

Physics 101

Lecture 24

Wed. March 3, 2004

Topics: Sound — speed, power,
intensity, intensity level

Doppler effect.

Ref: ch. 14

- Sound wave — longitudinal wave.

$$20 \text{ Hz} < f < 20 \text{ kHz}.$$

- Speed of sound

$$v = \lambda f \quad \left(= \frac{\lambda}{T} \right)$$

depends on medium

e.g. in air $v = 343 \text{ m/s}$

in steel $v = 6000 \text{ m/s}$

• Intensity of Sound .

$$I = \frac{P}{A} .$$

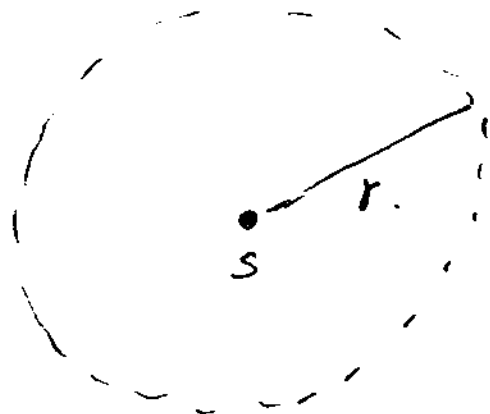
P — power = E/t .

A — Area .

e.g: If the power of a sound source (singing bird) is $3.52 \times 10^{-5} \text{ W}$, What is the sound intensity at 1m from the source ?

[Solution] : Given: $P = 3.52 \times 10^{-5} \text{ W}$.

The point source sends out a spherical wave.
at r meters away from the source, the surface area of the spherical wave front is :



$$A = 4\pi r^2 .$$

$\therefore$ The intensity at $r=1\text{m}$ is :

$$I = \frac{P}{4\pi r^2} = \frac{3.52 \times 10^{-5} \text{ W}}{4\pi \cdot (1\text{ m})^2} = 2.8 \times 10^{-6} \text{ W/m}^2 .$$

Another question: What is the sound intensity at $r=2\text{m}$?

$$I_2 = \frac{P}{4\pi (r)^2} = \frac{3.52 \times 10^{-5}}{4\pi (2)^2} = \underbrace{\frac{1}{4}} \cdot I_1 = 7.0 \times 10^{-7} \text{ W/m}^2$$

↑

When the distance is doubled,
the intensity is only $\frac{1}{4}$.
(Not halved).
because $I \propto \frac{1}{r^2}$.

e.g.: The sound intensity ~~is~~ at the window of
a bar is ~~is~~ 0.038 W/m^2 . The size of the
window is $2\text{m} \times 2\text{m}$.

What is the power of sound going through
the window?

[solution]

$$P = I \cdot A = 0.038 \text{ W/m}^2 \cdot 2 \times 2 (\text{m}^2) \\ = 0.15 \text{ W}.$$

• Intensity Level of sound.

— for describing the loudness of sound.

(Note: Intensity $\neq$ intensity level.)

Threshold intensity of human ear

(weakest sound we can hear):

$$I_0 = 1.0 \times 10^{-12} \text{ W/m}^2.$$

Maximum intensity for human ear.

(loudest sound we can stand)

$$I = 1 \text{ W/m}^2.$$

Intensity level:

$$\beta = 10 \log \left(\frac{I}{I_0} \right)$$

unit: dB. (Decibels)

(Note: Intensity is in W/m^2).

e.g. At threshold, $I = I_0 = 1 \times 10^{-12} \text{ W/m}^2$.

$$\beta = 10 \cdot \log \left(\frac{I}{I_0} \right) = 10 \cdot \log(1) = 0 \text{ dB}.$$

e.g. For $I = 1 \text{ W/m}^2$ (loudest sound that human can stand)

$$\beta = 10 \log \left(\frac{I}{I_0} \right) = 10 \cdot \log \left(\frac{1}{10^{-12}} \right) = 120 \text{ dB}.$$

e.g. A new born baby makes a sound of intensity level ~~of~~ of 60 dB. What is the sound intensity?

