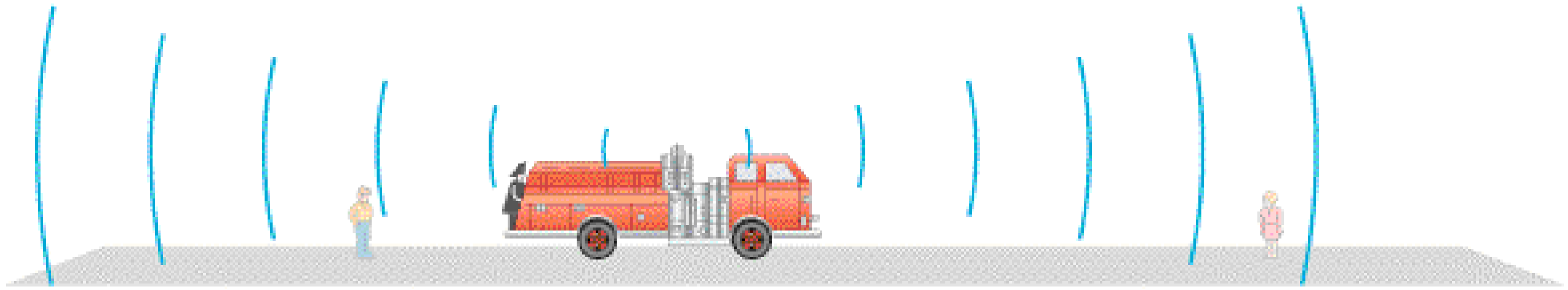
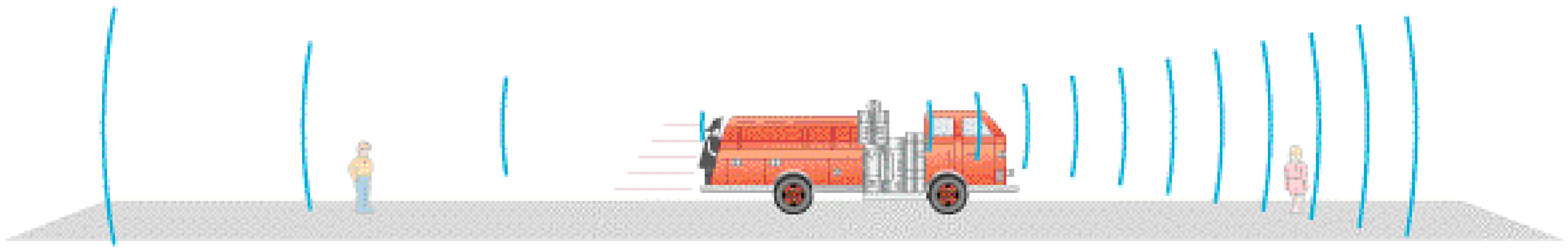
16-8. The Doppler Effect

