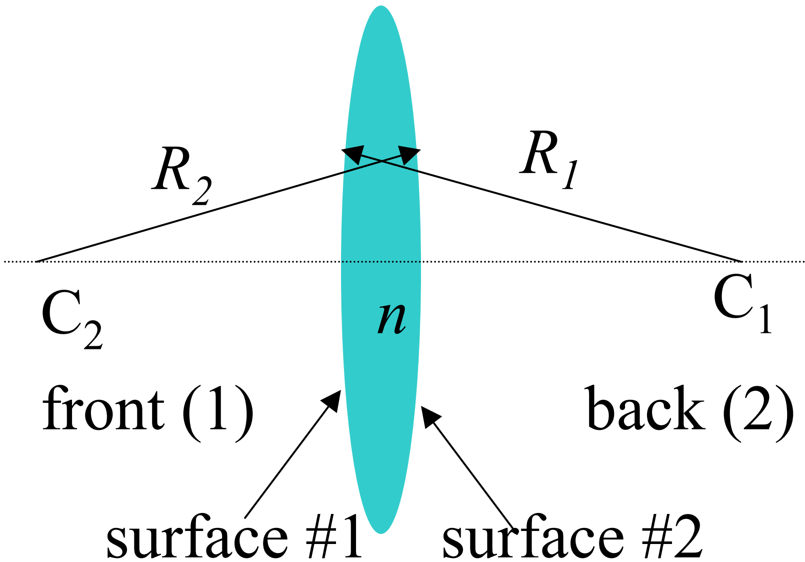
Announcements

1. Reminder – problem solving session Tuesday, Apr. 1, 2003 at 6 PM in Olin 107.
2. There will be an online quiz for Wednesday.
3. Topics for today:
   - Images formed with lenses – summary and corrections
   - Interference phenomena

Lens makers' equation:

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$



Sign convention:

R_i is positive if C_i is in "back" of lens

R_i is negative if C_i is in "front" of lens

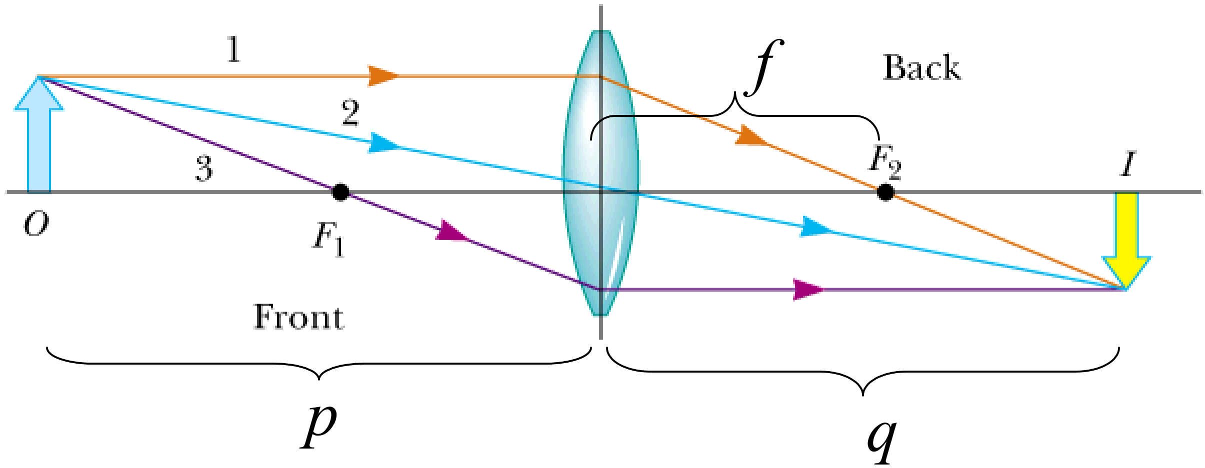
Lens makers' equation can be proven using

