Chapter 33-34 – Geometric Optics

Light rays moving in straight lines

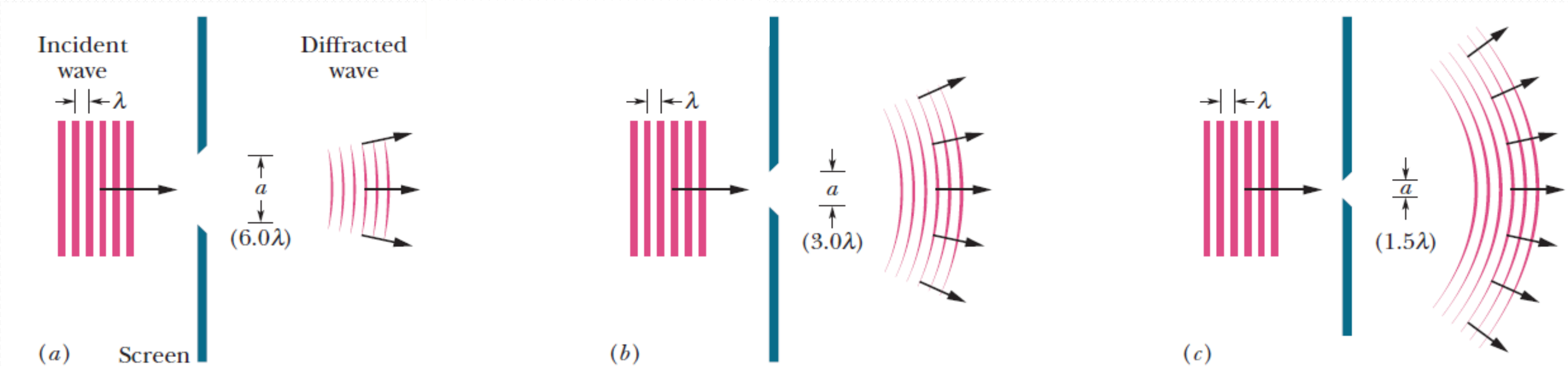
Ch35-36 - Wave Optics

Interference – double-slit, thin-film

Diffraction – single-slit, double-slit,
diffraction grating,
circular opening

Chapter 35

Diffraction



Diffraction = flaring/spreading of the wave beyond the barrier

Most noticeable when size of opening $a \sim \lambda$

Limits use of geometric optics (straight rays) to scales $\gg \lambda$

Consequence of Huygens principle

Same effect for barriers (instead of openings)

Same for any type of wave: water, etc.

Diffraction pattern (more than just flaring)

Fresnel v. bright spot (early 1800s)

secondary/side fringes due to self-interference

Light Waves

1678 Christiaan Huygens - wave theory of light:

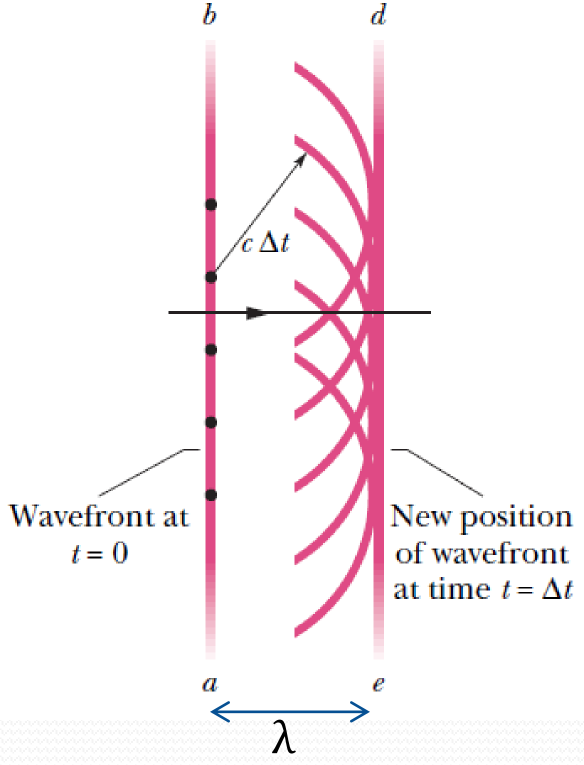
geometrical construction predicting the position of a WF from the present position

