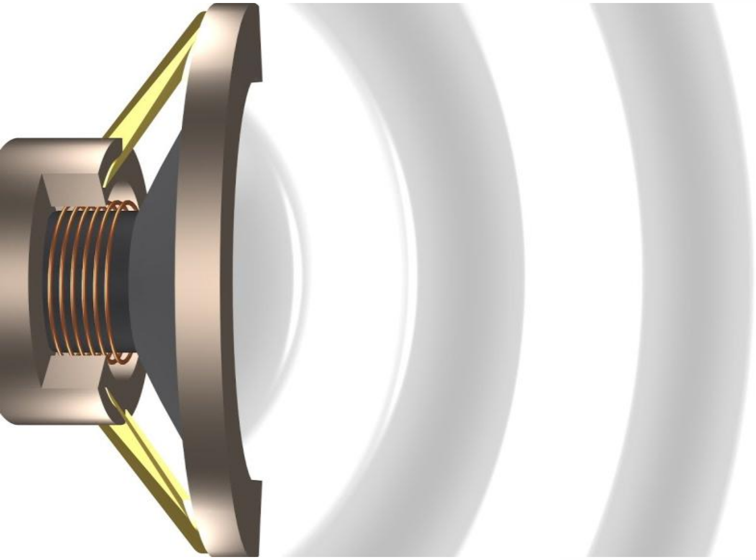
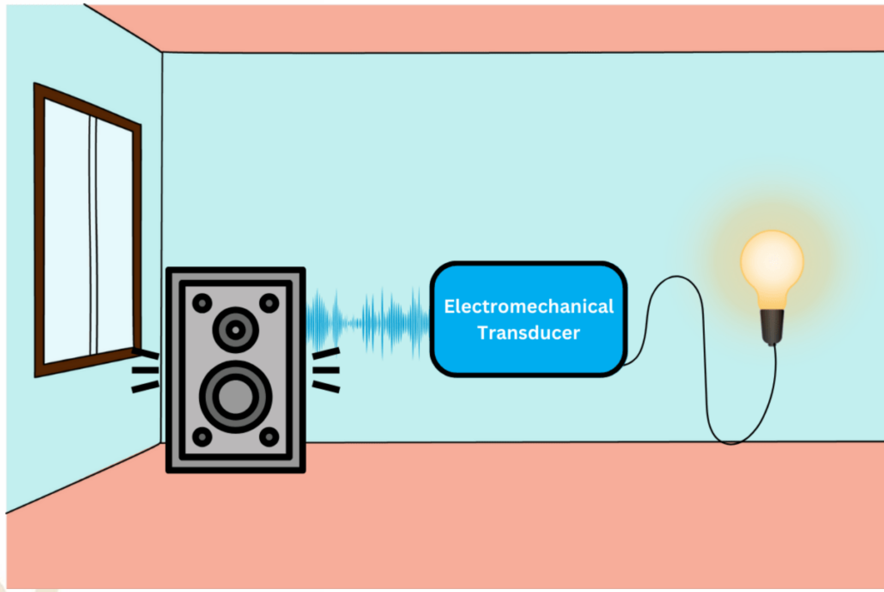
Unit One



Chapter 5



Sound Energy

Prepared and presented by: Mr. Mohamad Seif

OBJECTIVES

1. Determine the Power of Sound emitted by a source
2. Sound intensity
3. Hearing limits

Sound Power

Sound power: represents the energy per unit of time.

$$P = \frac{E}{t}$$

- **P:** sound power in watt (W)
- **E:** energy in Joules (J).
- **t:** time in seconds (S)

The power of a sinusoidal sound wave depends on the amplitude of the sound wave.

It is proportional to the square of the amplitude.

$$P = K.a^2$$

- **K:** positive constant.
- a: amplitude of sound

Sound Power

Application 1: Consider a sinusoidal sound wave of amplitude a=5cm.

1) Determine the power of the sound wave in terms of k.

$$P = K.a^2$$

$$P = K.(5)^2$$

$$P = 25K$$

2) If the amplitude is doubled, determine the new power P′

The amplitude is doubled then: $a' = 2a$

$$P' = K.(a')^2$$

$$P' = K.(2a)^2 \Rightarrow P' = 4Ka^2$$

$$P' = 4K(5)^2 \Rightarrow P' = 100K$$

Sound (acoustic) absorption:

When sound travels in air, part of the sound energy is converted into thermal energy due to friction between the oscillating air molecules.

We say that the sound is absorbed by the air.

Note: In this chapter, we assume that the absorption of sound in negligible, unless otherwise is stated

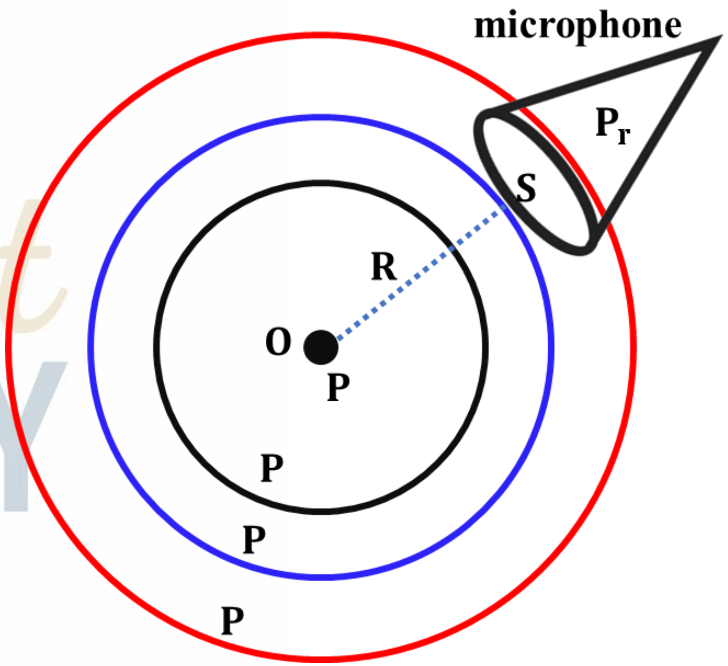
Sound Power

Distribution of power – Received power

Consider a source of sound O emits a sound of power P uniformly in all directions. Neglect the absorption of sound by air.