- Snell's law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$
- small angle approximation: $\sin\theta_1 \approx \tan\theta_1 \approx \theta_1$
- thin lens approximation: thickness << f, p, q

➔ Lens equation: $$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

Example:

Forming a real image using a converging lens



Example:

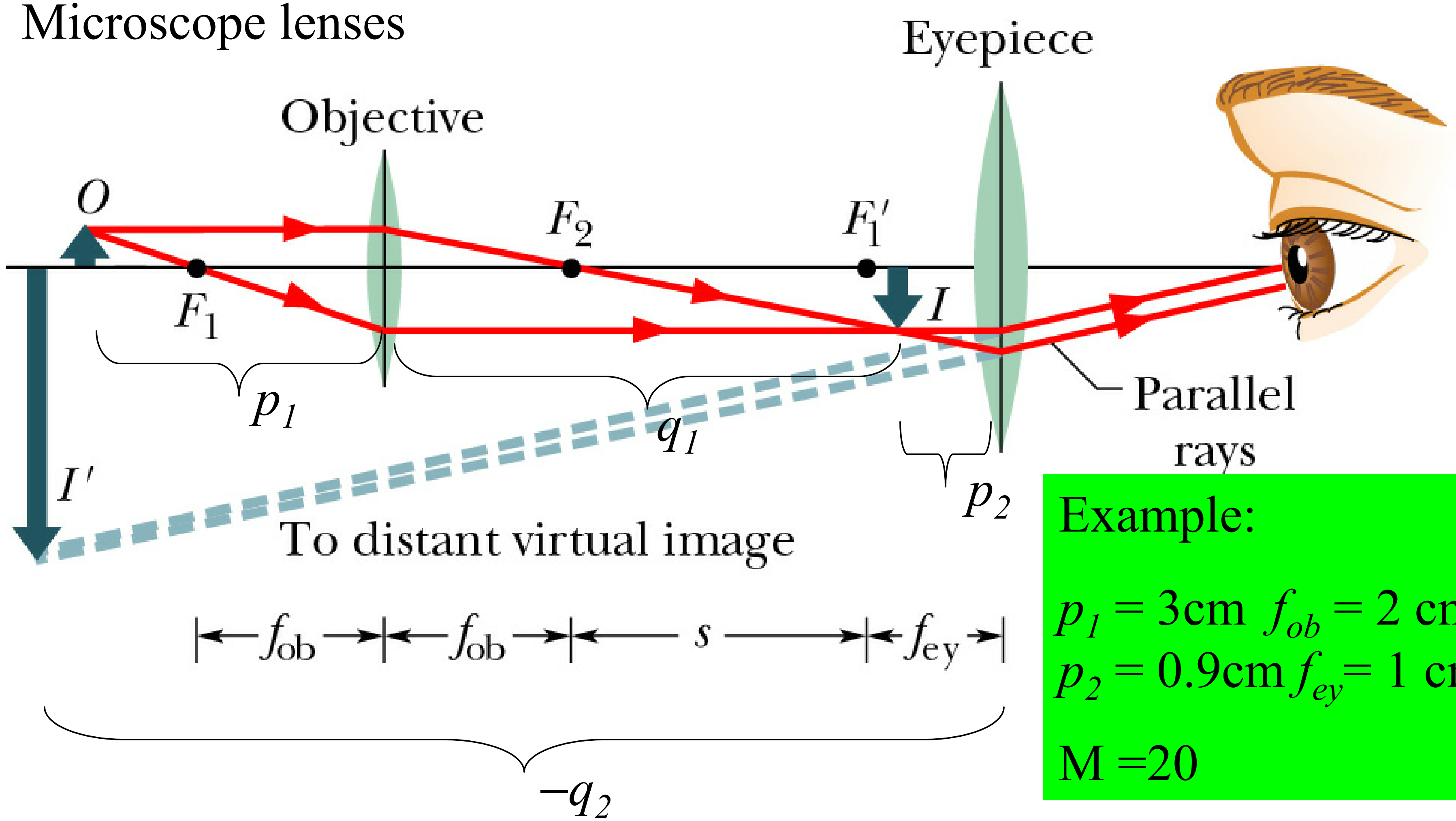
$f = 2$ cm, $p = 5$ cm

➔ $q = 3.33$ cm

(real image)

This could represent, for example the lens system of a camera.