1704 Newton – corpuscular hypothesis for light

1873 Maxwell treatise

Reminder:

Wave front – same $\vec{E}(t)$ – are planar *far* from source



Huygens Principle:

All points on a propagating wave front serve as

sources of secondary spherical wavelets

After time Δt the new position of the wave front

is at a surface tangent to 2^{nd}-ary wavelets

Example: Distance between wave fronts

$d = c\,\Delta t$ = radius of wavelets

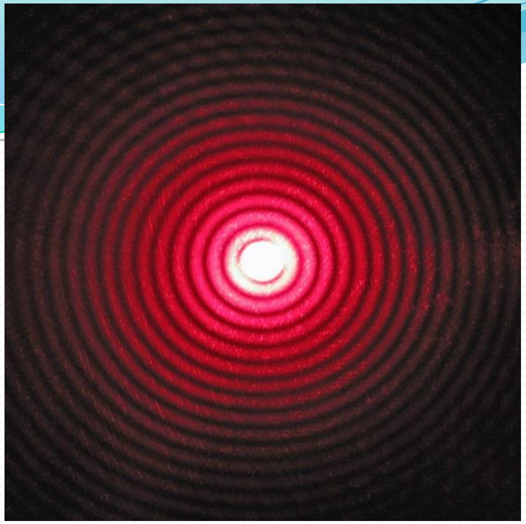
new WF "ed" ∥ old WF "ab"

$\Delta t \rightarrow T = \frac{1}{f} \qquad \rightarrow \qquad d = c\,T = \frac{c}{f} = \lambda$

Can be used to derive reflection and refraction laws (page 1103)

Circular-Opening Diffraction

Image of laser through small opening is not a point →
See central Fresnel spot

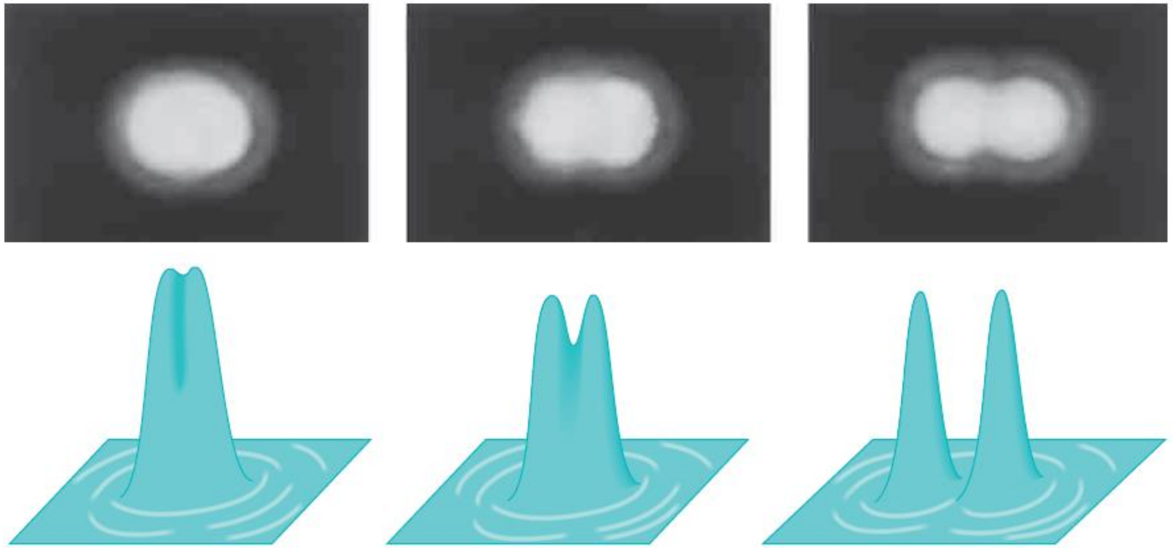


Resolution – ability to distinguish two objects as being separate
Resolution criterion – objects barely separated when
central diffraction max of 1st object is located at 1st diffraction min of 2nd object