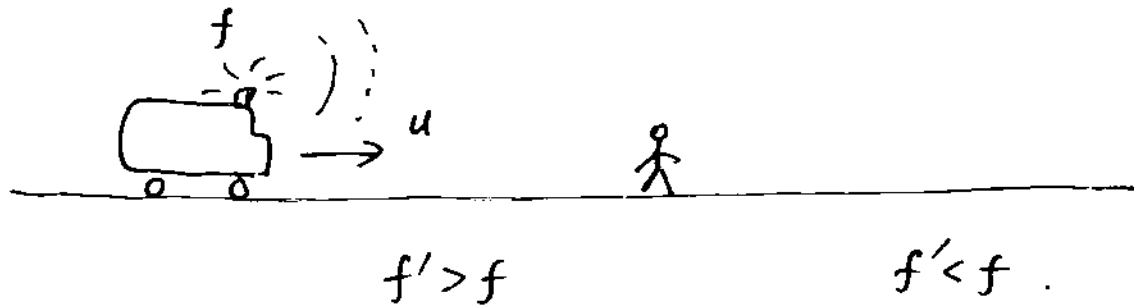
$$\beta = 10 \cdot \log \left(\frac{I}{I_0} \right). \quad \left(\begin{array}{l} \text{given } \beta, \\ \text{solve for } I \end{array} \right)$$

$$\log \left(\frac{I}{I_0} \right) = \frac{\beta}{10}.$$

$$\frac{I}{I_0} = 10^{\frac{\beta}{10}},$$

$$\begin{aligned} I &= I_0 \cdot 10^{\frac{\beta}{10}} \\ &= 10^{-12} \cdot 10^{\frac{60}{10}} \\ &= 10^{-6} \text{ W/m}^2. \end{aligned}$$

• Doppler effect.



When there is a relative motion between the source and the observer, the frequency shifts.

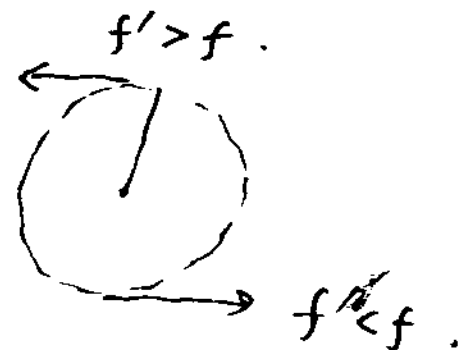
— Approaching, freq. increases. ($f' > f$)

— Receding, freq. decreases ($f' < f$).

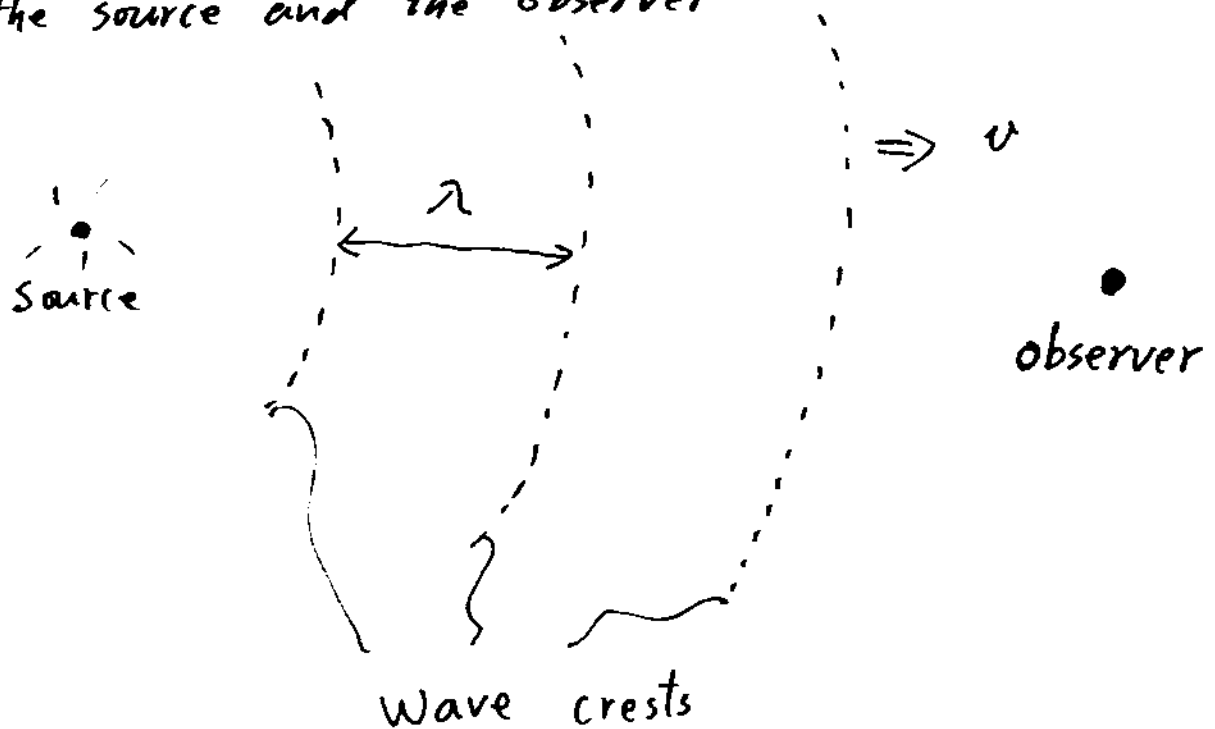
f — frequency generated by the source.

f' — frequency received by the observer.