Microscope lenses



Example:

$p_1 = 3\text{cm} \;\; f_{ob} = 2\text{ cm}$
$p_2 = 0.9\text{cm} \;\; f_{ey} = 1\text{ cm}$

M =20

$$\frac{1}{p_1} + \frac{1}{q_1} = \frac{1}{f_{ob}}; \;\; \frac{1}{p_2} + \frac{1}{q_2} = \frac{1}{f_{ey}} \qquad M = \frac{-q_1}{p_1}\frac{-q_2}{p_2}$$

Peer instruction question –

How can you photograph a microscope image?

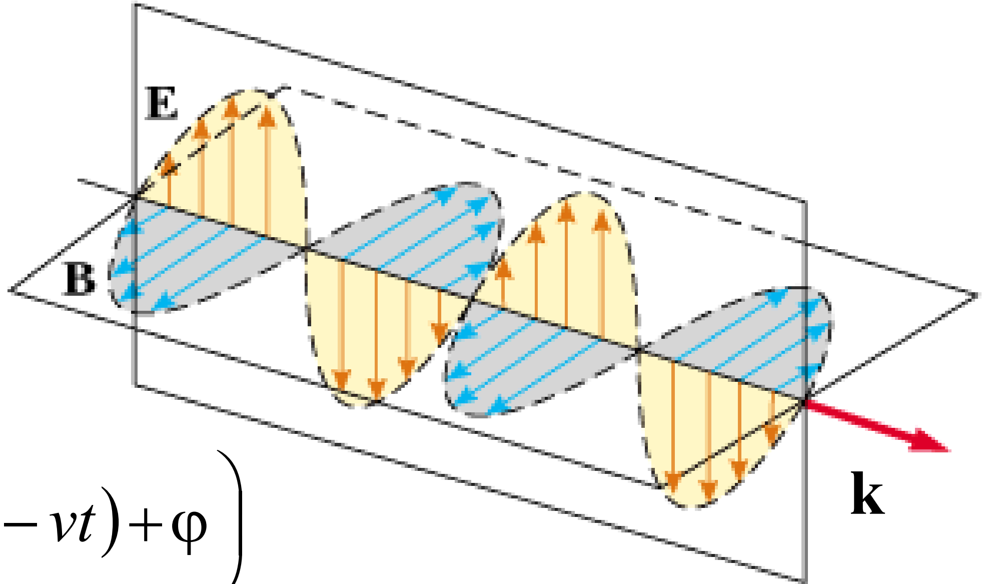
(A) Simply place a camera where the eye would go.

(B) It is not possible to photograph a microscope image.

(C) You would need to modify the setup.

Wave phenomena associated with light

Plane polarized electromagnetic wave at an instant of time:



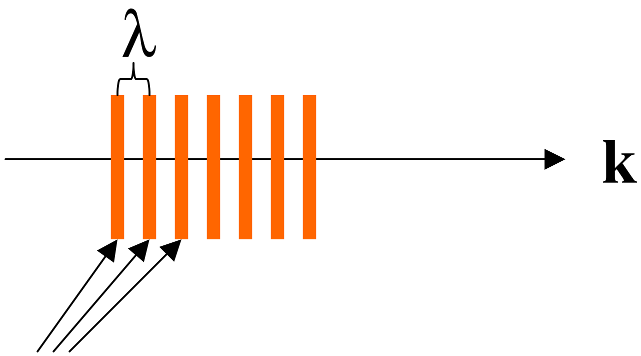
$$E_y(x,t) = E_{\max} \sin\left(\frac{2\pi}{\lambda}(x - vt) + \varphi\right)$$