Rayleigh's Criterion

$$sin\theta_R = 1.22\ \frac{\lambda}{D}$$

where
θ angle to 1st minimum
D diameter of opening
1.22 factor – for circular shape



Top: Images of two stars formed by a converging circular lens
Bottom: Image intensities
Center: Rayleigh's criterion is satisfied

Single-Slit Diffraction

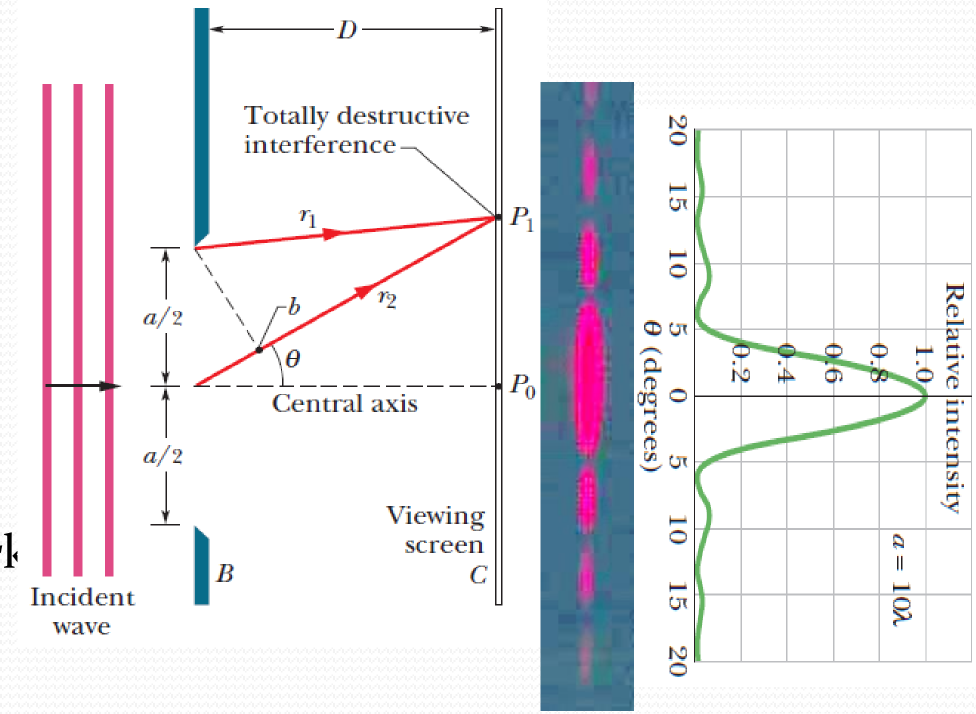
Dark fringes (destructive interference)

$$\boxed{a \sin \theta = m\lambda} \qquad \sin\theta = m\frac{\lambda}{a}$$

Position (y) of dark fringes $\quad tan\theta = \frac{y}{D}$

$$y = m\frac{\lambda}{a}D \qquad \text{where } m = \pm 1, \pm 2, \ldots .$$

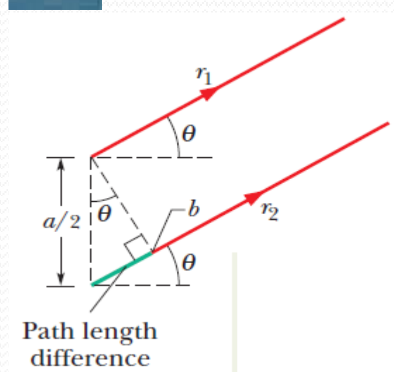
Bright fringes approx. half way betw. dark



