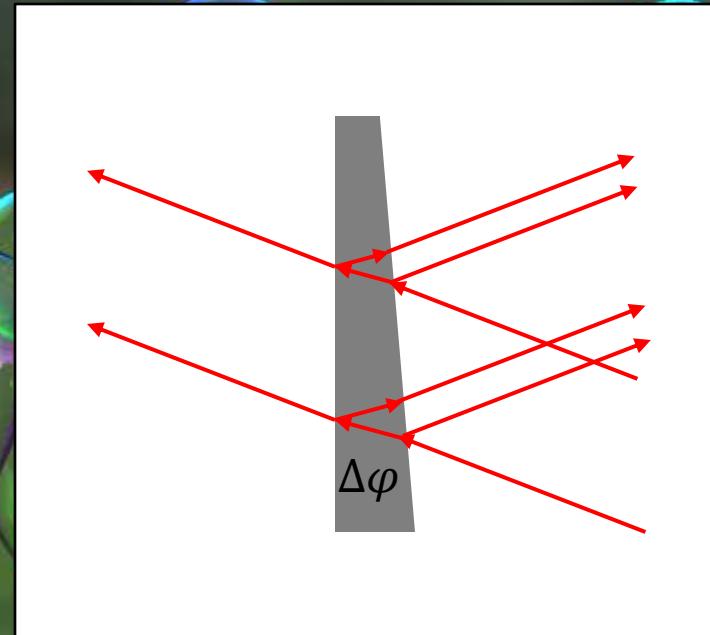
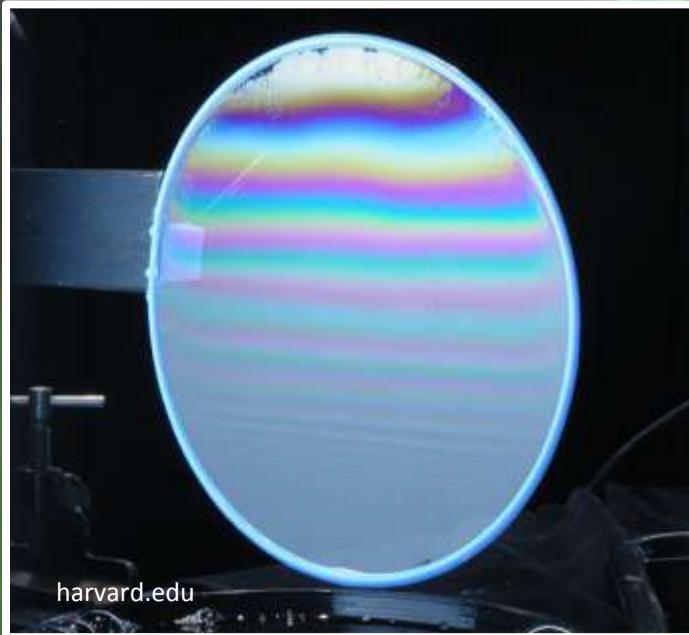