A microphone is placed at a distance R.

The power P of the emitted sound is distributed uniformly over each sphere.



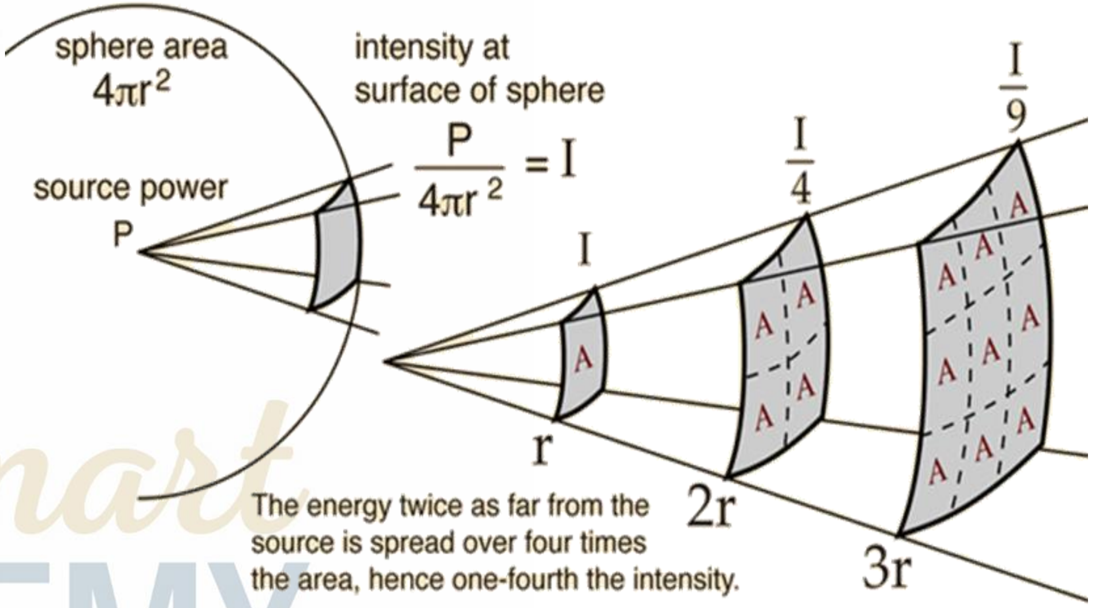
The surface area S receives a part (P_r) of the total power P of the sound

$$P_r = \frac{P \times S}{4\pi R^2}$$

Sound Intensity

The sound intensity at a point is the power of the sound per unit area held normally to the direction of travel of the sound wave at the given point.

$$I = \frac{P}{S} = \frac{P}{4\pi R^2}$$



- **P: sound power received by the area S, expressed in (W).**
- **S: surface area of the sphere (m^2)**
- **I: sound intensity (W/m^2)**

Hearing Limits

Threshold of hearing:

The minimum sound intensity that can be hearted by the human ear.

Threshold of pain:

The maximum sound intensity that can be hearted by a human without causing pain to the ear.

Note: The hearing limit vary with the frequency of the audible sound, sound pressure, and the age of person.

For a frequency $f = 1000Hz$:

- The threshold of hearing: $I_0 = 10^{-12} W/m^2$
- The threshold of pain: $I = 1 W/m^2$

Application 2:

An explosion takes place at a point O, and emits a spherical sound wave of power 1W.

A microphone of membrane area $S_m = 25cm^2$ is placed at 10m from O.

The membrane of the microphone is held normally to the direction of propagation of the sound wave.

1) **Determine the power received by the membrane due to the sound of the explosion.**
2) **Determine the sound intensity received by the membrane due to the sound of the explosion.**

$P = 1W; S_m = 25cm^2; R = 10m.$

1) **Determine the power received by the membrane due to the sound of the explosion.**