Intensity in single-slit diffraction
(Fraunhofer diffraction pattern)

$$I = I_0\left(\frac{sin\alpha}{\alpha}\right)^2 \qquad \text{where} \qquad \alpha = \pi\,\frac{a}{\lambda}\sin\theta$$

I_0 intensity in Fresnel bright spot

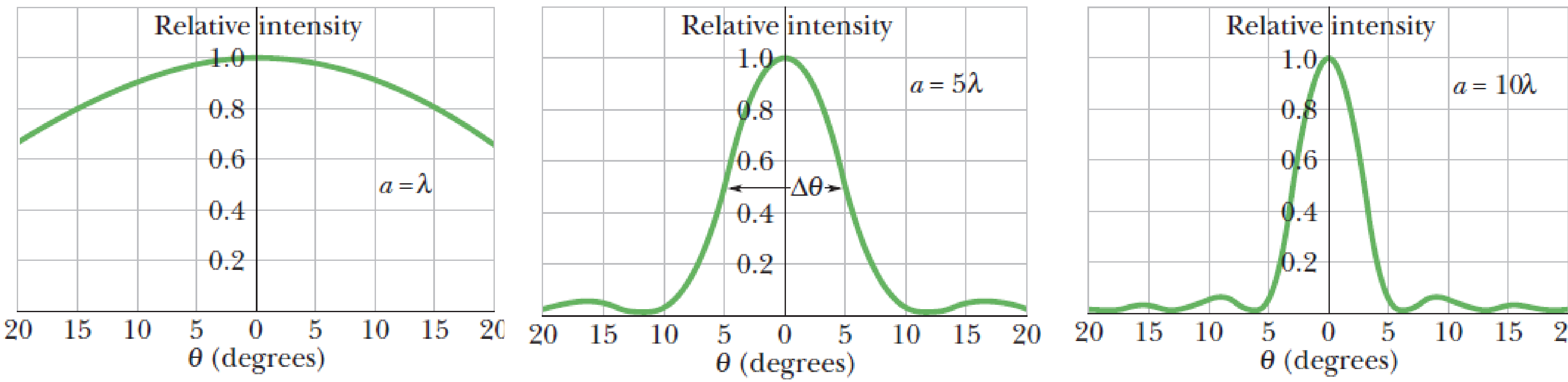


Note:

$I = 0 \quad \text{for} \quad \alpha = m\pi \quad \rightarrow \quad a\sin\theta = m\lambda$

Chapter 36

Single-Slit Diffraction



Narrower slit → wider max
(more flaring)

Wider slit → narrow max

Full width of central max = distance between 1st diffraction minima on each side

$$\boxed{FWCM = 2\,L\,\frac{\lambda}{a}}$$

Double-Slit Diffraction

Intensity in double-slit interference (DSI)

$$I = I_m cos^2\beta$$

d = distance between slits

$\beta = \pi \frac{d}{\lambda} \sin\theta$

$cos^2\beta$ interference factor

$a \ll \lambda$ same intensity

Intensity in single-slit diffraction (SSD)

