Lecture 9

- Power and Intensity

- Doppler effect for

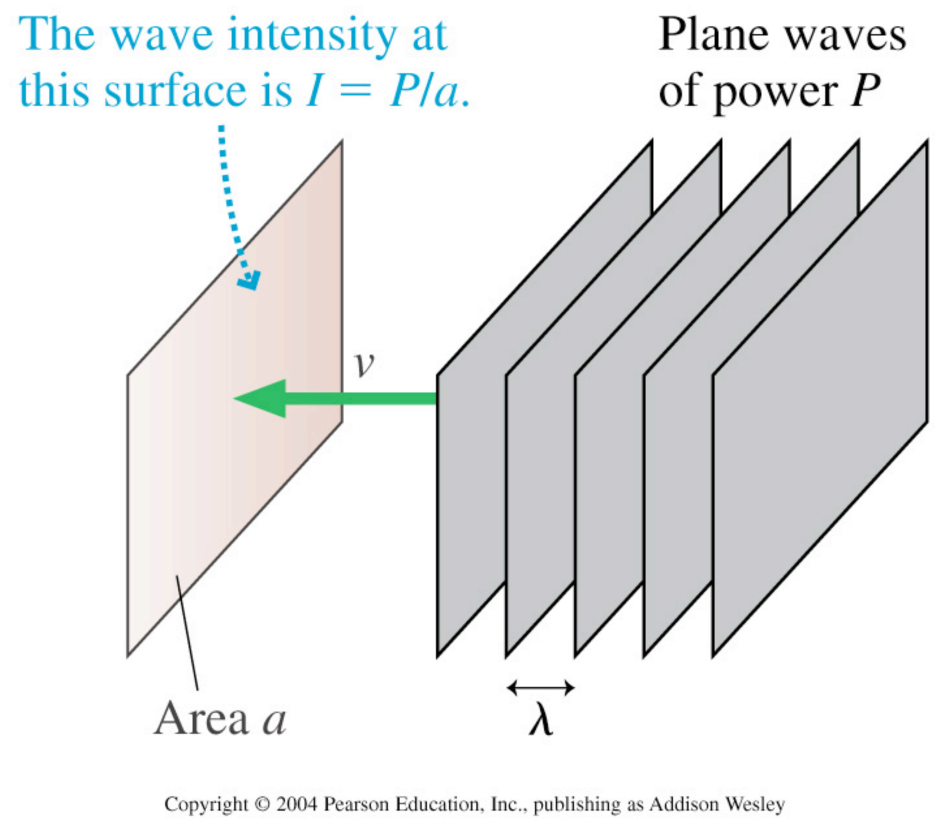
  (i) mechanical waves e.g. sound

  (ii) EM waves

Power and Intensity

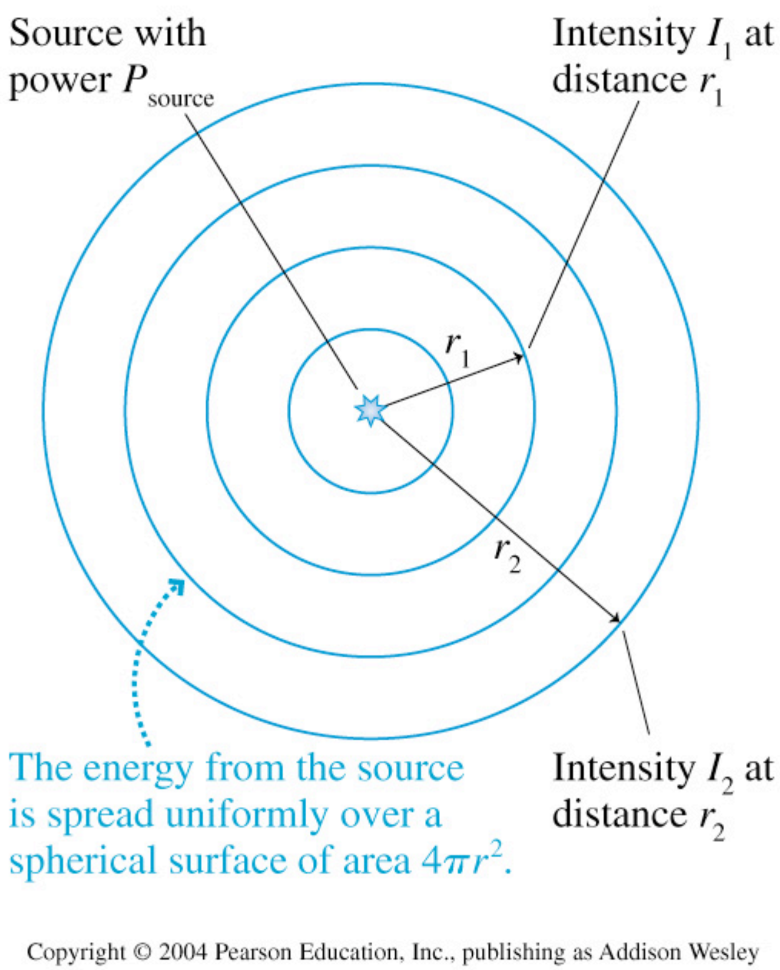
- Power is rate of transfer of energy by wave
- Brightness/loudness depends also on area receiving power:

intensity, $I = \frac{P}{a}$ = power-to-area ratio
(SI units: W/m^2)