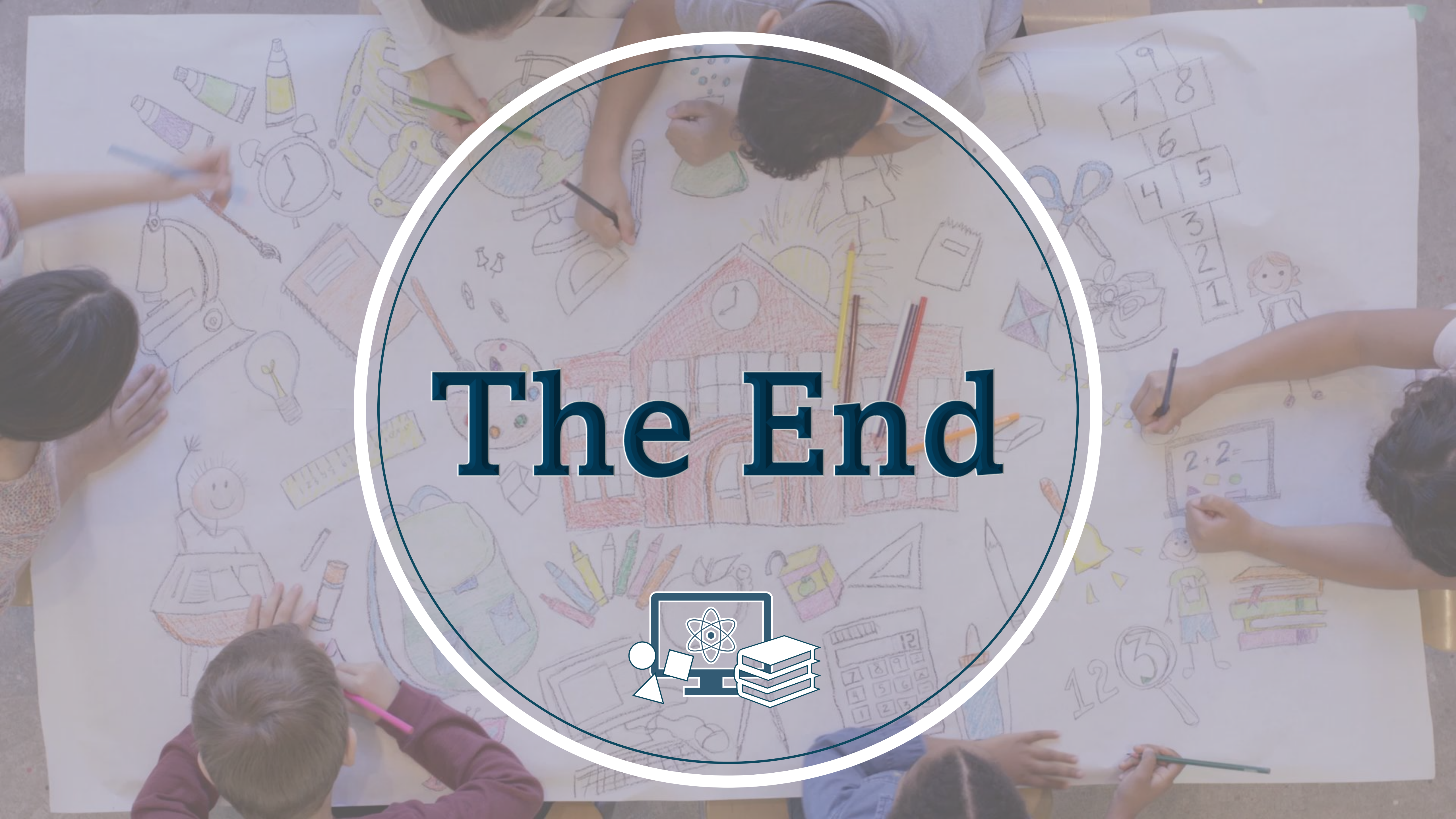
$$P_r = \frac{P \times S}{4\pi R^2} \Rightarrow P_r = \frac{1 \times 25 \times 10^{-4}}{4\pi(10)^2} \Rightarrow P_r = 2 \times 10^{-6} W$$

2) **Determine the sound intensity received by the membrane due to the sound of the explosion.**

$$I = \frac{P_r}{S_m} = \frac{2 \times 10^{-6}}{25 \times 10^{-4}} = 8 \times 10^{-4} W/m^2$$

$$I = \frac{P}{S} = \frac{P}{4\pi R^2} = \frac{1}{4\pi(10)^2}$$

$$I = 8 \times 10^{-4} W/m^2$$



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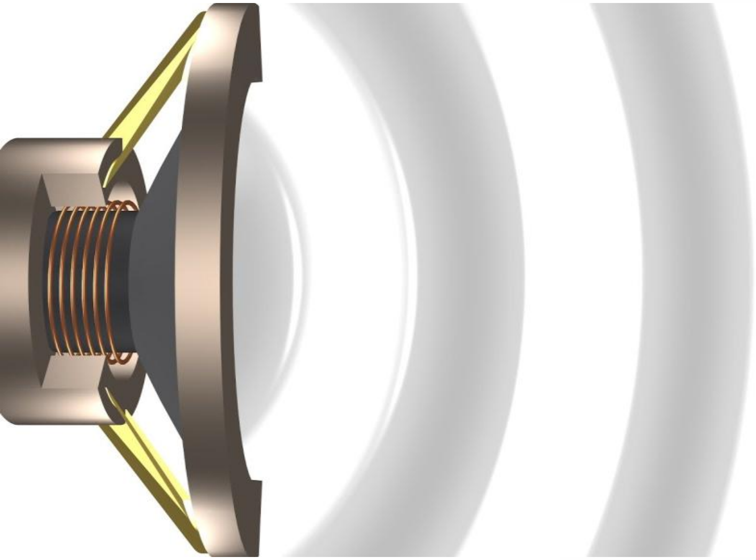
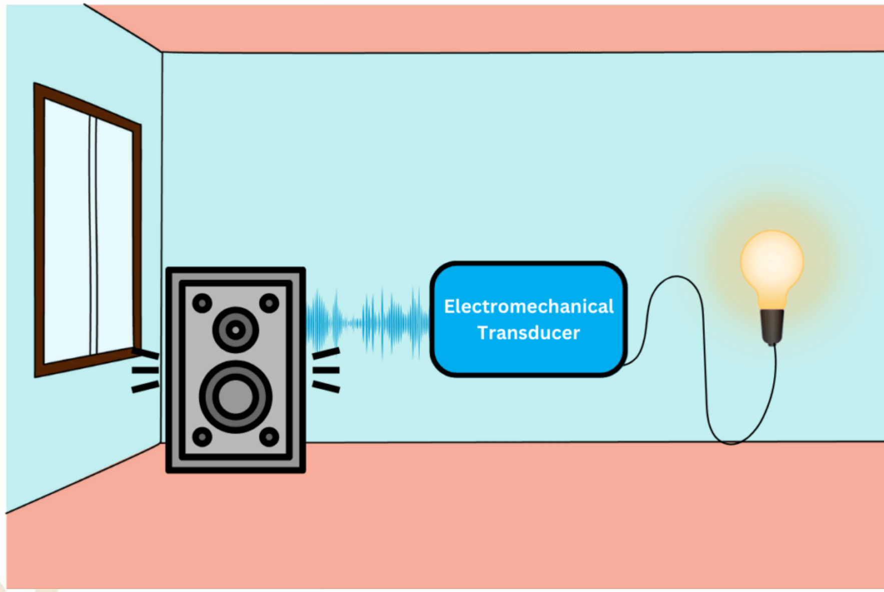