$$I = I_m \left(\frac{sin\alpha}{\alpha}\right)^2$$

a = slit opening

$\alpha = \pi \frac{a}{\lambda} \sin\theta$

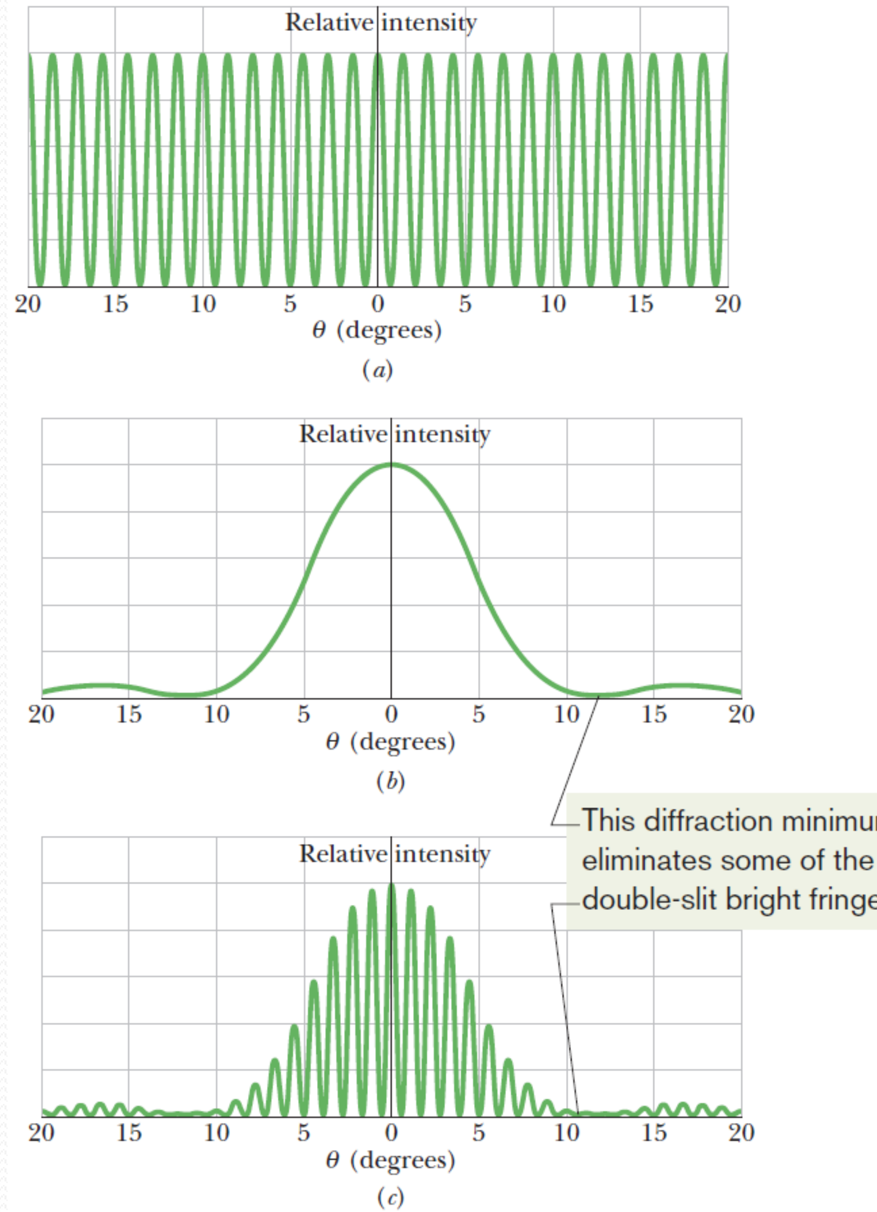
$\left(\frac{sin\alpha}{\alpha}\right)^2$ diffraction factor

Intensity in double-slit diffraction (DSD)