- Uniform spherical wave

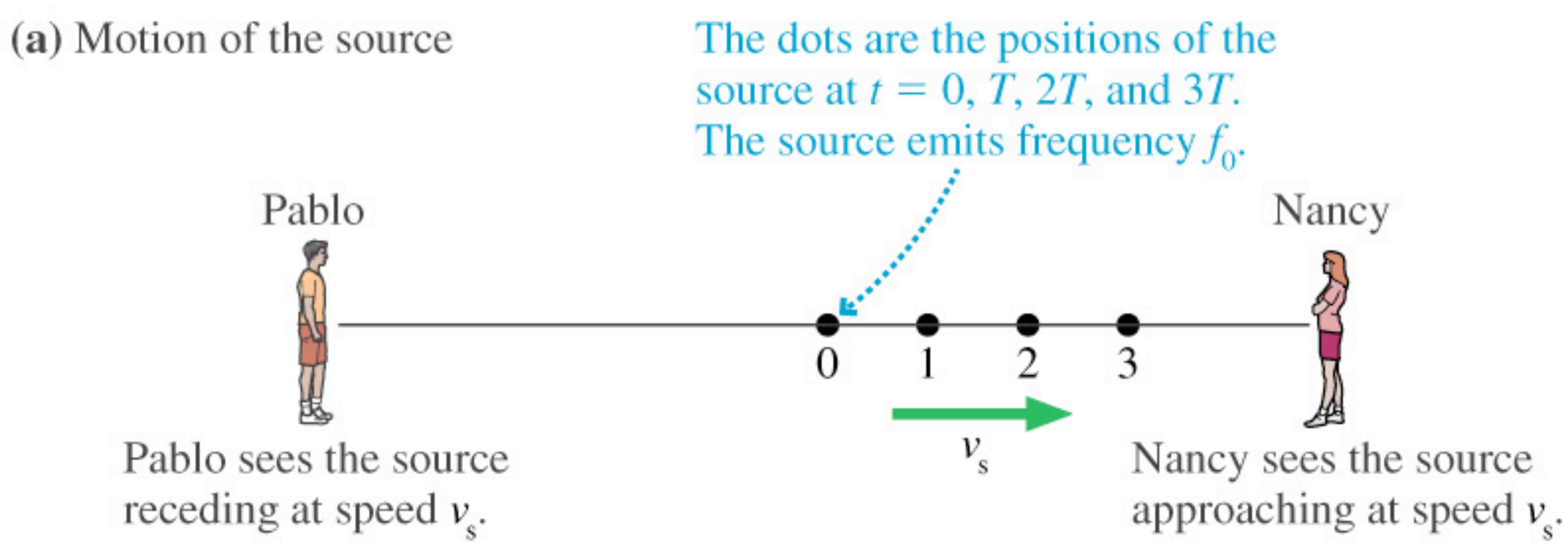
$I = \frac{P_{source}}{4\pi r^2}$
(from energy conservation:
total energy crossing wavefront is same)
$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$



$I \propto A^2$
(energy of oscillations $E = \frac{1}{2}kA^2$)