Constructive



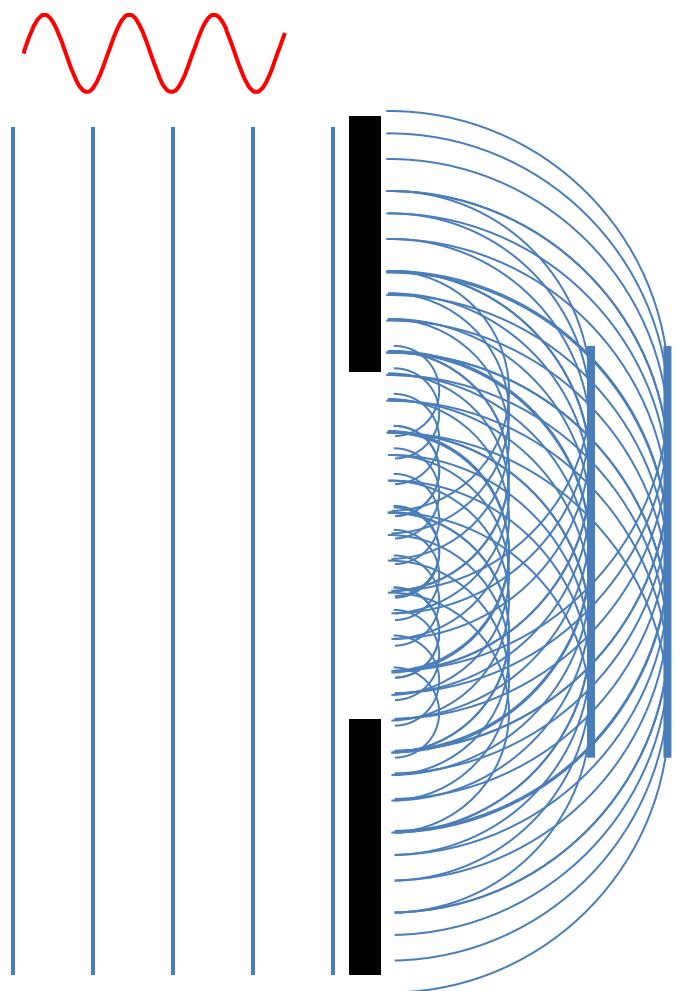
Destructive

Thin film interference

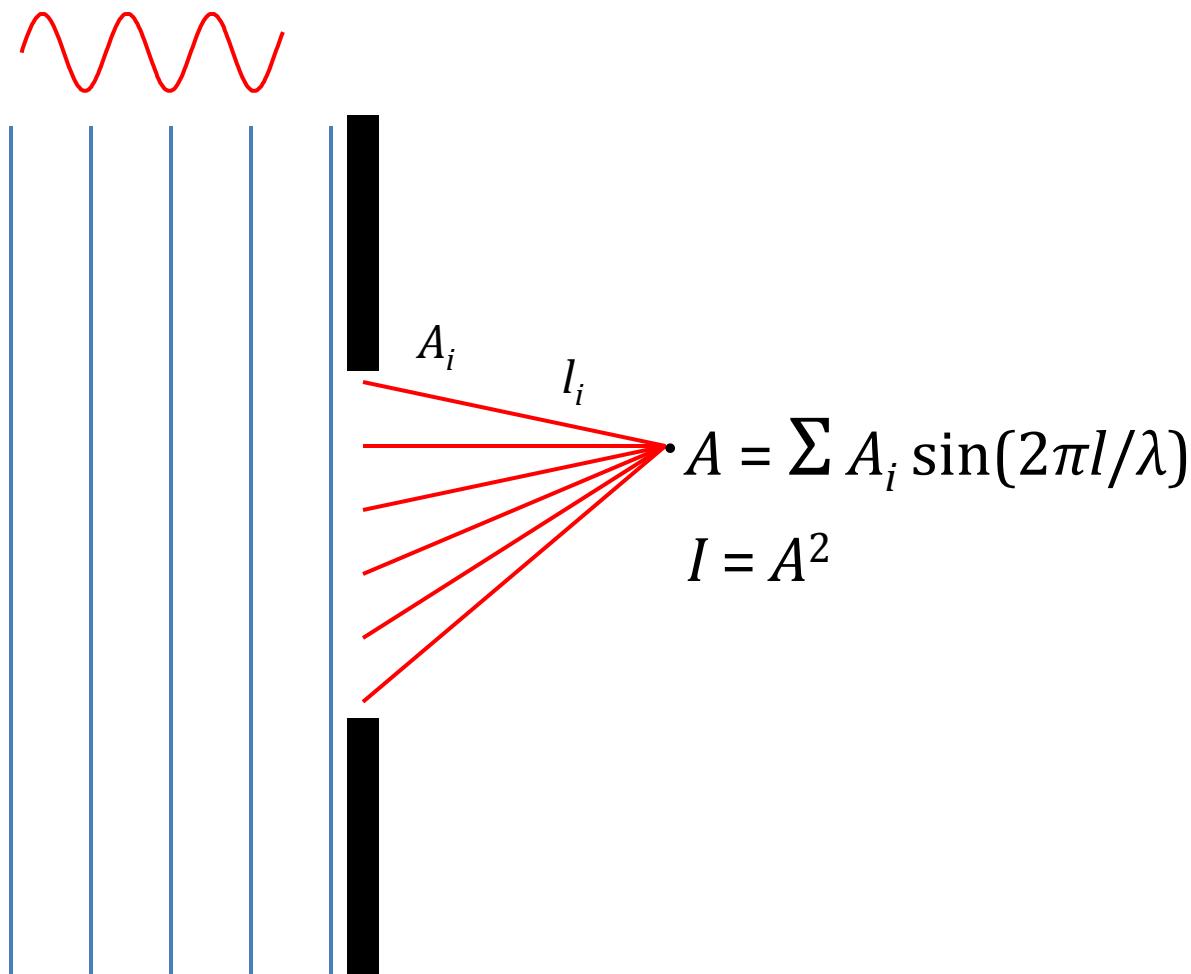