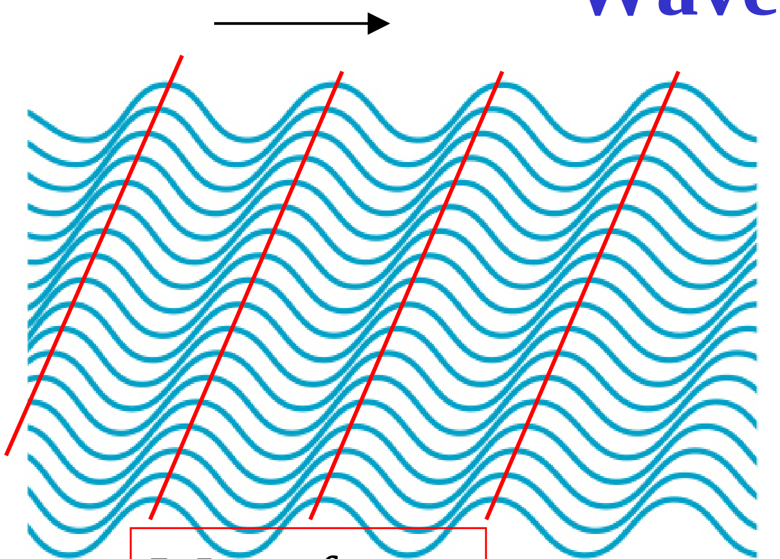


(a) At rest



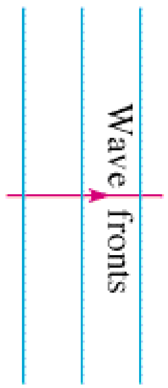
(b) Firetruck moving

Wave Fronts



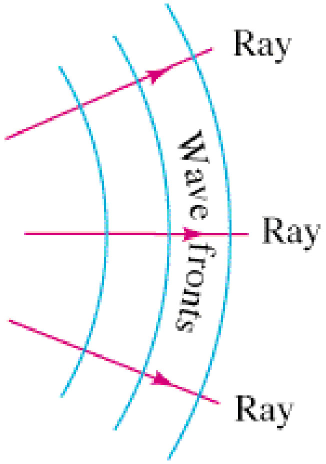
Wave fronts

Top View

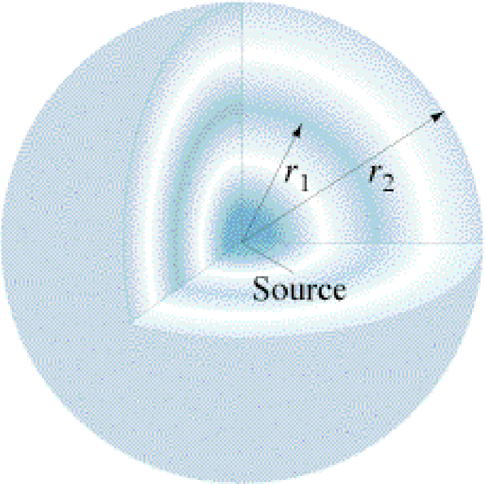


Point Source

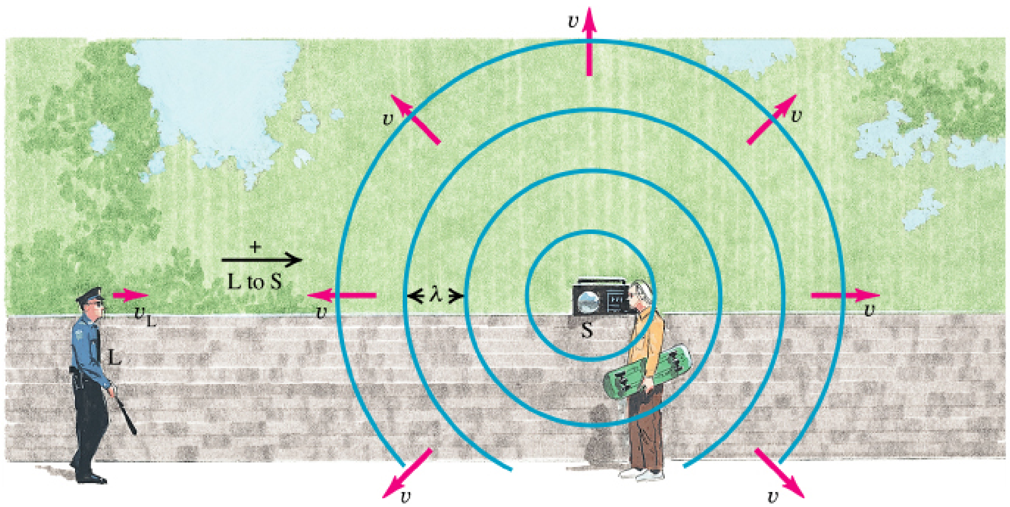
2-D



3-D



Moving Listener & Stationary Source



Speed of sound: v

Speed of moving listener towards source: v_L

Speed of sound relative to listener: $v+v_L$

Source frequency: f_S

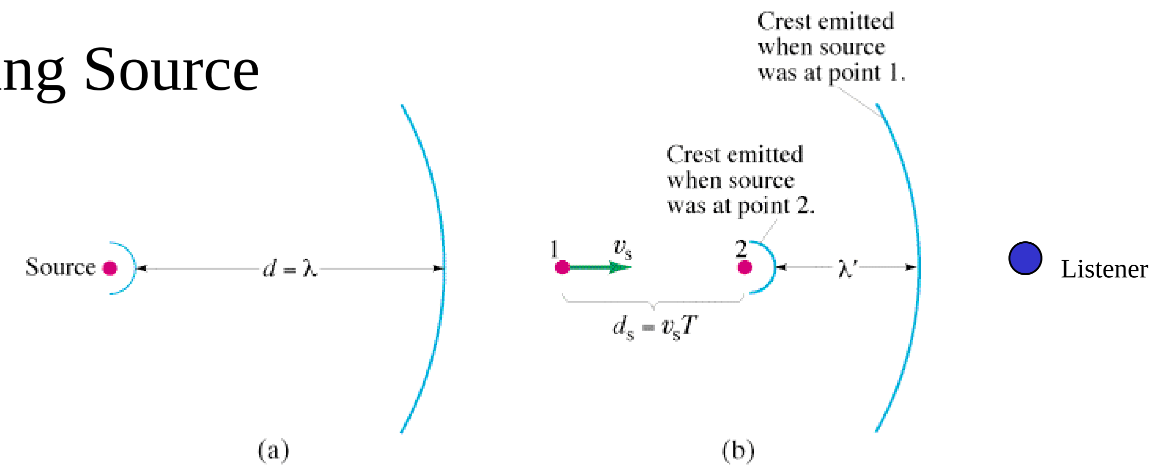
Sound frequency received by listener:

$$f_L = \frac{v+v_L}{\lambda} = \frac{v+v_L}{v/f_S} = \frac{v+v_L}{v} f_S = (1+\frac{v_L}{v}) f_S$$

Moving towards source, $+v_L,\ f_L > f_S$
away, $-v_L,\ f_L < f_S$