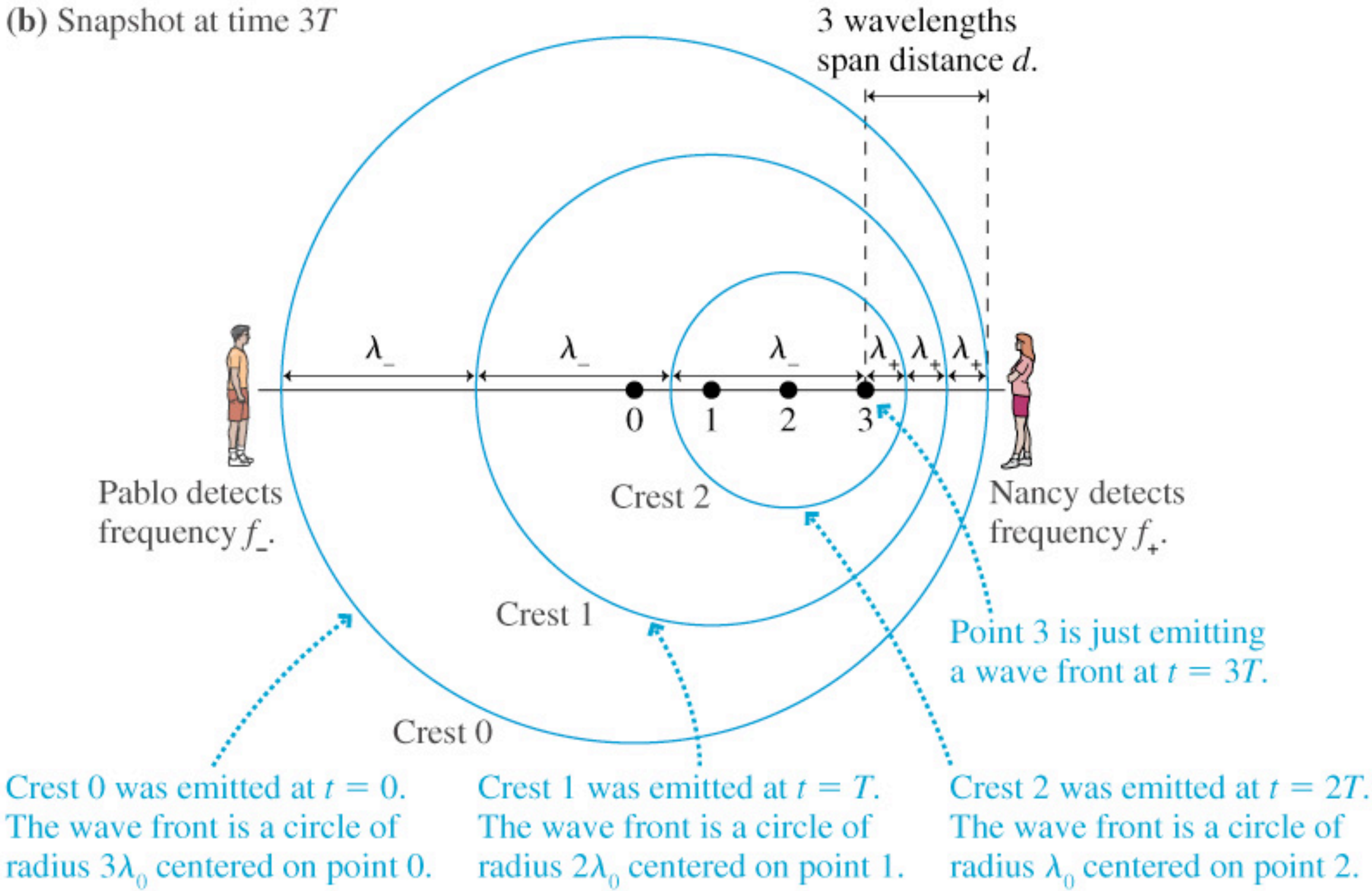
Doppler effect

- relative motion between observer and wave source modifies frequency e.g. pitch of ambulance siren drops as it goes past
- moving source: Pablo detects $(\lambda_-, \ f_-)$, Nancy detects $(\lambda_+, \ f_+)$ vs. $(\lambda_0, \ f_0)$ if source at rest



Doppler effect: derivation

- motion of wave crest (once leaves source) governed by medium (not affected by source moving) $\longrightarrow$ wave crests bunched up in front/ stretched out behind: $\lambda_+ < \lambda_0 < \lambda_-$ + speed $v \Rightarrow f_+ > f_0 > f_-$



In time $t = 3T$,
source moves $3v_sT$,
wave (crest 0) moves $3vT$
$\Rightarrow$ 3 wave crests in
$3vT \mp 3v_sT ... = 3\lambda_\pm$

$\downarrow$

$$f_\pm = \frac{v}{\lambda_\pm} = \frac{v}{v \mp v_s}$$

Doppler effect for moving source

$$f_+ = \frac{f_0}{1 - v_s/v} \qquad \text{(Doppler effect for an approaching source)}$$

$$f_- = \frac{f_0}{1 + v_s/v} \qquad \text{(Doppler effect for a receding source)}$$

Doppler effect: moving observer

- not same as source moving: motion relative to medium (not just source vs. observer) matters...

$$f_+ = (1 + v_o/v)f_0 \qquad \text{(observer approaching a source)}$$

$$f_- = (1 - v_o/v)f_0 \qquad \text{(observer receding from a source)}$$

Doppler effect for <u>EM</u> waves

- no medium: use Einstein's theory of relativity

$\lambda_{red} = \sqrt{\frac{1+v_s/c}{1-v_s/c}}$

(receding source: longer wavelength, red shift)

$\lambda_{blue} = \sqrt{\frac{1-v_s/c}{1+v_s/c}}$

(approaching source: shorter wavelength, blue shift)

where v_s is the speed of the source *relative* to the observer