- Thickness
- Angle
- Wavelength

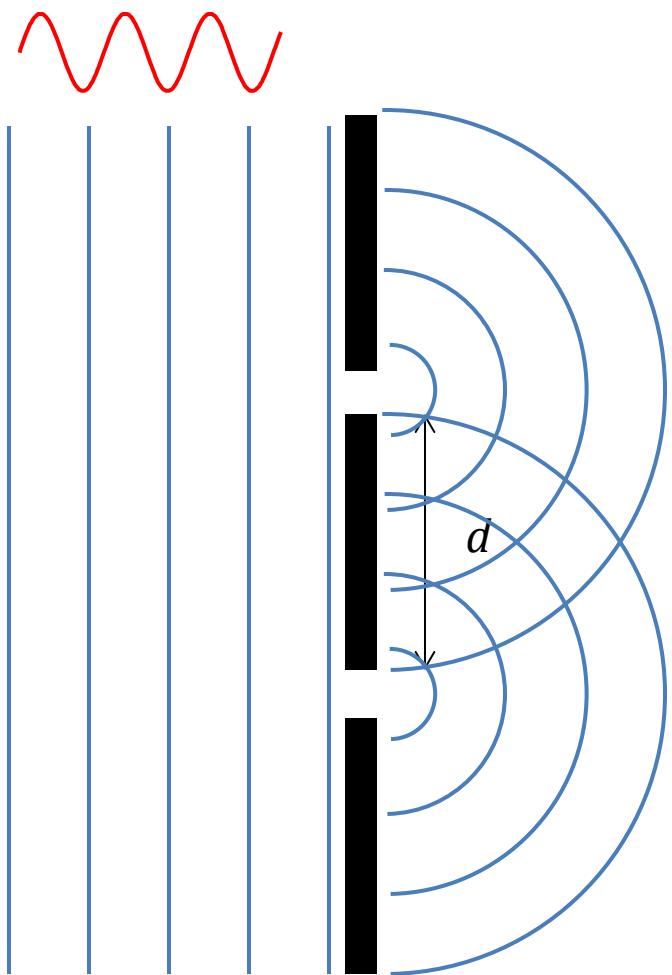
Light propagation = diffraction + interference



