

Phys101 Lectures 31, 32

Sound, Decibels, Doppler Effect

Key points:

- **Intensity of Sound: Decibels**
- **Doppler Effect**

Ref: 12-1,2,7.

Characteristics of Sound

Sound can travel through any kind of matter, but not through a vacuum.

TABLE 12–1 Speed of Sound in Various Materials (20°C and 1 atm)

Material	Speed (m/s)
Air	343
Air (0°C)	331
Helium	1005
Hydrogen	1300
Water	1440
Sea water	1560
Iron and steel	≈ 5000
Glass	≈ 4500
Aluminum	≈ 5100
Hardwood	≈ 4000
Concrete	≈ 3000

The speed of sound is different in different materials; in general, it is slowest in gases, faster in liquids, and fastest in solids.

The speed depends somewhat on temperature, especially for gases.

Characteristics of Sound

Loudness: related to intensity of the sound wave

Pitch: related to frequency

Audible range: about 20 Hz to 20,000 Hz; upper limit decreases with age

Ultrasound: above 20,000 Hz;

Infrasound: below 20 Hz

Intensity of Sound: Decibels

TABLE 12–2 Intensity of Various Sounds

Source of the Sound	Sound Level (dB)	Intensity (W/m^2)
Jet plane at 30 m	140	100
Threshold of pain	120	1
Loud rock concert	120	1
Siren at 30 m	100	1×10^{-2}
Auto interior, at 90 km/h	75	3×10^{-5}
Busy street traffic	70	1×10^{-5}
Talk, at 50 cm	65	3×10^{-6}
Quiet radio	40	1×10^{-8}
Whisper	20	1×10^{-10}
Rustle of leaves	10	1×10^{-11}
Threshold of hearing	0	1×10^{-12}

The intensity of a wave is the energy transported per unit time across a unit area.

The human ear can detect sounds with an intensity as low as $10^{-12} \text{ W}/\text{m}^2$ and as high as $1 \text{ W}/\text{m}^2$.

Perceived loudness, however, is not proportional to the intensity.

Sound Level: Decibels

The loudness of a sound is much more closely related to the **logarithm** of the intensity.

Sound level is measured in **decibels (dB)** and is defined as:

$$\beta \text{ (in dB)} = 10 \log \frac{I}{I_0}.$$

I_0 is taken to be the **threshold of hearing**:

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

Example: Sound intensity on the street.

At a busy street corner, the sound level is 75 dB. What is the intensity of sound there?

Example: Loudspeaker response.

A high-quality loudspeaker is advertised to reproduce, at full volume, frequencies from 30 Hz to 18,000 Hz with uniform sound level ± 3 dB. That is, over this frequency range, the sound level output does not vary by more than 3 dB for a given input level. By what factor does the intensity change for the maximum change of 3 dB in output sound level?

Conceptual Example: Trumpet players.

A trumpeter plays at a sound level of 75 dB. Three equally loud trumpet players join in. What is the new sound level?

$$\beta_1 = 10 \log \frac{I_1}{I_0}$$

$$\beta_4 = 10 \log \frac{4I_1}{I_0}$$

$$\beta_4 = 10 \left(\log 4 + \log \frac{I_1}{I_0} \right)$$

$$= 10 \log 4 + 10 \log \frac{I_1}{I_0}$$

$$= 6 + \beta_1$$

$$= 6 + 75$$

$$= 81 \text{ dB}$$

Example: Airplane roar.

The sound level measured 30 m from a jet plane is 140 dB. What is the sound level at 300 m? (Ignore reflections from the ground.)