Unit One

Chapter 5



Sound Energy

Prepared and presented by: Mr. Mohamad Seif

OBJECTIVES

1. Sound intensity level
2. Range of Audibility of the Human Ear

Sound intensity level

Loudness (Volume):

We add two radios each of them is adjusted to emit a sound of intensity I

The point M from the two radios a sound of intensity 2I

At M, we hear a louder sound, but this sound is not “two times louder” than that emitted by one radio.

The degree of sensation (feeling) produced by the sound on the ear is called loudness.

Sound intensity level

Sound intensity level (SIL) is the <u>level</u> of the intensity of a sound relative to a reference value, expressed in decibels(dB).

$$L = 10\log\left[\frac{I}{I_0}\right]$$

- **I: sound intensity (W/m^2).**
- **$I_0 = 10^{-12}\ W/m^2$: lowest sound intensity hearable by an undamaged human ear under room conditions.**
- **L: sound intensity level, expressed in decibel (dB).**
- **Log: is a mathematical function**

Sound intensity level

Application 3:

Determine the sound intensity level corresponding to the standard thresholds of hearing and that of pain.

Given:

- **The standard threshold of hearing is $I_0 = 1 \times 10^{-12} W/m^2$.**
- **The standard threshold of pain is $I = 1 W/m^2$**

For $I = I_0$:

$$L = 10\log\left[\frac{I}{I_0}\right]$$

$$L = 10\log\left[\frac{1\times10^{-12}}{1\times10^{-12}}\right] \Rightarrow L = 0dB$$

Sound intensity level

For threshold of pain $I = 1W/m^2$:

$$L = 10\log\left[\frac{I}{I_0}\right]$$

$$L = 10\log\left[\frac{1}{1\times10^{-12}}\right] \Rightarrow L = 120dB$$

This value means the threshold of pain is at the sound intensity level $L = 100dB$

Sound intensity level

Some rules of logarithm function

Rule	Example
$\log 1 = 0$	
$\log 10 = 1$	
$\log 10^n = n \log 10 = n$	$\log 10^3 = 3$
$\log(ab) = log(a) + log(b)$	$\log(2 \times 7) = log(2) + log(7)$
$\log\frac{a}{b} = log(a) - log(b)$	$\log\frac{5}{9} = log(5) - log(9)$
If $\text{n} = \log a$ then $a = 10^n$	If $2 = \log a$ then $a = 10^2$