Demo: Moving buzzer.



- ① When there is no relative motion between the source and the observer



The wave length is the distance between two wave crests as shown above.

$$\lambda = vT$$

λ — wave length.

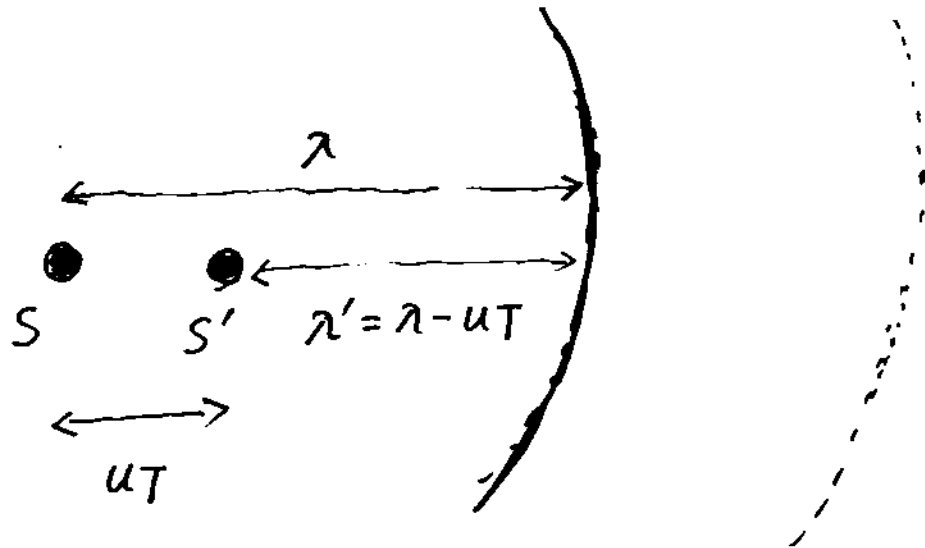
v — speed of wave

T — period.

The frequency : $f = \frac{1}{T} = \frac{v}{\lambda}$

(2). Source approaching. moving with respect to the medium.

(When the source is moving towards the observer with a speed u)



at time $t=0$, the source sends out the first wave front

at time $t=T$, the first wave front has travelled by a distance λ .

but the source has moved by a distance uT and is sending out the next wave front.

Therefore, the observed wave length is

$$\lambda' = \lambda - uT \quad (\text{distance between 2 wave crests}).$$

Then, the observed frequency is:

$$f' = \frac{v}{\lambda'} = \frac{f}{(1 - \frac{u}{v})}$$

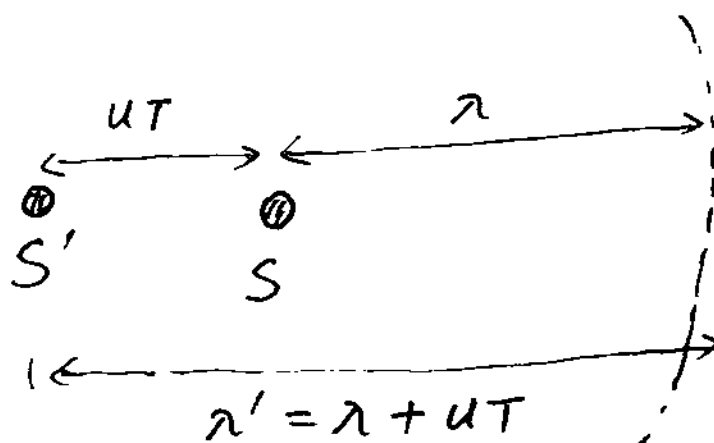
when source
is approaching.

$$\left[\begin{array}{l} \text{Proof: } \lambda' = \lambda - uT \\ \frac{\lambda'}{\lambda} = 1 - \frac{uT}{\lambda} \\ \frac{\lambda'}{\lambda} = 1 - \frac{u}{v} \quad (\because \lambda = vT) \\ \frac{f}{f'} = 1 - \frac{u}{v} \quad (\because \lambda = \frac{v}{f}) \\ \therefore f' = \frac{f}{1 - \frac{u}{v}} \end{array} \right]$$

Since $f' > f$, the observed frequency f' is higher than the original frequency f generated by the source.

③ Source receding

— When the source is moving away from the observer with a speed u .



The observed wavelength becomes longer:

$$\lambda' = \lambda + uT. \quad \frac{\lambda'}{\lambda} = 1 + \frac{u}{v}.$$

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

$$\therefore f' = \frac{f}{1 + \frac{u}{v}} < f.$$

Therefore, the observed frequency is lower.

than the original frequency generated by the source.