Superposition of light waves: $E_y^{tot}(x,t) = E_y^1(x,t) + E_y^2(x,t)$

Example: $E_y(x,t) = E_{\max} \sin\left(\frac{2\pi}{\lambda}(x - vt)\right) + E_{\max} \sin\left(\frac{2\pi}{\lambda}(x + vt)\right)$

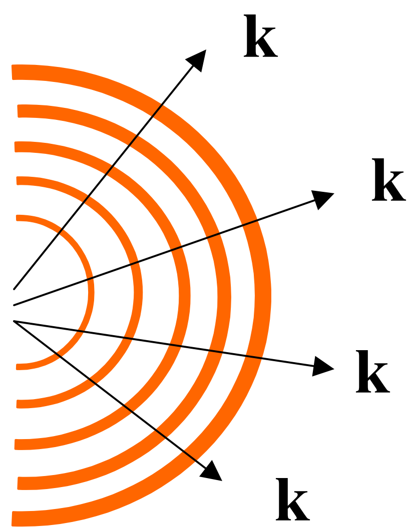
$$= 2E_{\max} \sin\left(\frac{2\pi x}{\lambda}\right) \cos\left(\frac{2\pi vt}{\lambda}\right)$$

Top view of plane EM wave

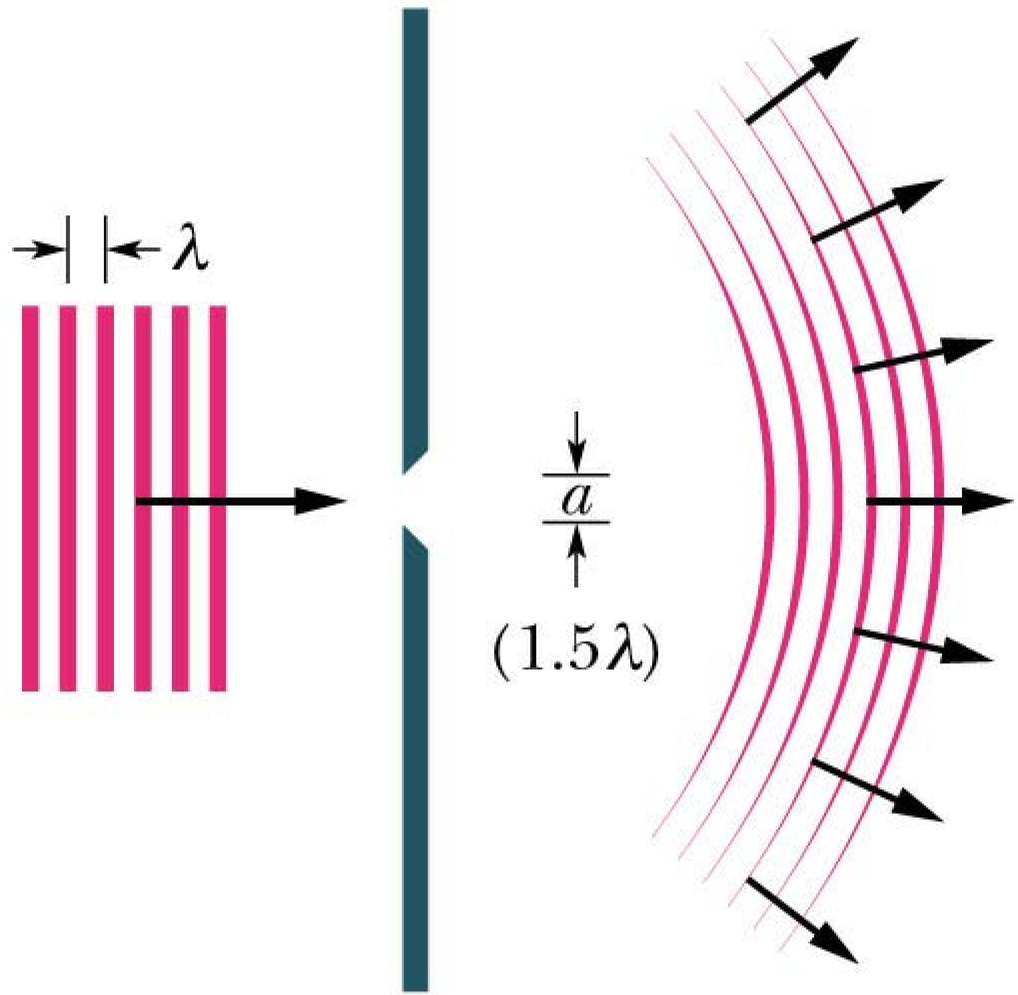


peaks of E field (perpendicular to screen)

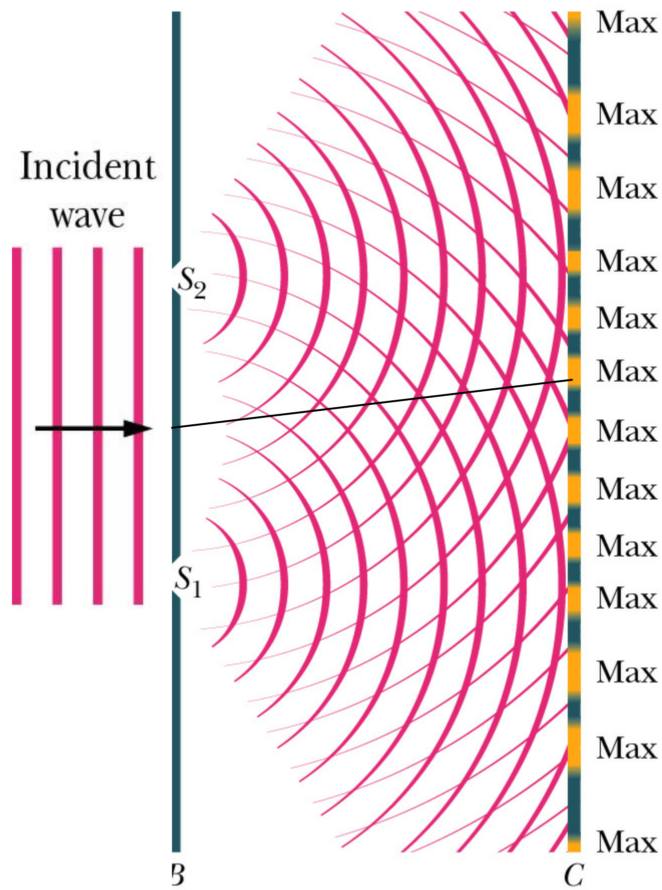
Top view of spherical EM wave



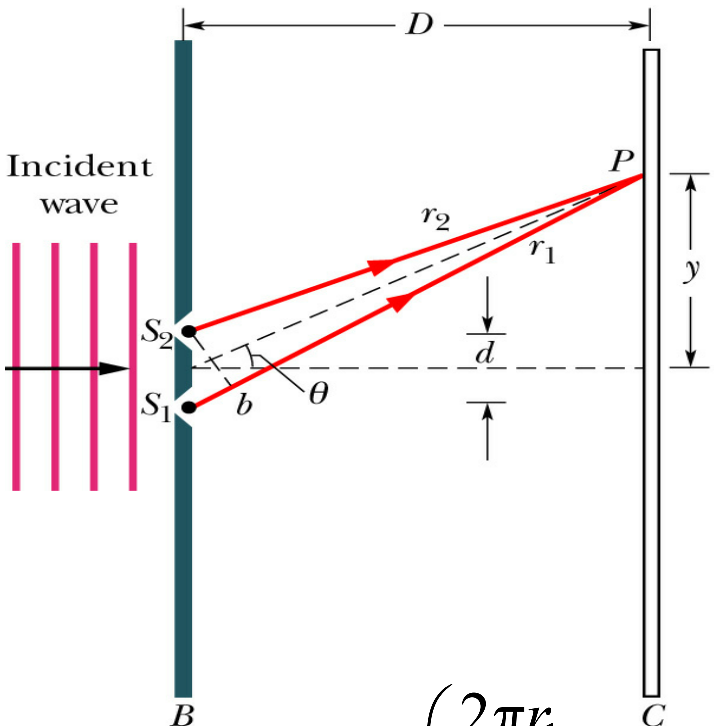
Production of a spherical wave from a plane wave using a slit