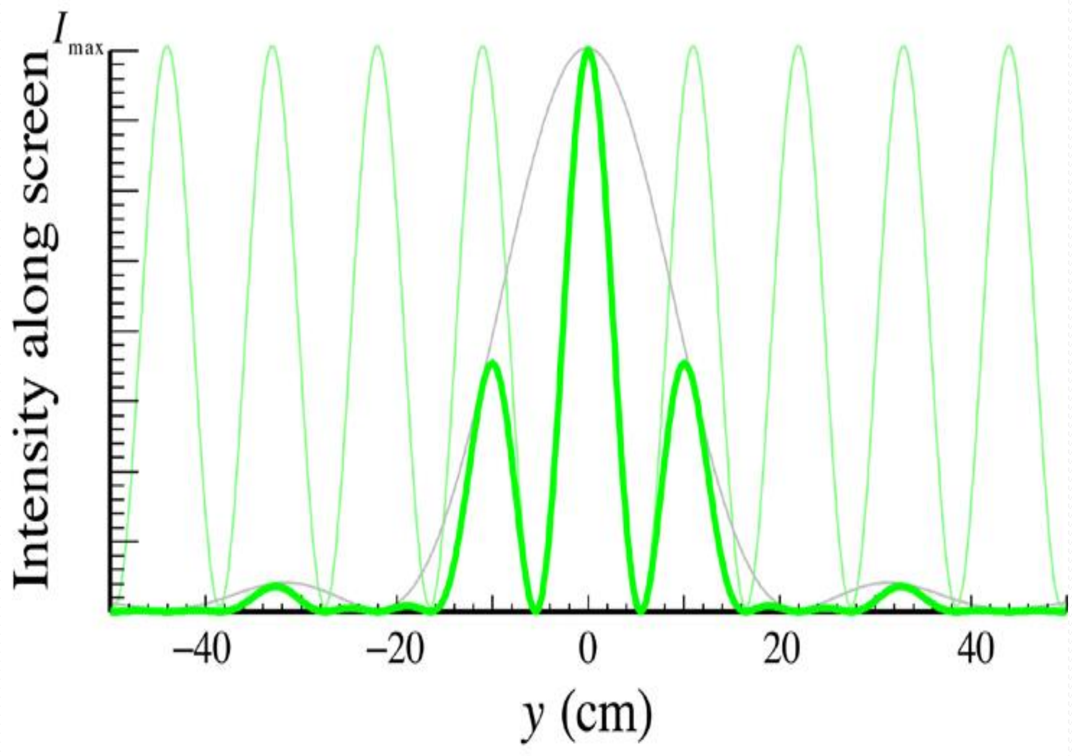
$$I = I_m\, cos^2\beta \left(\frac{sin\alpha}{\alpha}\right)^2$$

Note:

SSD becomes an envelope for interference pattern



Double-Slit Diffraction



Intensity in double-slit diffraction

$$I = I_m \, cos^2\beta \left(\frac{sin\alpha}{\alpha}\right)^2$$

Where $\alpha = \pi \frac{a}{\lambda} \sin\theta$

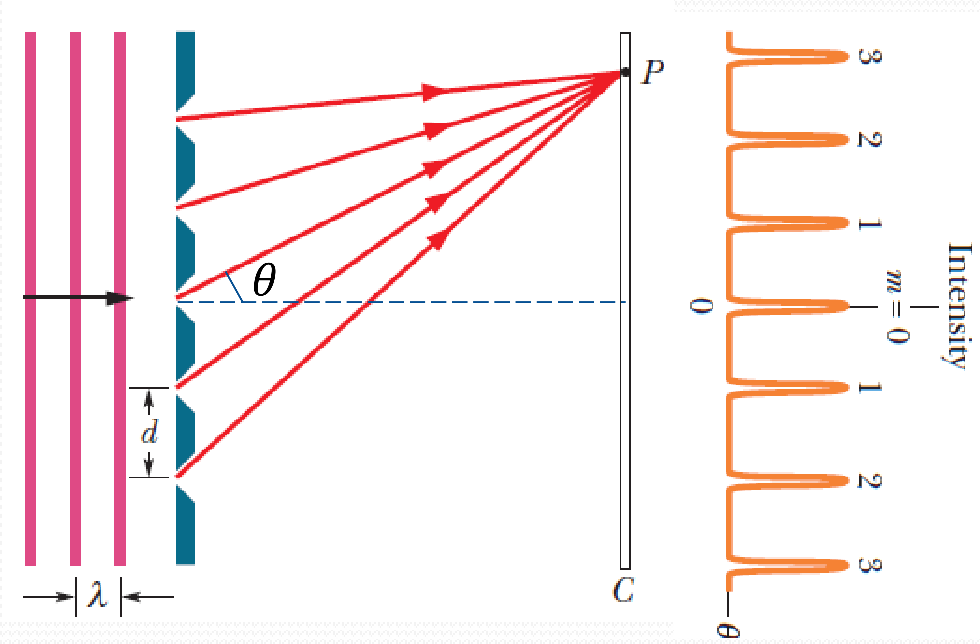
$$\beta = \pi \frac{d}{\lambda} \sin\theta$$