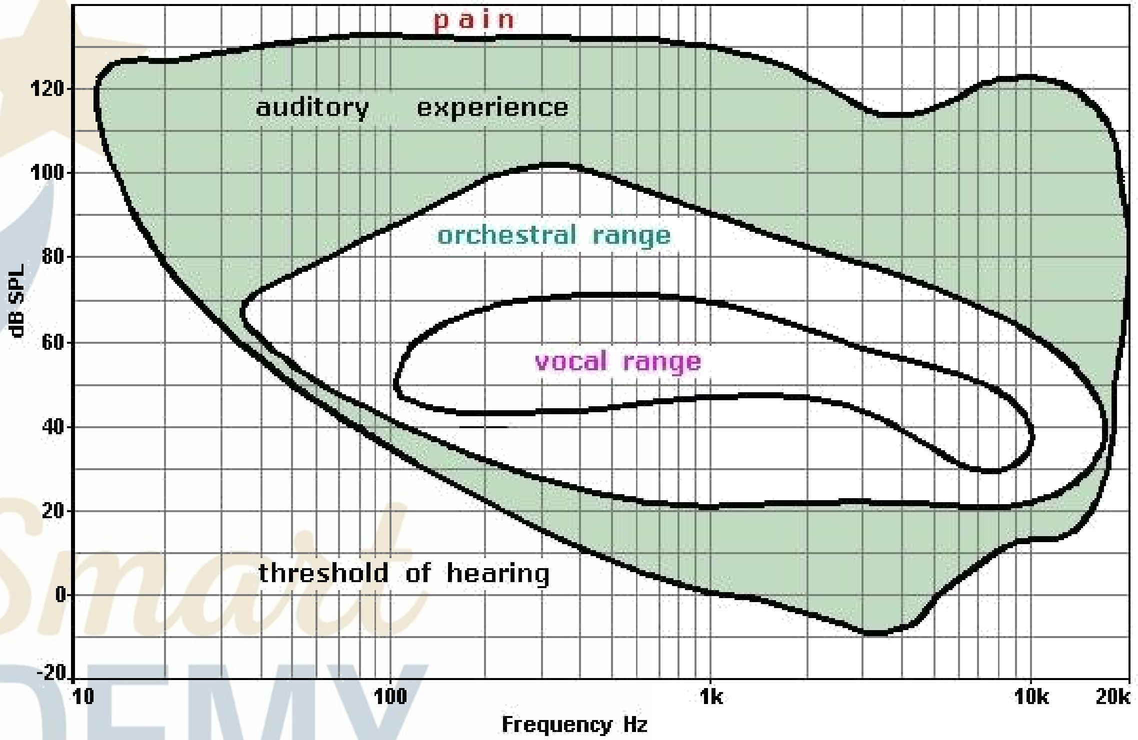
Range of Audibility of the Human Ear

The threshold of hearing varies with frequency

The threshold of hearing is approximately 0dB for a frequency of 1000Hz.

The threshold of pain varies slightly with frequency

The threshold of pain is approximately 120dB.



All the sounds in the colored regions are audible to the normal human ear.

Application 3:

A person receives, in a direction normal to his ear; a constant acoustic power of 5 μW. The average area of the person's ear is 12 cm^2.

1) **Calculate the sound energy received by the person in an hour.**
2) **Calculate the sound intensity received by the ear.**
3) **Is this intensity dangerous? Why?**
4) **Calculate the sound intensity level of the received sound.**
5) **By means of which instrument can we measure the sound intensity level?**

$P = 5\ \mu W;\ S_{ear} = 12\ cm^2.$

1) Calculate the sound energy received by the person in an hour.

The energy E of a constant power P, received during a time t, is:

$E = P.t$ ➡ $E = 5 \times 10^{-6} \times 3600$ ➡ $E = 18 \times 10^{-3} J$

2) Calculate the sound intensity received by the ear.

$I = \frac{P}{S}$ ➡ $I = \frac{5 \times 10^{-6}}{12 \times 10^{-4}}$ ➡ $I = 4.17 \times 10^{-3}\ W/m^2$

$P = 5\ \mu W;\ S_{ear} = 12\ cm^2.$

3) Is this intensity dangerous? Why?

This intensity ($I = 4.17 \times 10^{-3}\ W/m^2$) is not dangerous, since it is less than the intensity of pain ($1 W/m^2$).

4) Calculate the sound intensity level of the received sound.

$$L = 10 \log \frac{I}{I_0} \Rightarrow L = 10 \log \left[\frac{4.17 \times 10^{-3}}{10^{-12}}\right] \Rightarrow L = 96.2 dB$$

5) By means of which instrument can we measure the sound intensity level?

We measure the sound intensity level by means of a sound level meter.

Application 4:

An observer hears the sound of an explosion which takes place 500m away.

The intensity level of the heard sound is 104dB. The sound spreads uniformly in all directions (spherical wave).

1. **Calculate the corresponding sound intensity at 500m**
2. **Deduce the sound power of the explosion**
3. **Prove that the intensity kevel of the sound of this explosion at a distance 4 times longer is $L' \approx 92dB$.**
4. **Given that air absorbs Sound energy at the rate 7dB//km. Determine the real value of L at 2000m from the source of explosion.**

$R = 500m$; $L = 104dB.$

1. Calculate the corresponding sound intensity at 500m

$$L = 10\log\frac{I}{I_0} \Rightarrow 104 = 10\log\frac{I}{I_0} \Rightarrow 10.4 = \log\frac{I}{I_0}$$

$$\frac{I}{I_0} = 10^{10.4} \Rightarrow \frac{I}{10^{-12}} = 10^{10.4} \Rightarrow I = 0.025W/m^2$$

2. Deduce the sound power of the explosion

$$I = \frac{P}{S} \Rightarrow P = I \times S = I \times 4\pi R^2 \Rightarrow P = 0.025 \times 4\pi(500)^2$$

$$P = 7.85 \times 10^3 W$$

3. **Prove that the intensity level of the sound of this explosion at a distance 4 times longer is $L' \approx 92dB$.**

$$I' = \frac{P}{S} = \frac{P}{4\pi R^2} \Rightarrow I' = \frac{7.85 \times 10^3}{4\pi(4 \times 500)^2}$$

$$I' = 1.56 \times 10^{-3} W/m^2$$

$$L' = 10 \log \frac{I'}{I_0} \Rightarrow L' = 10 \log \frac{1.56 \times 10^{-3}}{10^{-12}}$$

$$L' \approx 92dB$$

4. Given that air absorbs Sound energy at the rate 7dB//km. Determine the real value of L at 2000m from the source of explosion.

The rate of absorbs Sound energy by air is 7dB//km.