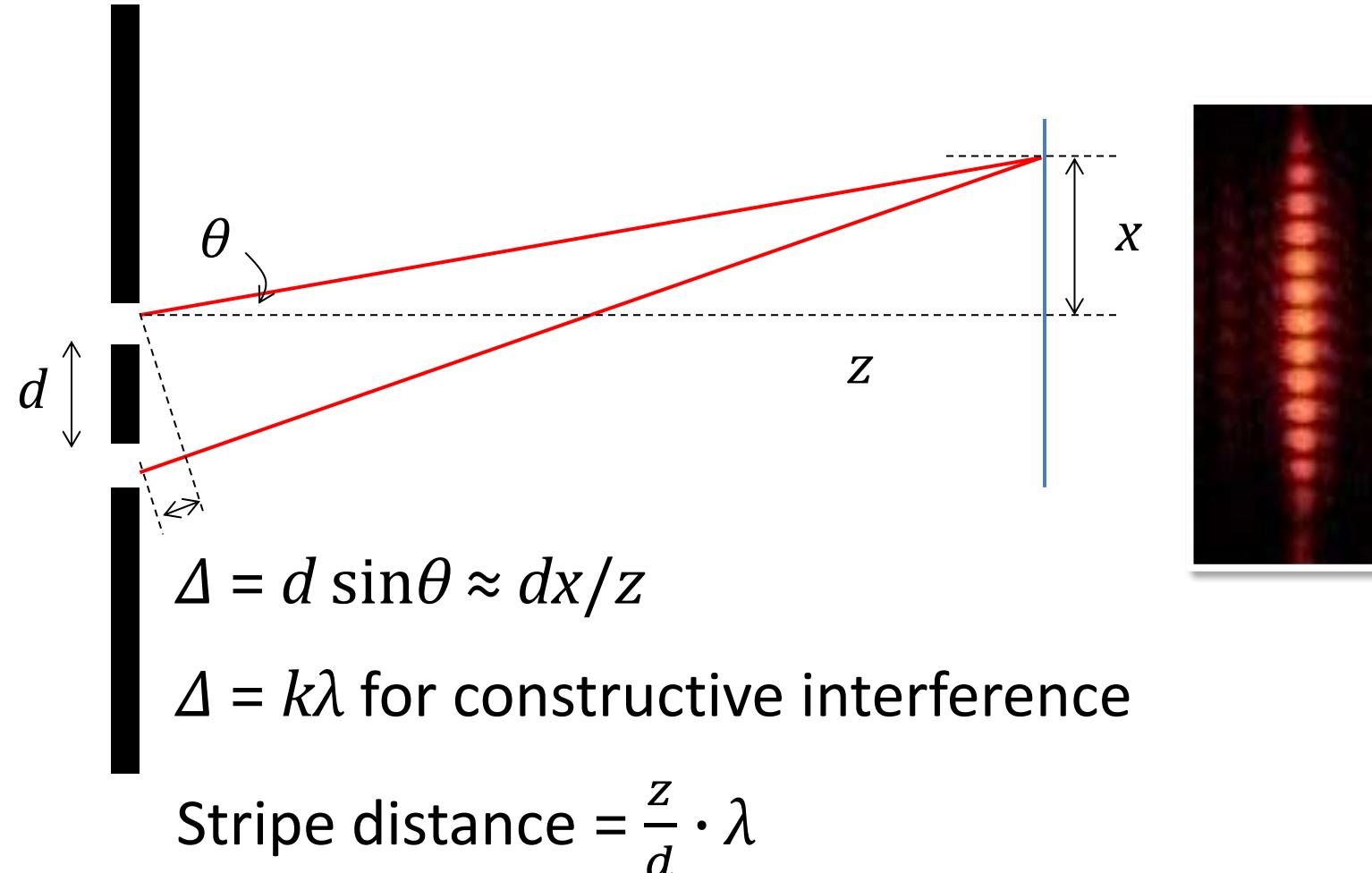
Light propagation = diffraction + interference



Double slit interference



Double slit interference



Light as electromagnetic waves

Maxwell's equations

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

Light as electromagnetic waves

Maxwell's equations

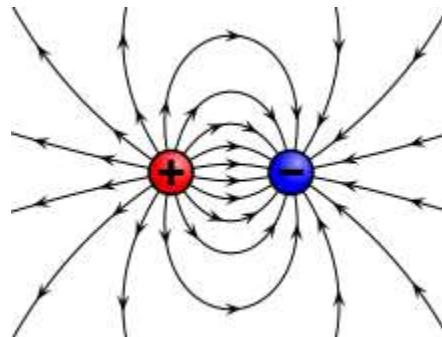
$$\nabla \cdot E = \frac{\rho}{\epsilon_0}$$

Charge density

Electric field

$$\nabla \times E = -\frac{\partial B}{\partial t}$$
$$\nabla \times B = \mu_0 J + \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$$

