Phys101 Lectures 32, 33

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} W/m^2** and as high as **1 W/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.

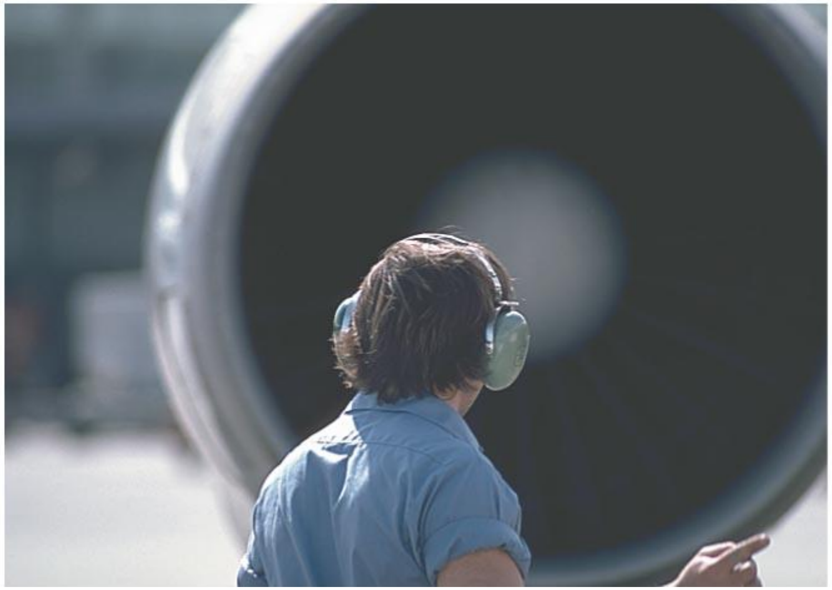
A high-quality loudspeaker is advertised to reproduce, at full volume, frequencies from 30 Hz to 18,000 Hz with uniform sound level ± 3 dB. That is, over this frequency range, the sound level output does not vary by more than 3 dB for a given input level. By what factor does the intensity change for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

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.)

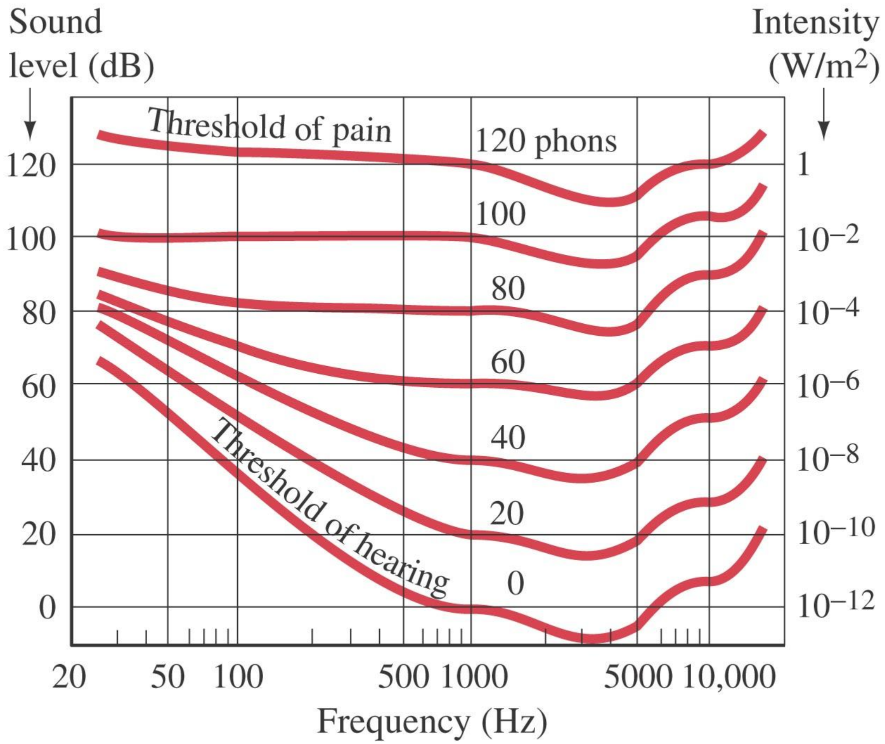


Example: How tiny the displacement is.