a = slit opening
d = distance between slits

$$tan\theta \cong sin\theta = \frac{y}{L}$$

$$\boxed{I = I\left(\frac{a}{\lambda}, \frac{d}{\lambda}, \frac{y}{L}\right)}$$

Diffraction Grating



Slits are called *rulings*

visible ~1000/*mm*

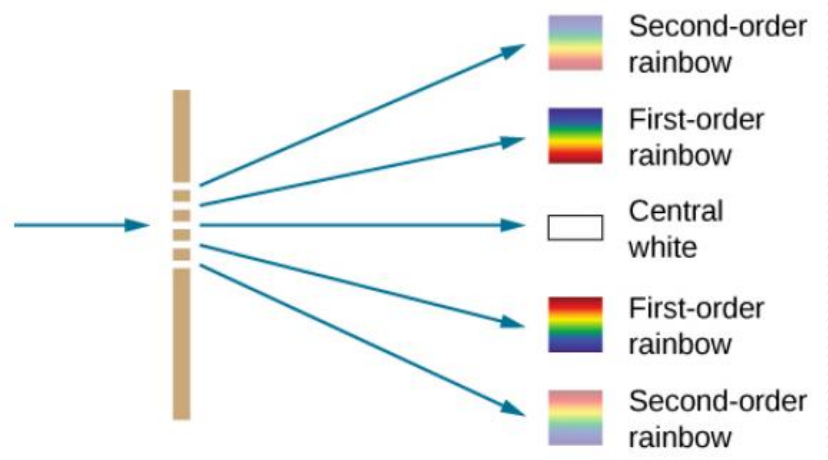
light-years away from the 5 wires used by Fraunhofer in 1821 – founder of stellar spectroscopy

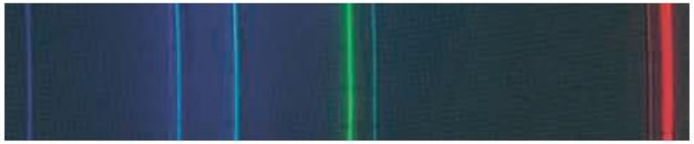
Interference pattern =

narrow bright fringes (lines) separated by wide dark areas

Diffraction Grating

Spectroscopy = measure θ → calculate λ





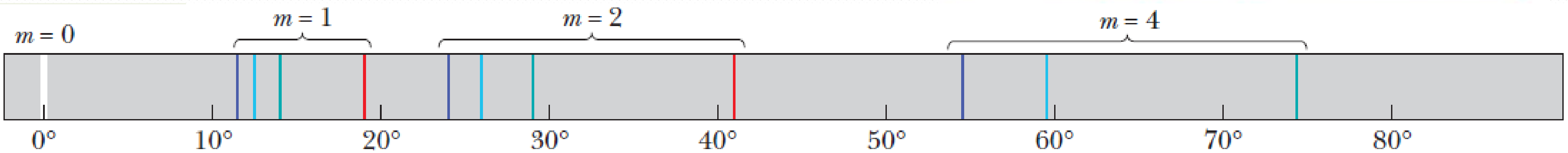


Fig. 36-24 The zeroth, first, second, and fourth orders of the visible emission lines from hydrogen. Note that the lines are farther apart at greater angles. (They are also dimmer and wider, although that is not shown here.)