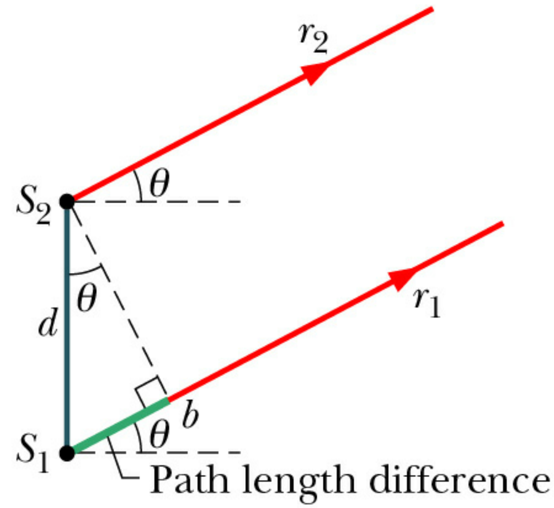


Interference of spherical waves in phase:



Mathematical analysis of bright fringes:





δ

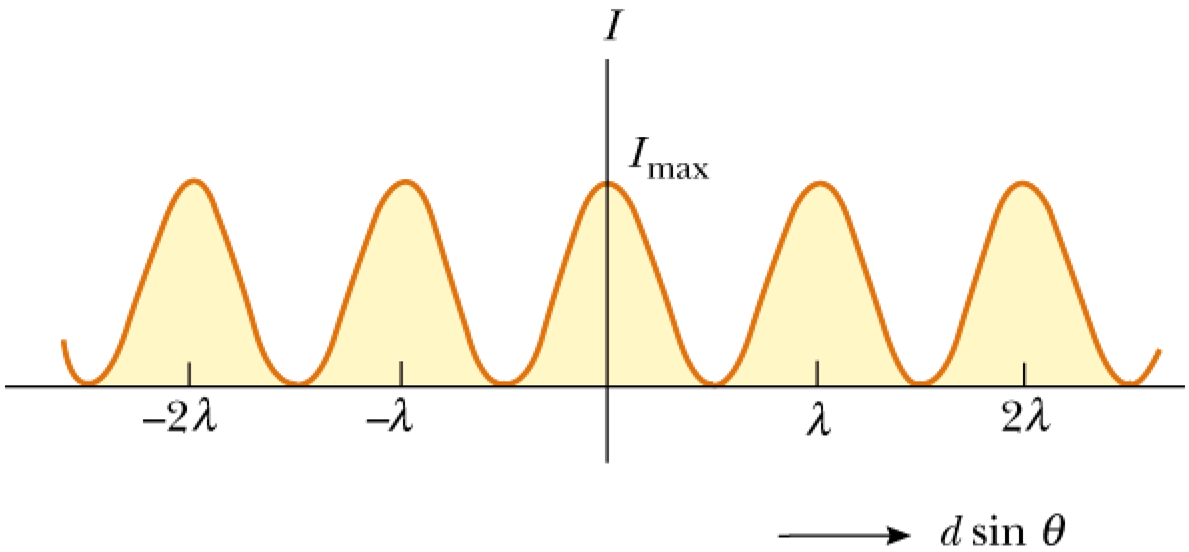
$$r_1 - r_2 = \delta = d \sin\theta$$

$$E(P,t) = E_{\max} \sin\left(\frac{2\pi r_1}{\lambda} - 2\pi f t\right) + E_{\max} \sin\left(\frac{2\pi r_2}{\lambda} - 2\pi f t\right)$$

$$= 2E_{\max} \sin\left(\frac{\pi(r_1 + r_2)}{\lambda} - 2\pi f t\right)\cos\left(\frac{\pi(r_1 - r_2)}{\lambda}\right)$$