Static electric field generated by charges



wikipedia

Light as electromagnetic waves

Maxwell's equations

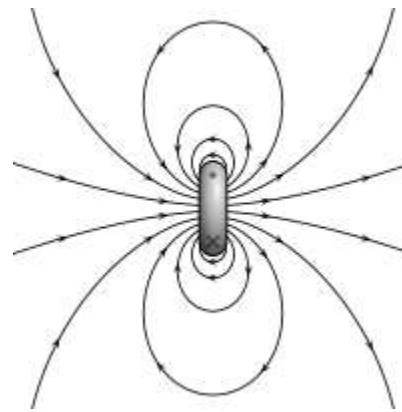
$$\nabla \cdot E = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot B = 0$$

Magnetic field

$$\nabla \times B = \mu_0 J + \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$$

Magnetic force lines form closed circles.



wikipedia

Light as electromagnetic waves

Maxwell's equations

$$\nabla \cdot E = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot B = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times B = \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$$

A changing magnetic field generates electric field

Rate of change

Light as electromagnetic waves

Maxwell's equations

$$\nabla \cdot E = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot B = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times B = \mu_0 J + \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$$

Electric current

Electric current and changing electric field generate magnetic field

Light as electromagnetic waves

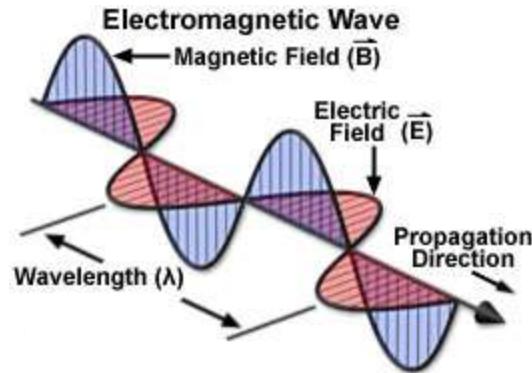
Maxwell's equations

$$\nabla \cdot E = \frac{\rho}{\epsilon_0}$$

$$\nabla \cdot B = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times B = \mu_0 J + \mu_0 \epsilon_0 \frac{\partial E}{\partial t}$$

