Physics 101

Lecture 24.

Friday, March 7, 2003.

Topics covered:

Sound — Speed, power, intensity.
intensity level

Doppler effect.

Ref: Ch. 14.

- Sound wave — longitudinal wave.

  $20\,Hz < f < 20\,KHz$.

- Speed of sound $v = \lambda f$.

  depends on medium.

  e.g.: in air, $20°C$, $v = 343$ m/s
  $0°C$: $v = 331$ m/s

  in solids — faster.
  e.g.: in steel: $v \approx 6000$ m/s.

- Intensity of Sound.

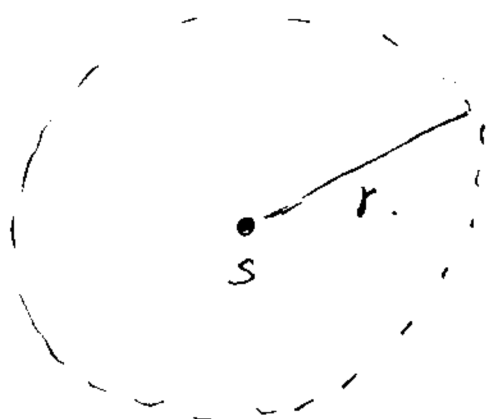
$$I = P/A \qquad P - \text{power} = E/t.$$
$$A - \text{Area}.$$

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

[Solution]: Given: $P = 3.52 \times 10^{-5}$ 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 $r = 1m$ is:

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

Another question : what is the sound intensity at $r = 2\,m$?

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

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 at the window of a bar is 0.038 W/m^2. The size of the window is $2m \times 2m$.

What is the power of sound going through the window ?

[solution]

$$P = I \cdot A = 0.038 \ W/m \cdot 2 \times 2 \ (m^2)$$

$$= 0.15 \ W.$$

- 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):

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

Maximum intensity for human ear. (loudest sound we can stand)

$$I = 1\ W/m^2.$$

Intensity level:

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

unit: dB.

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

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

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

e.g: For $I = 1\ W$. (loudest sound that human can stand)

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

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

$$\beta = 10 \cdot \log\left(\frac{I}{I_0}\right).$$ (given β, solve for I)

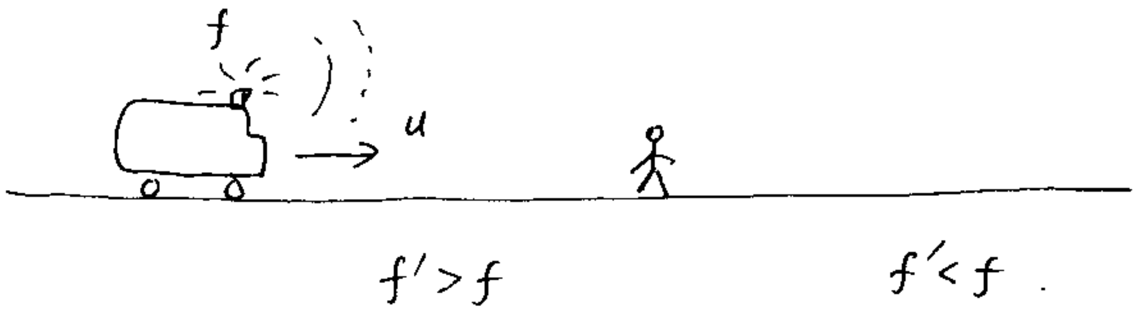
$$\log\left(\frac{I}{I_0}\right) = \beta/10.$$

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

$$= 10^{-12} \cdot 10^{60/10}$$

$$= 10^{-6}\ W/m^2.$$

- Doppler effect.



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

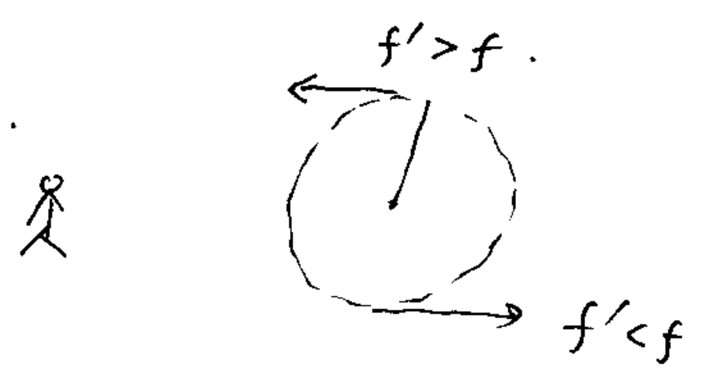
— Approaching, freq. increases. ($f' > f$)