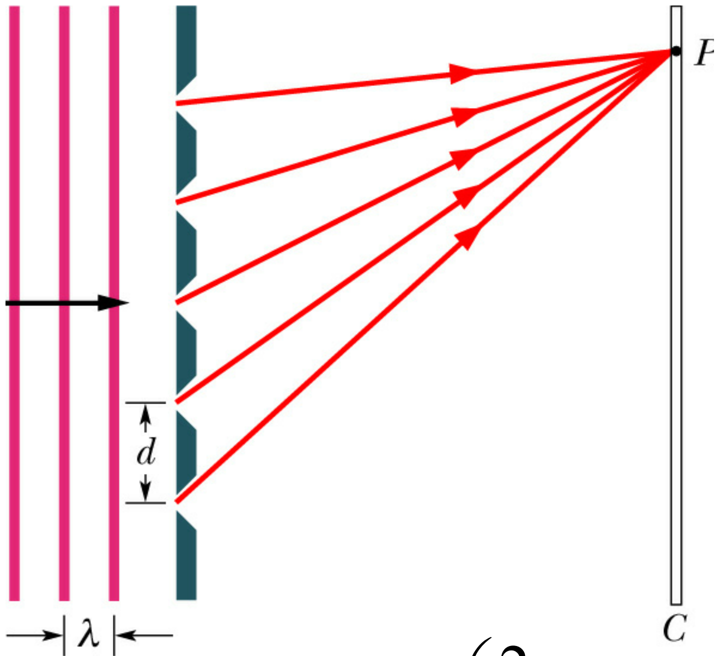
➔ intensity maxima occur for $\frac{\pi(r_1 - r_2)}{\lambda} = m\pi \quad \Rightarrow d \sin\theta = m\lambda$

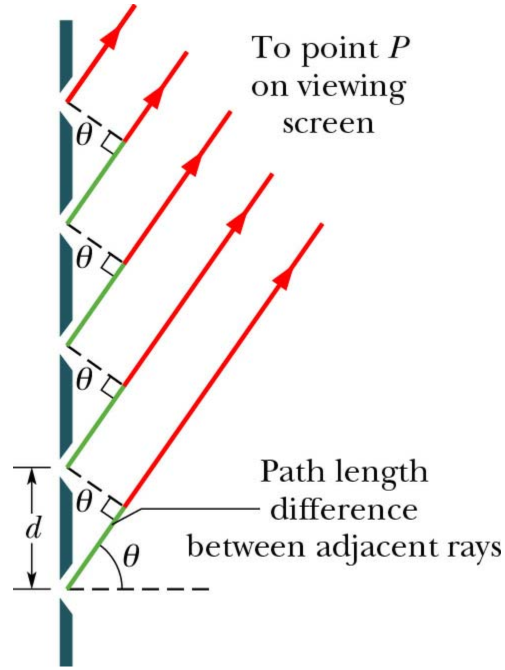
Intensity pattern at screen for double slit:



$$I = |\mathbf{S}|_{av} = \underbrace{\frac{E_{max}^2}{2\mu_0 c}}_{I_{max}} \cos^2\left(\frac{\pi d \sin\theta}{\lambda}\right)$$