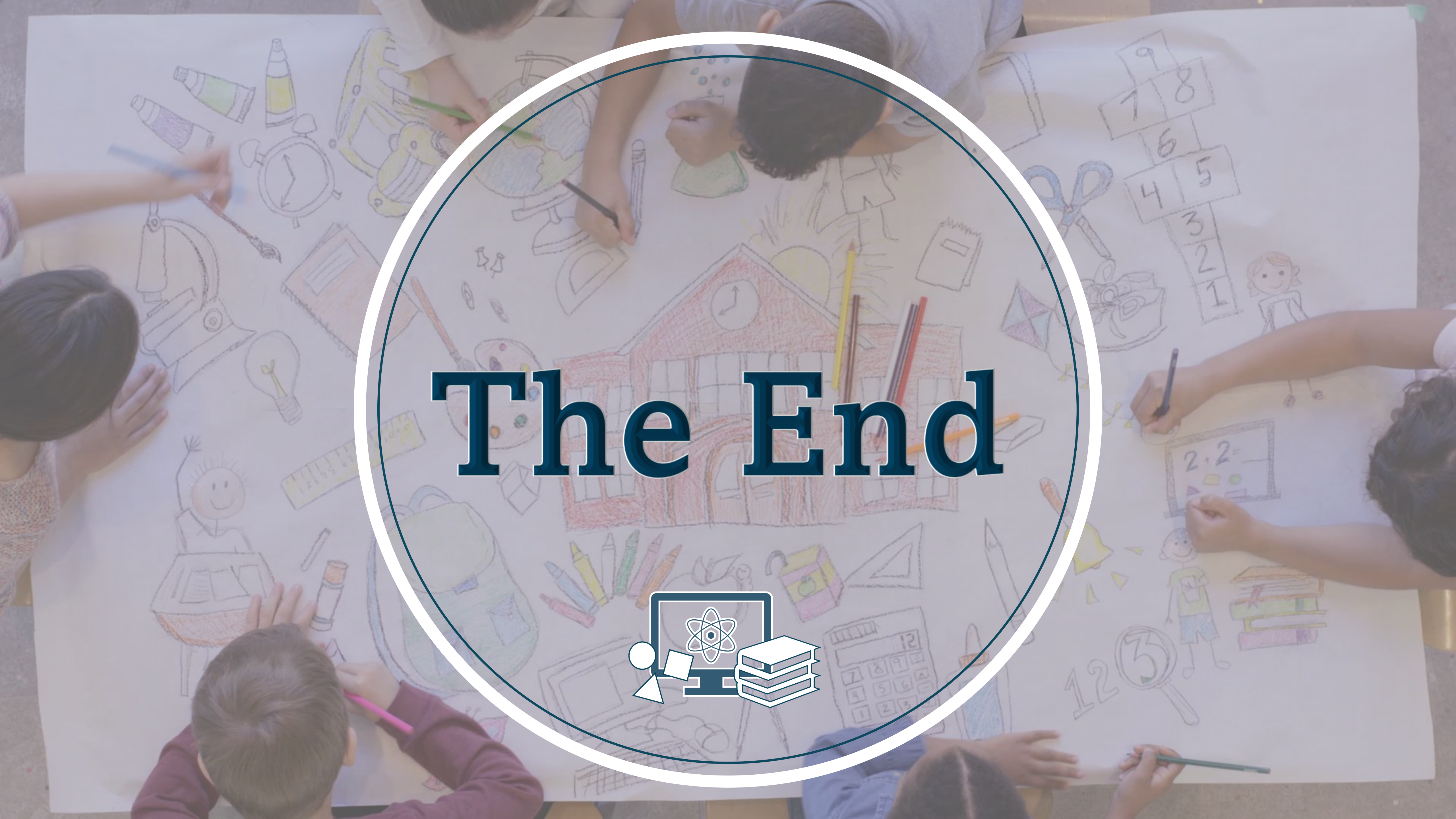
The distance from the source is 200m=2km

Then, the absorbs energy by air is 7×2

$$L_{real} = L' - (7 \times 2)$$

$$L_{real} = 92 - 14$$

$$L_{real} = 78dB$$



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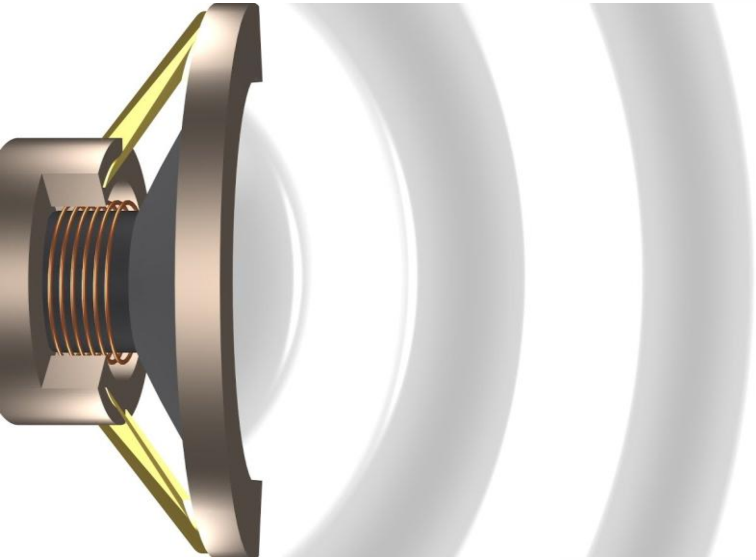
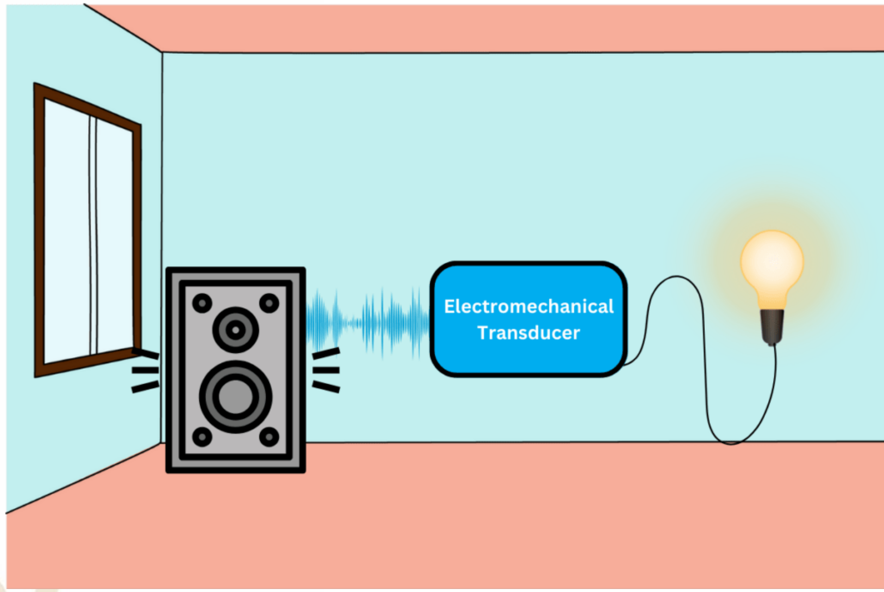
Unit One