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

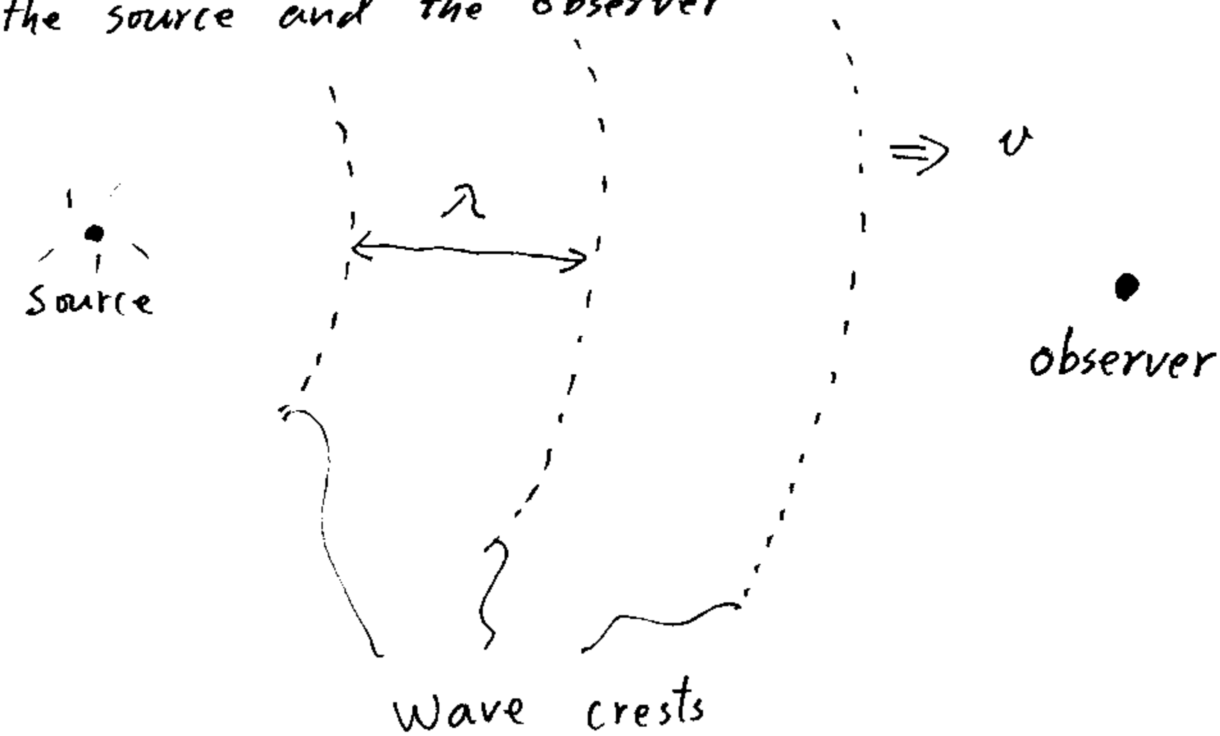
f — frequency generated by the source.

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.

$$\lambda = v T.$$

λ — wave length.

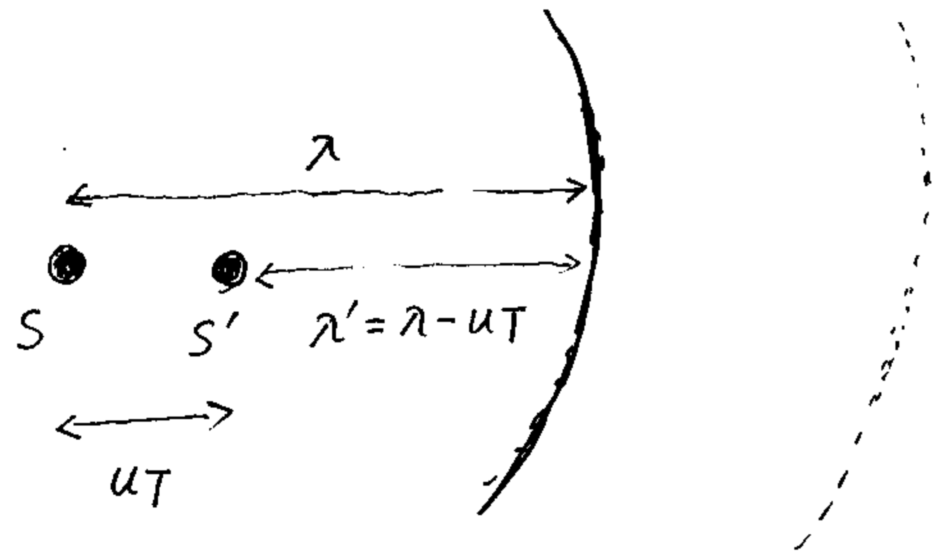
v — speed of wave

T — period.

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

② Source approaching.

(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:

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

when source is approaching.

[Proof: $\lambda' = \lambda - uT$

$$\frac{\lambda'}{\lambda} = 1 - \frac{uT}{\lambda}$$

$$\frac{\lambda'}{\lambda} = 1 - \frac{u}{v}. \qquad (\because \lambda = vT)$$

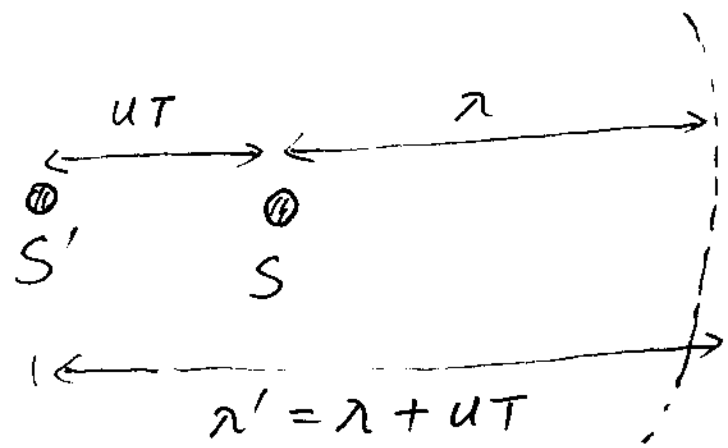
$$\frac{f}{f'} = 1 - \frac{u}{v}. \qquad (\because \lambda = \frac{v}{f})$$

$$\therefore f' = \frac{f}{1 - \frac{u}{v}} .$$]

Since $f' > f$. the oberved 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:

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

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

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

Therefore, the observed frequency is lower than the oringinal frequency generated by the source.