Diffraction pattern for multiple slits – diffraction grating





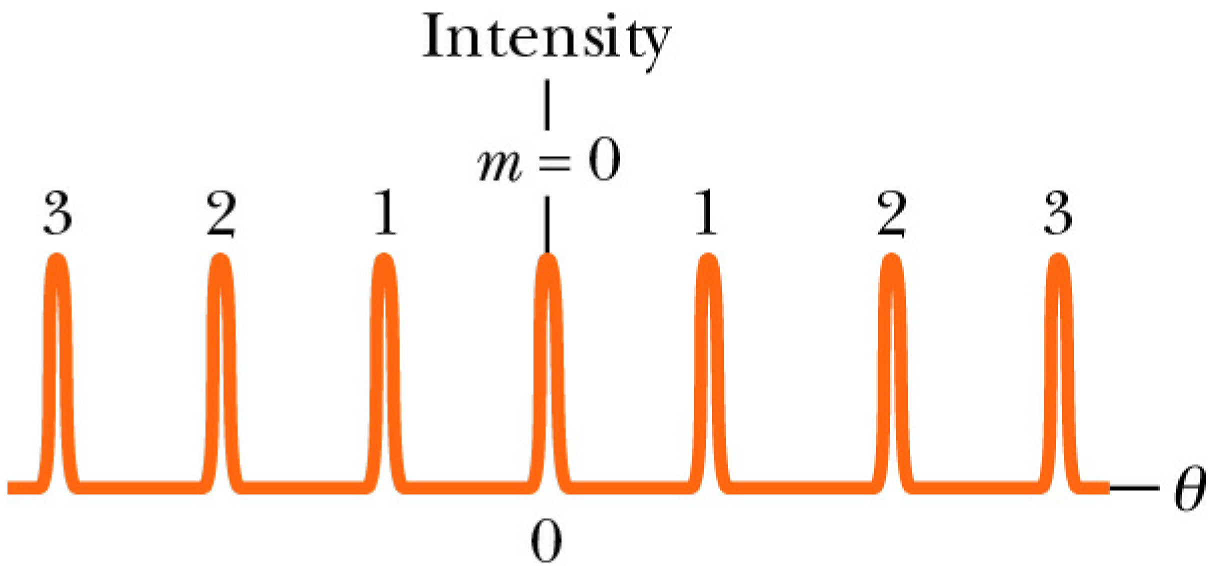
$$E(P,t) = \sum_i E_{\max} \sin\left(\frac{2\pi r_i}{\lambda} - 2\pi f t \right)$$

$$= E_{\max} \sin\left(\frac{\pi r_{av}}{\lambda} - 2\pi f t \right) \frac{\sin\left(\frac{N\pi d \sin\theta}{\lambda} \right)}{\sin\left(\frac{\pi d \sin\theta}{\lambda} \right)}$$

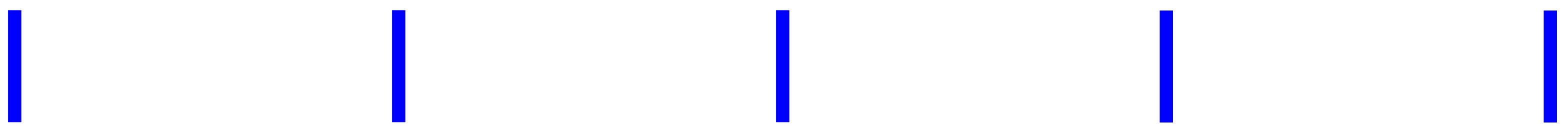
Intensity pattern for *N* slits

$$I = I_{max}\left[\frac{\sin\left(\frac{N\pi d\sin\theta}{\lambda}\right)}{\sin\left(\frac{\pi d\sin\theta}{\lambda}\right)}\right]^2$$

Peaks at $d\sin\theta = m\lambda$ (same as for double slit but peak widths much narrower)



Peer instruction question



The above lines show the diffraction pattern of blue light from a given grating. Where would you expect red light to be diffracted?

(A) Approximately midway between each blue line

(B) Separation between red lines is greater than that of blue lines

(C) Separation between red lines is smaller than that of blue lines