Diffraction Grating

Rulings = slits

Number of rulings N

Number of rulings/mm $n = N/L$

Grating spacing $d = \frac{1}{n} = \frac{L}{N}$ or $L = Nd$

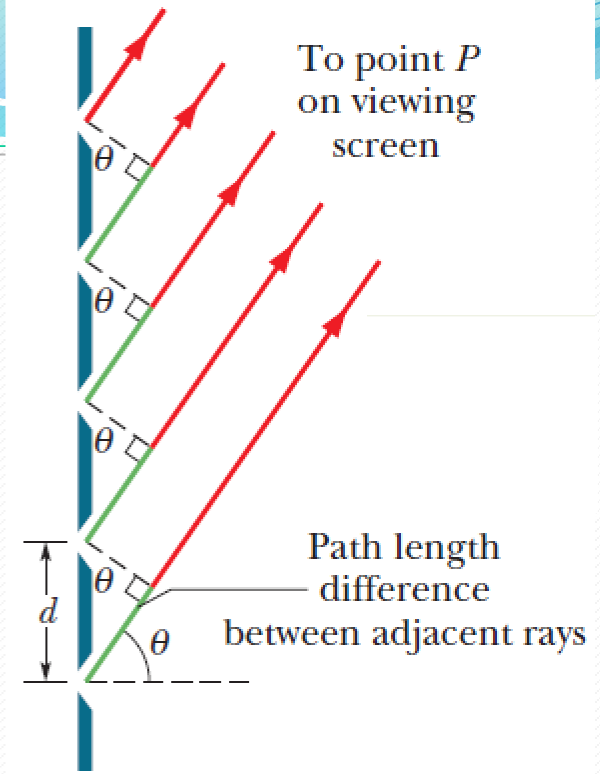
Example: visible $n \sim 1000/mm$

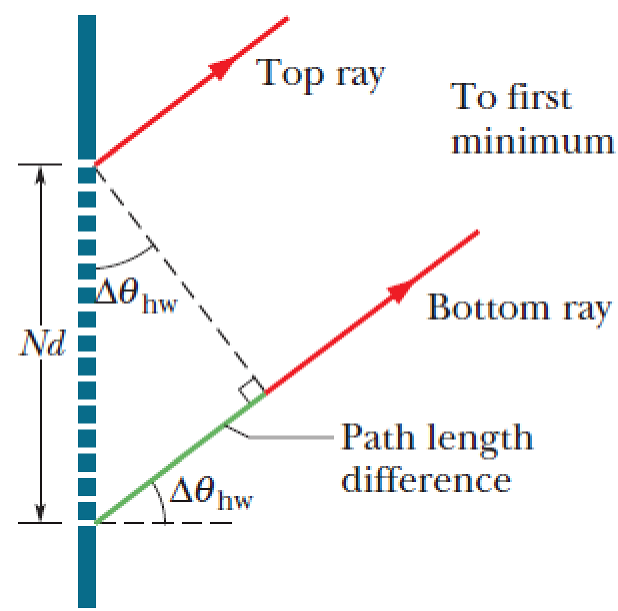
$$d \sim \frac{1mm}{1000} \sim 1\mu m$$

Lines (maxima) $\Delta x = d\ sin\theta = m\,\lambda$

Resolving power $R = \frac{\lambda_{ave}}{\Delta\lambda} = m\,N$

$[R] = 1$ (or $\frac{nm}{cm}$)

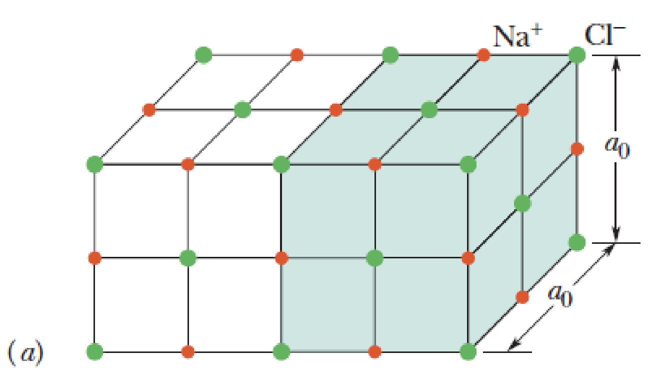




Chapter 36

X-Ray Diffraction

1895 Rontgen: X-rays = el.mg waves w/$\lambda = 10^{-10} m$
Atomic spacing in crystal $\sim 10^{-10} m$
1912 Max von Laue experiment



Bragg's law for CI: $2d\ sin\theta = m\ \lambda$