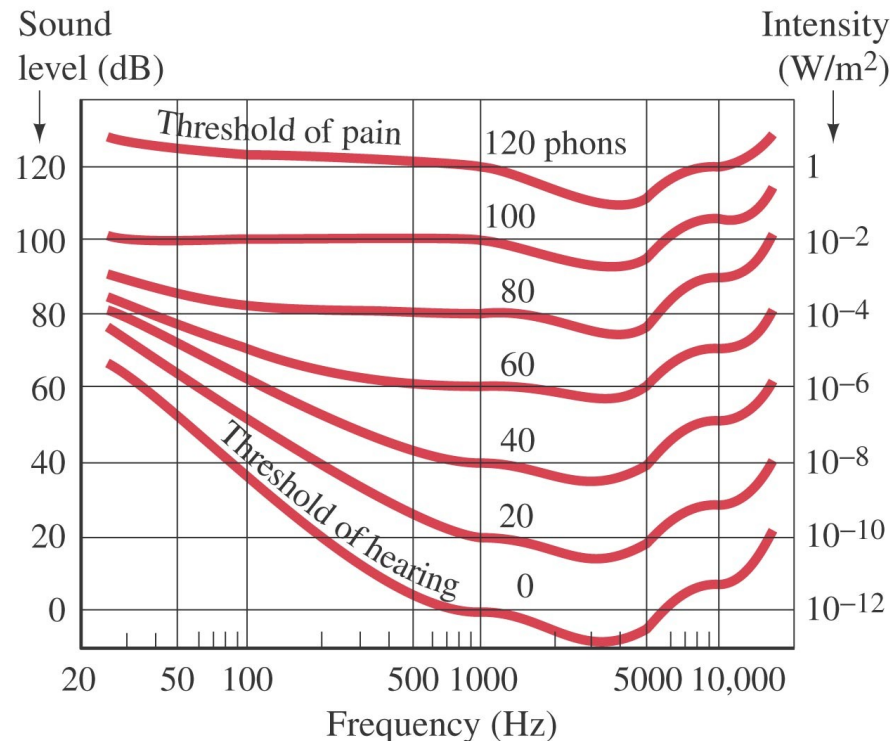


Example: How tiny the displacement is.

Calculate the displacement of air molecules for a sound having a frequency of 1000 Hz at the threshold of hearing.

Intensity of Sound: Decibels

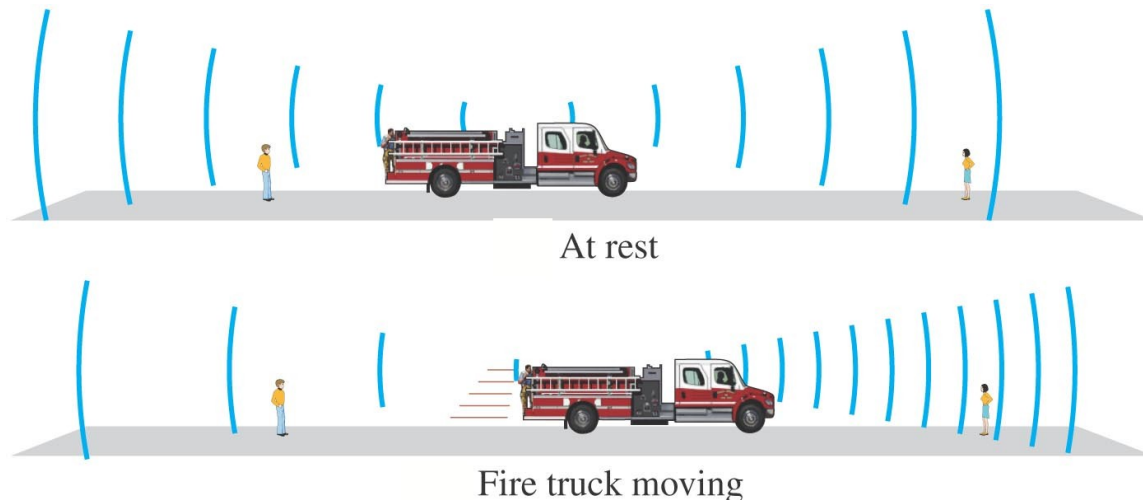
The ear's **sensitivity** varies with **frequency**. These curves translate the **intensity** into **sound level** at different **frequencies**.