Chapter 5

Sound Energy

Prepared and presented by: Mr. Mohamad Seif

OBJECTIVES

1 **Explain Doppler effect and apply its equations**

Doppler Effect

Have you noticed that when a car moves past you, its the sound changes?

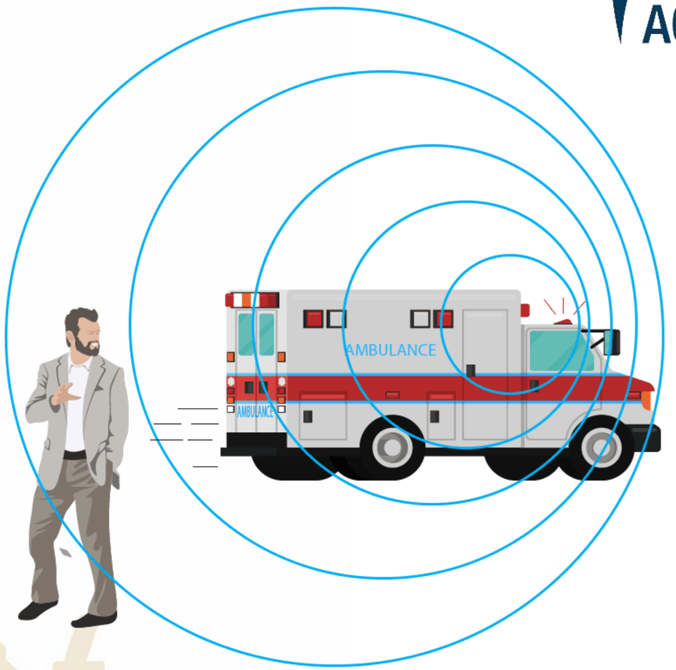
The sound seems like "eeeeeeeooowwwww".

This is one example of the doppler effect.

Doppler Effect

What is Doppler effect?

Doppler effect is defined as a variation in the frequency of a wave (sound, light…) when the source and the observer are in motion with respect to each other



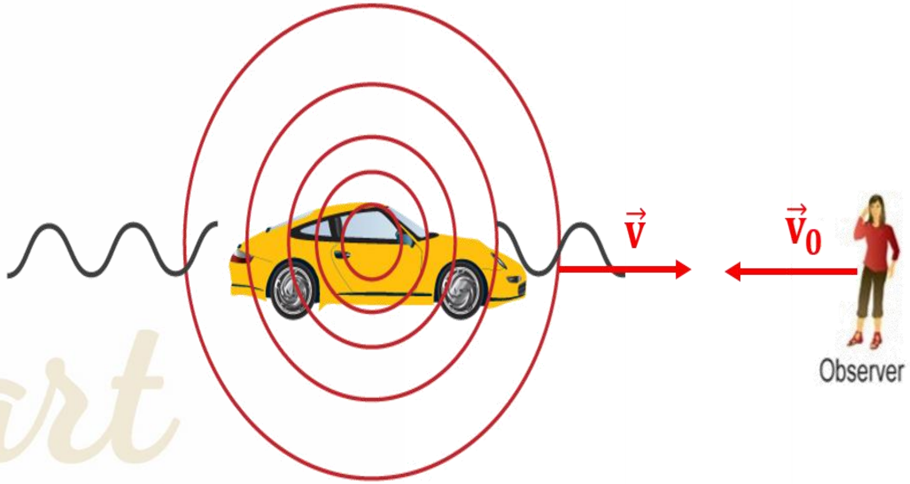
We will discuss the following cases:

Doppler Effect

Case 1: The observer is moving towards a stationary source of sound

An observer with a speed v_0 ($v_0 < v$) is moving towards a stationary car.

The car emits a spherical sound wave of frequency f and of wavelength λ.



The sound wave appears to have a higher speed: $v + v_0$.