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

Intensity of Sound: Decibels

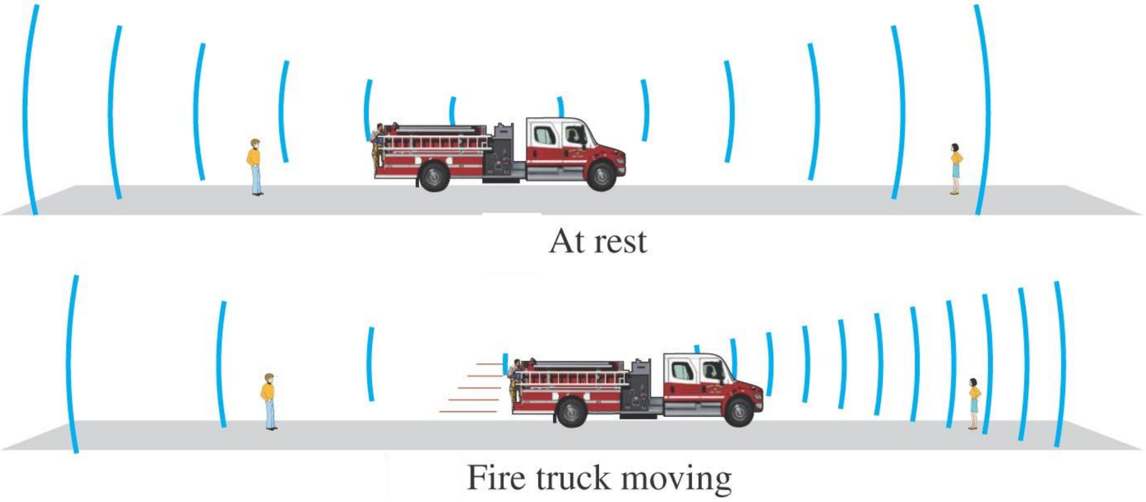
The ear's sensitivity varies with frequency. These curves translate the intensity into sound level at different frequencies.



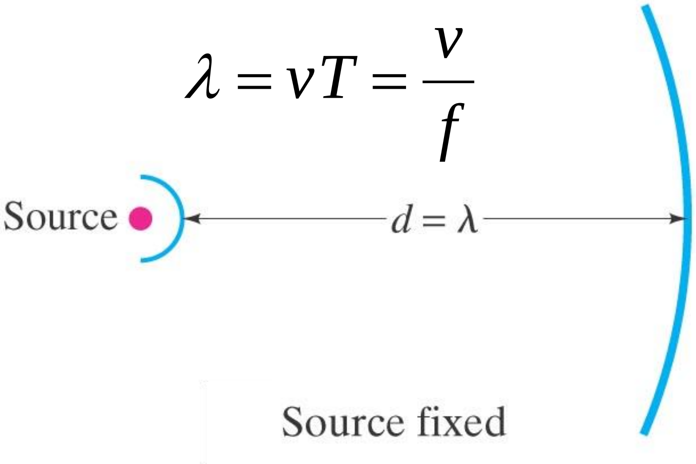
Doppler Effect

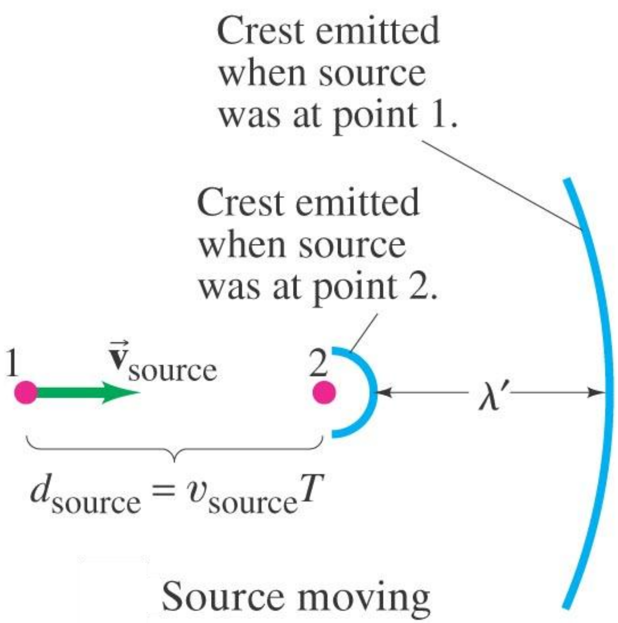
The **Doppler effect** occurs when a **source** of sound is **moving** with respect to an **observer**.

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.