Approaching Source & Stationary Listener

Approaching Source



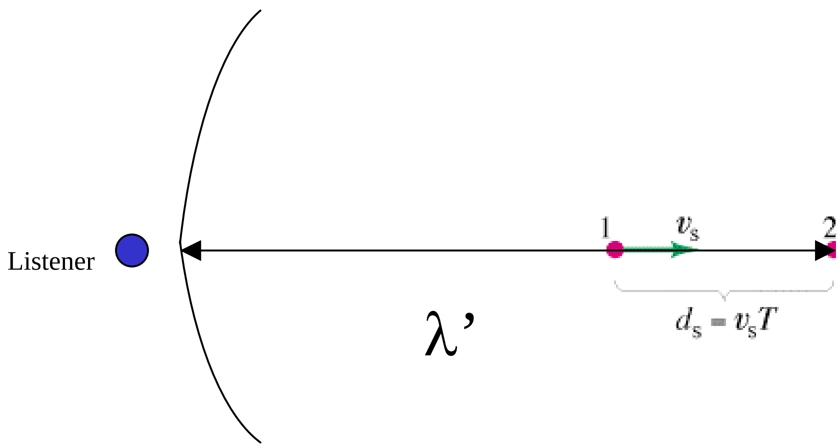
$$\lambda' = \lambda - v_S T = vT - v_S T = \frac{v - v_S}{f_S}$$

Frequency received by a stationary listener

$$f_L = \frac{v}{\lambda'} = \frac{v}{(v - v_S)/f_S} = \frac{v}{v - v_S} f_S$$

Receding Source & Stationary Listener

Receding Source

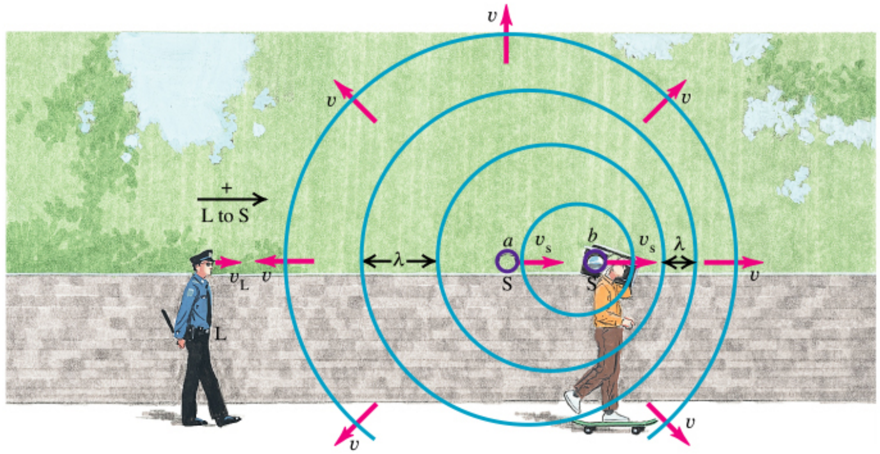


$$\lambda' = \lambda + v_S T = vT + v_S T = \frac{v + v_S}{f_S}$$

Frequency received by a stationary listener

$$f_L = \frac{v}{\lambda'} = \frac{v}{(v + v_S)/f_S} = \frac{v}{v + v_S} f_S$$

Moving Listener & Moving Source



$$f_L = \frac{v+v_L}{\lambda'} = \frac{v+v_L}{(v+v_S)/f_S} = \frac{v+v_L}{v+v_S} f_S$$