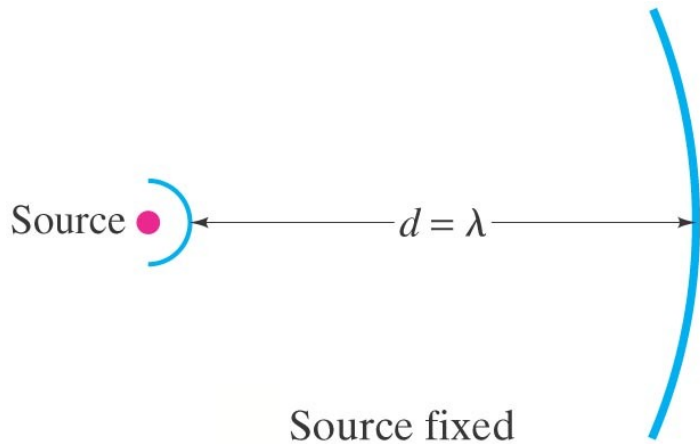


Doppler Effect

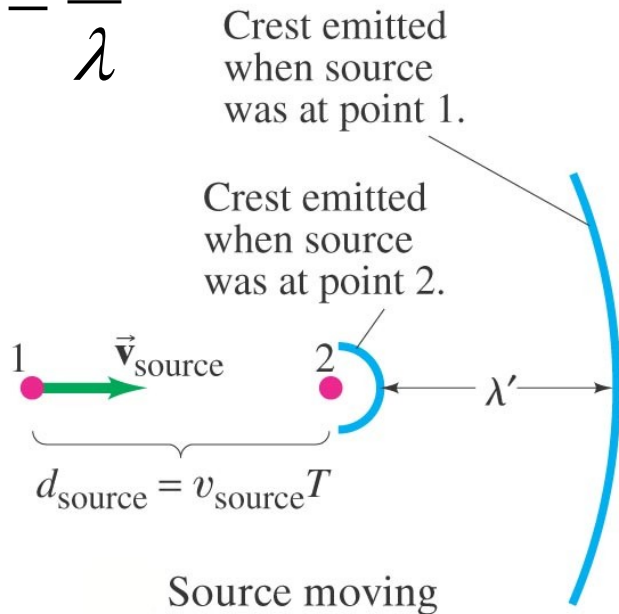
The Doppler effect occurs when a source of sound is moving with respect to an observer.

A source moving toward an observer appears to have a higher frequency and shorter wavelength; a source moving away from an observer appears to have a lower frequency and longer wavelength.





$$f = \frac{v}{\lambda}$$



v – velocity of sound

If we can figure out what the **change in the wavelength is**, we also know the **change in the frequency**.

When the source is approaching, the **observed wavelength is shorter**:

$$\lambda' = \lambda - v_{source}T$$

Then the observed frequency is:

$$\begin{aligned} f' &= \frac{v}{\lambda'} = \frac{v}{\lambda - v_{source}T} \\ &= \frac{v}{\lambda \left(1 - \frac{v_{source}T}{\lambda} \right)} = \frac{f}{1 - \frac{v_{source}T}{\lambda}} \\ &= \frac{f}{1 - \frac{v_{source}}{v}} > f \end{aligned}$$

Doppler Effect

The change in the frequency is given by:

$$f' = \frac{f}{\left(1 - \frac{v_{\text{source}}}{v_{\text{snd}}}\right)}.$$

Source approaching:
Higher freq.
 $f' > f$

Similarly, if the source is moving away from the observer:

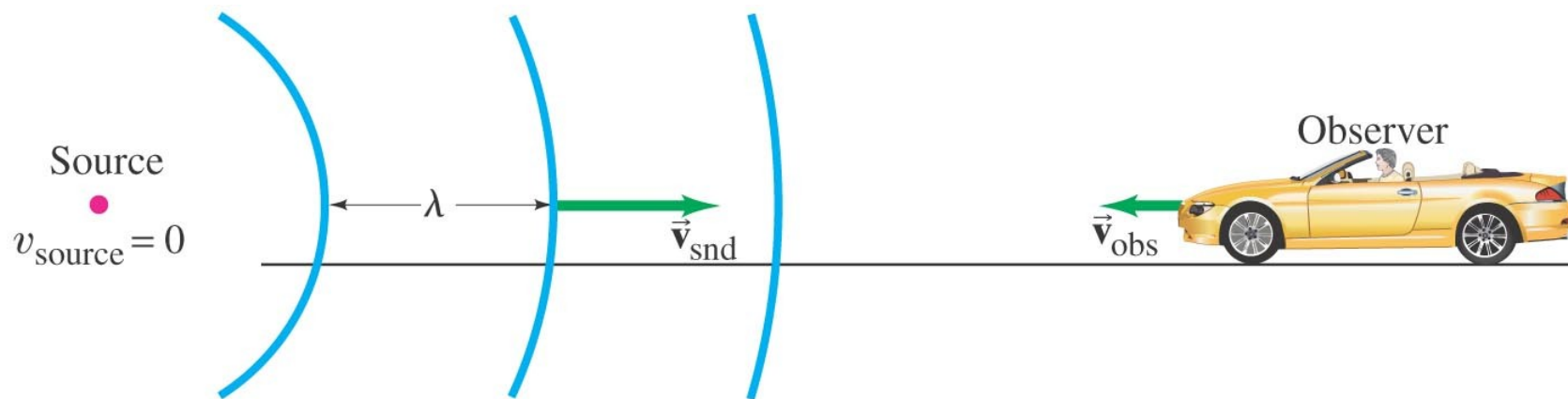
$$f' = \frac{f}{\left(1 + \frac{v_{\text{source}}}{v_{\text{snd}}}\right)}.$$

Source receding:
Lower freq.
 $f' < f$

Doppler Effect

$$f = \frac{v}{\lambda}$$

If the **observer** is moving with respect to the source, things are a bit different. The **wavelength** remains the same, but the **wave speed** is different for the observer.