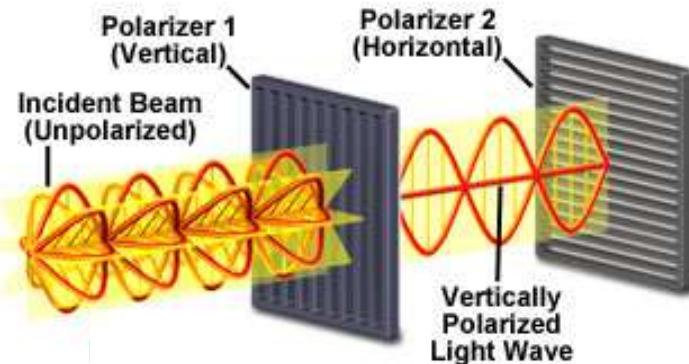


Michael Davidson

Speed of light = $1/\sqrt{\mu_0 \epsilon_0}$

Polarization

Polarization of Light Waves



Michael Davidson



wikipedia

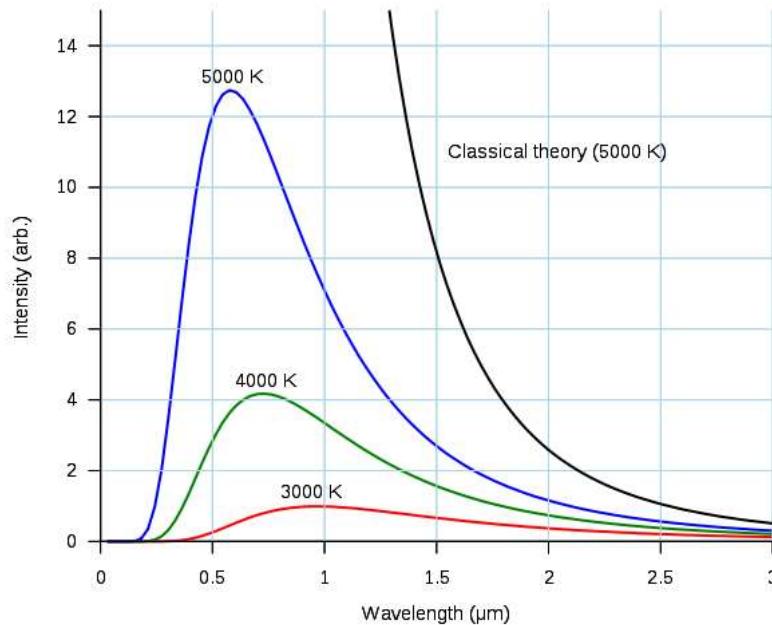
Light as particles



From blackbody emission

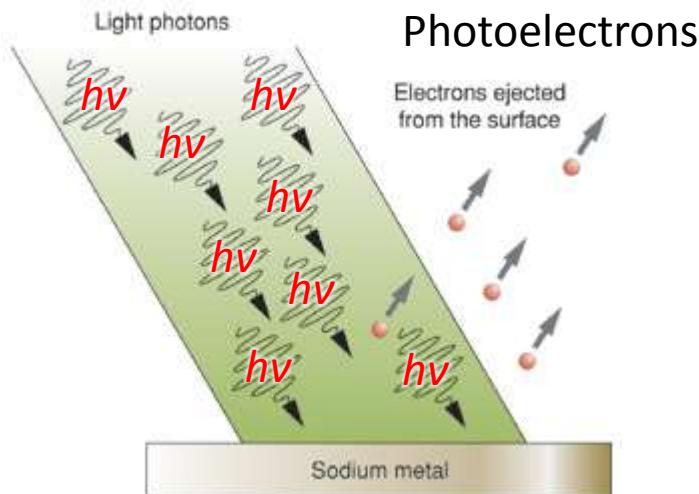


Max Planck



$$E = h\nu$$

Photoelectric effect



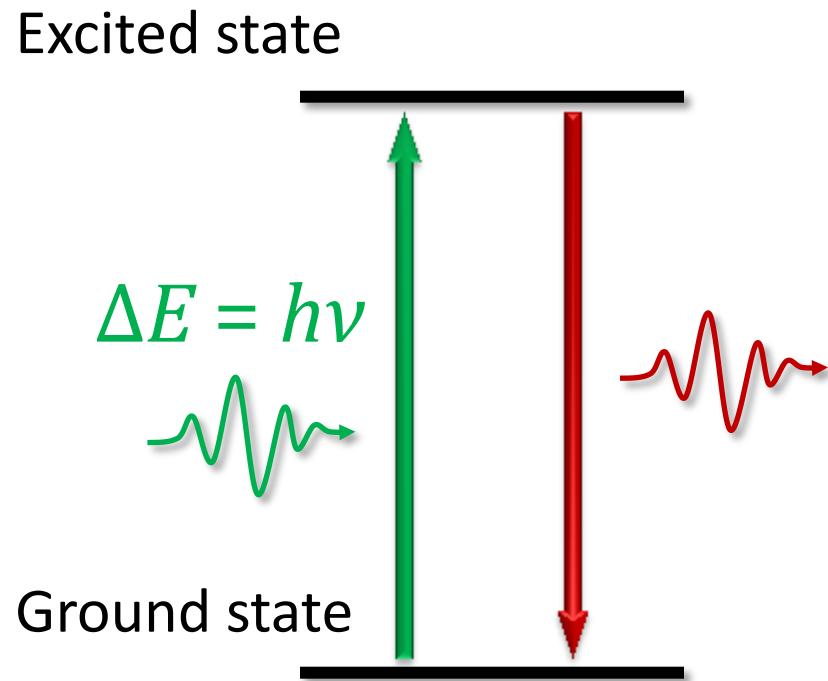
The Encyclopedia of Science

Albert Einstein



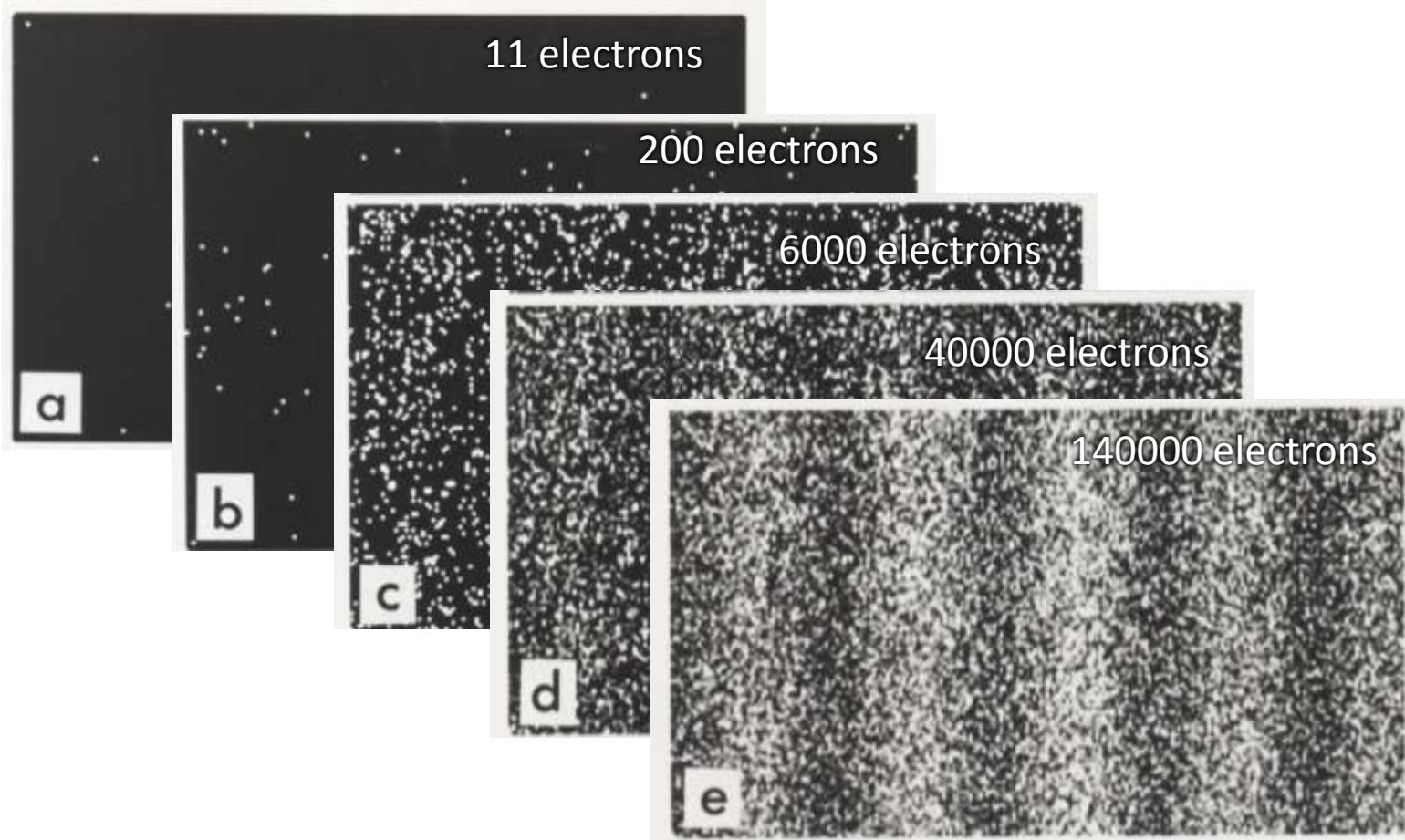
1 Einstein = 1 mole of photons

Photon: the quantized energy of light



Wave-particle duality

Double-slit experiment of electrons



What light really is?

A photograph of a dark night sky filled with stars. The stars appear as small white points of light scattered across the dark blue to black gradient of the sky. In the lower portion of the image, the silhouettes of several tall evergreen trees are visible against the starry background. The foreground is mostly dark, suggesting a field or a path through the trees.