Signs: Separately consider the source & listener

Whenever source / listener approaches the other, $f_L > f_S$

Approaching source, $-v_S$

Approaching listener, $+v_L$

Whenever source / listener recedes from each other, $f_L < f_S$

Receding source, $+v_S$

Receding listener, $-v_L$

Doppler Effect for Electromagnetic Wave

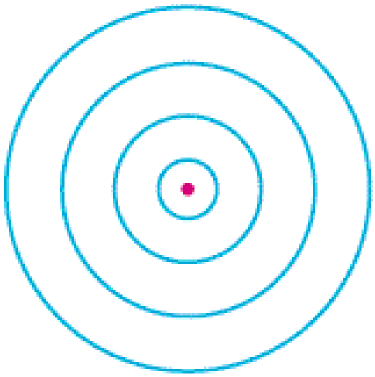
Taking into account relativistic effects

$$f_R = \sqrt{\frac{c-v}{c+v}}\, f_S$$

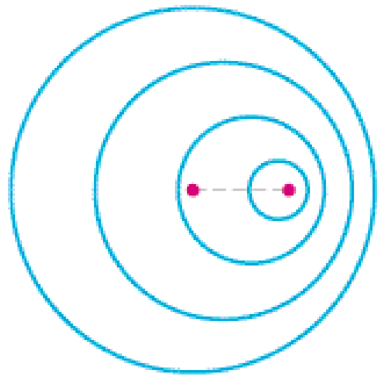
v positive: $f_R < f_S$, source is moving away from receiver

v negative: $f_R > f_S$, source is approaching receiver

16-9. Shock Waves & Sonic Boom



(a) $v_{obj} = 0$

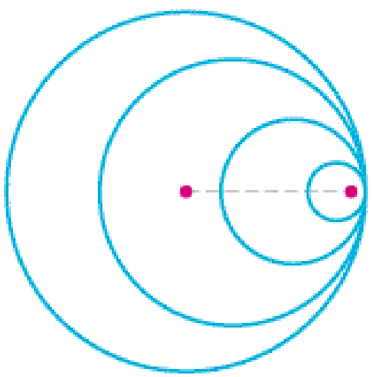


(b) $v_{obj} < v_{snd}$

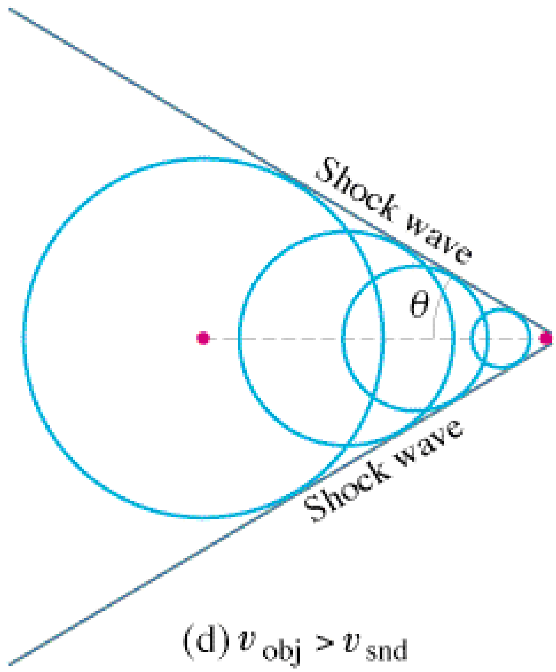
Mach number

v_{obj}/v_{snd}

>1 for supersonic speeds



(c) $v_{obj} = v_{snd}$



(d) $v_{obj} > v_{snd}$

Credit: Ensign John Gay
USS Constellation, US Navy