$v' = v + v_{\text{obs}}$ when the observer is approaching

$$f' = \frac{v'}{\lambda} = \frac{v + v_{\text{obs}}}{\lambda} = \frac{v}{\lambda} \left(1 + \frac{v_{\text{obs}}}{v} \right) = f \left(1 + \frac{v_{\text{obs}}}{v} \right)$$

For an observer moving toward a stationary source:

Observed sound velocity: $v' = v + v_{obs}$

Observed frequency:

$$f' = \frac{v'}{\lambda} = \frac{v + v_{obs}}{\lambda} = \frac{v}{\lambda} \left(1 + \frac{v_{obs}}{v} \right) = f \left(1 + \frac{v_{obs}}{v} \right)$$

**Observer approaching:
Higher freq.
 $f' > f$**

And if the observer is moving away:

$$v' = v - v_{obs}$$

$$f' = \frac{v'}{\lambda} = \frac{v - v_{obs}}{\lambda} = \frac{v}{\lambda} \left(1 - \frac{v_{obs}}{v} \right) = f \left(1 - \frac{v_{obs}}{v} \right)$$

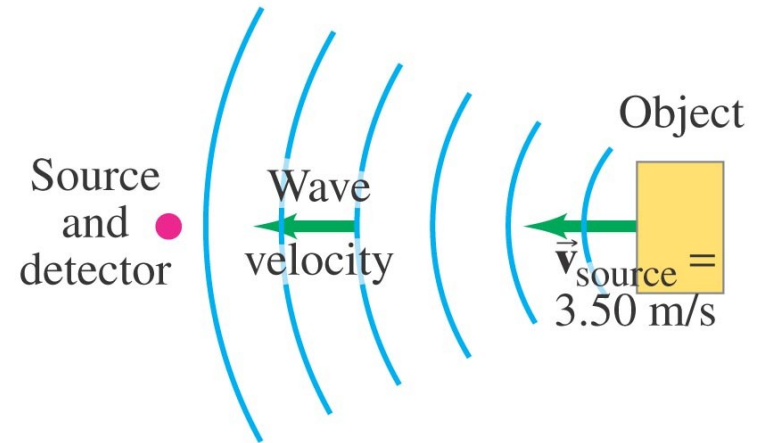
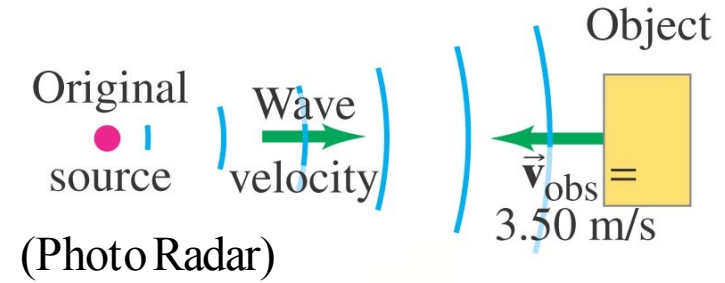
**Observer receding:
Lower freq.
 $f' < f$**

Example: A moving siren.

The siren of a police car at rest emits at a predominant frequency of 1600 Hz. What frequency will you hear if you are at rest and the police car moves at 25.0 m/s (a) toward you, and (b) away from you?

Example 12-15: Two Doppler shifts.

A 5000-Hz sound wave is emitted by a stationary source. This sound wave reflects from an object moving 3.50 m/s toward the source. What is the frequency of the wave reflected by the moving object as detected by a detector at rest near the source?



Doppler Effect

All four equations for the Doppler effect can be combined into one; you just have to keep track of the signs!

$$f' = f \left(\frac{v_{\text{snd}} \pm v_{\text{obs}}}{v_{\text{snd}} \mp v_{\text{source}}} \right).$$

The signs:

Approaching: higher freq. $f' > f$

Receding: lower freq. $f' < f$