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





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:

$$f' = \frac{v}{\lambda'} = \frac{v}{\lambda - v_{source}T}$$

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

$$= \frac{f}{1 - \frac{v_{source}}{v}} > f$$

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

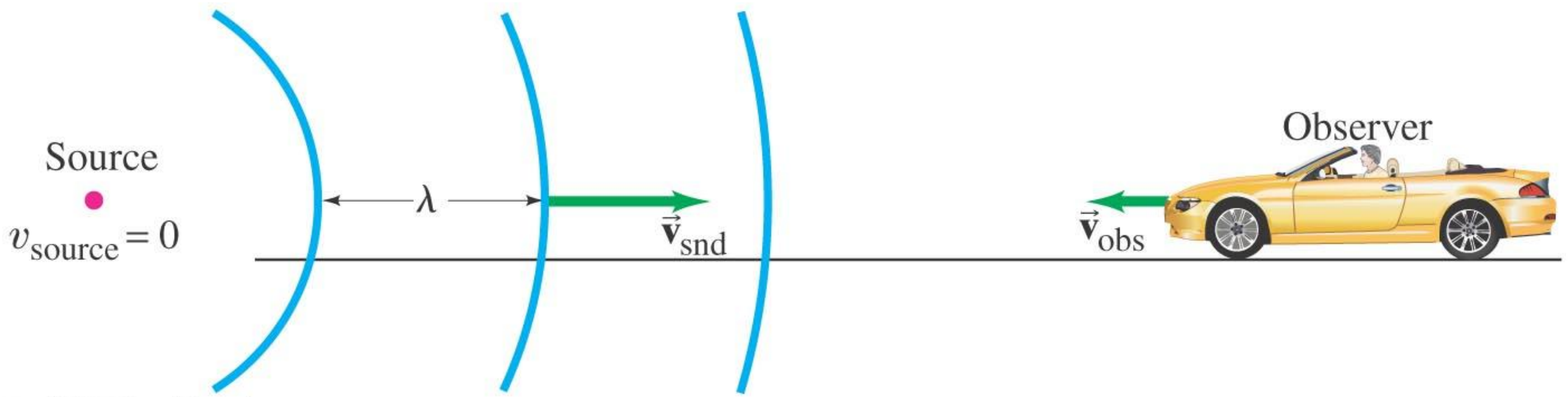
Similarly, if the source is moving **away** from the observer:

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

Source receding:
Lower freq.
f'<f

Doppler Effect

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.



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

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**:

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

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

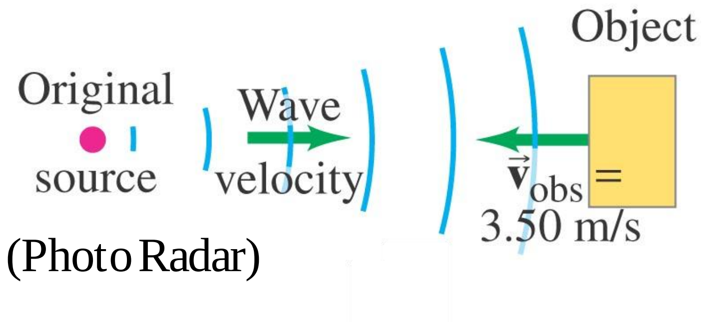
Observer receding:
Lower freq.
f’<f

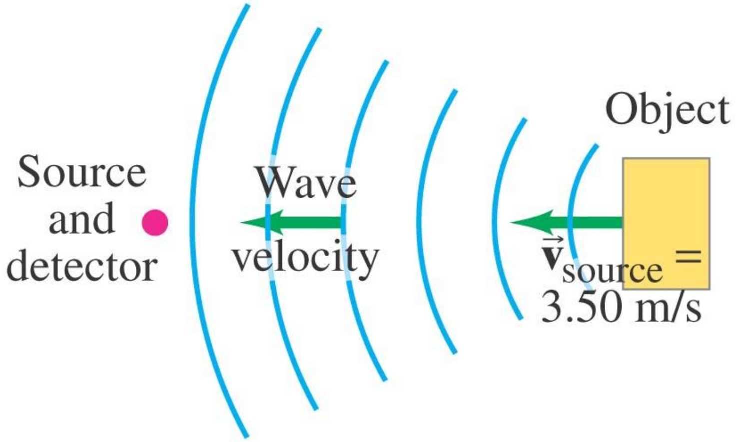
Example: A moving siren.

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: Two Doppler shifts.

A 5000-Hz sound wave is emitted by a stationary source. This sound wave reflects from an object moving 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. $f' < f$