Then the apparent frequency of the heard sound is $f' = \frac{v+v_0}{\lambda}$

Doppler Effect

But $\lambda = \frac{v}{f}$, substitute in the last equation:

$$f' = \frac{v + v_0}{\lambda}$$

$$f' = \frac{v + v_0}{\frac{v}{f}}$$

$$f' = f\frac{(v + v_0)}{v}$$

$$(v + v_0) > v$$

Then :

$$f' > f$$

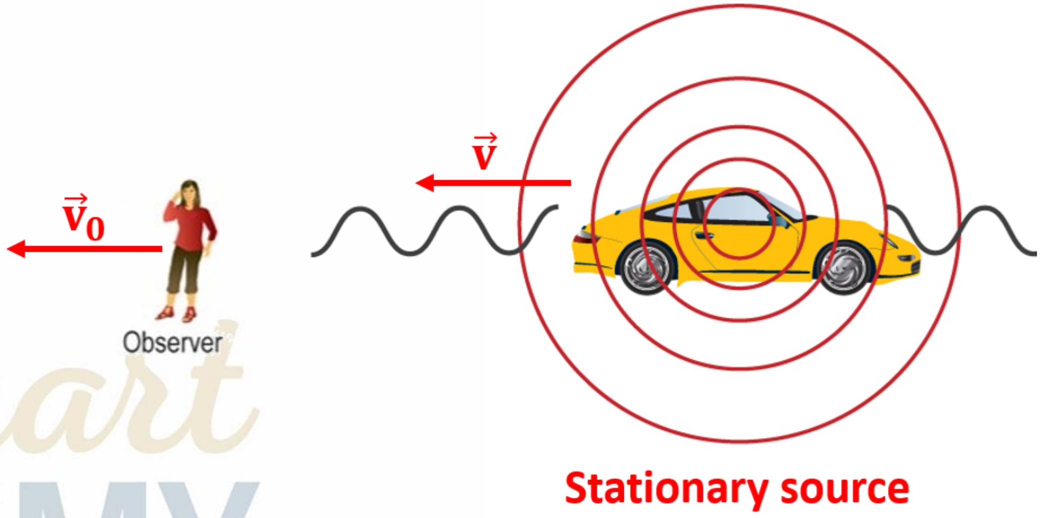
The observer hears a sound of frequency f′ higher than the frequency of the source

Doppler Effect

Case 2: The observer is moving away from a stationary source of sound

An observer with a speed v_0 ($v_0 < v$) is moving away from a stationary car.

The car emits a spherical sound wave of speed v, frequency f and of wavelength λ



The sound wave appears to have a lower speed: $v - v_0$.

Then the apparent frequency of the heard sound is $f' = \frac{v - v_0}{\lambda}$

Doppler Effect

But $\lambda = \frac{v}{f}$, substitute in the last equation:

$$f' = \frac{v - v_0}{\lambda}$$

$$f' = \frac{v - v_0}{\frac{v}{f}}$$

$$f' = f\frac{(v - v_0)}{v}$$

$$(v - v_0) < v$$

Then:

$$f' < f$$

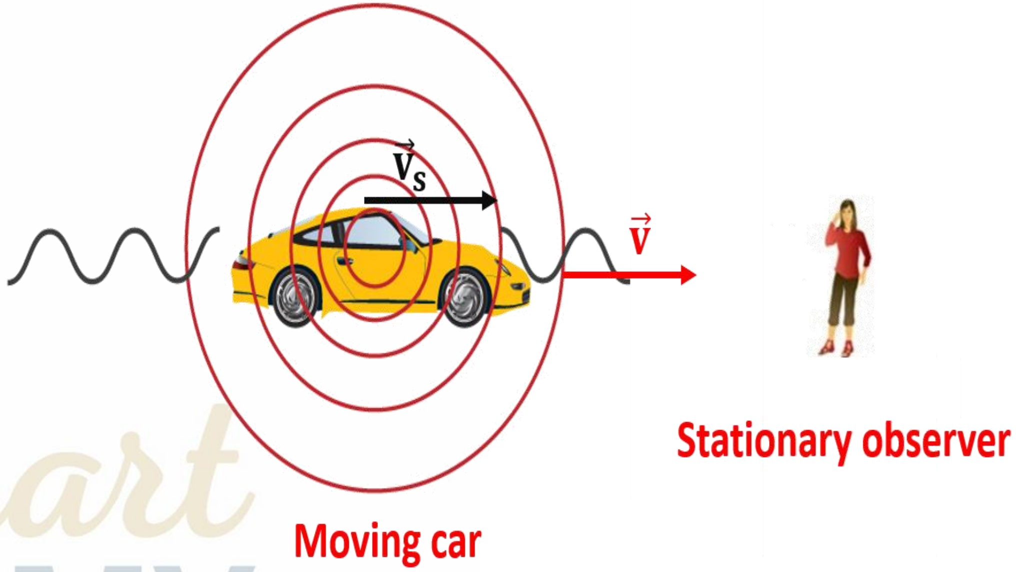
The observer hears a sound of frequency f′ lower than of the source

Doppler Effect

Case 3: The source is moving towards a stationary observer

A car is moving with a speed v_s ($v_s < v$) towards a stationary observer.

The car emits a spherical sound of frequency f, of wavelength λ & speed v.



The apparent wavelength of the sound wave is: $\lambda' = \lambda - d$, where d is the traveled distance by the car.

The apparent frequency of the heard sound is $f' = \frac{v}{\lambda'} = \frac{v}{\lambda - d}$

Doppler Effect

But $\lambda = \frac{v}{f}$, and $d = \frac{v_s}{f}$; substitute in the last equation:

$$f' = \frac{v}{\lambda - d}$$

$$f' = \frac{v}{\frac{v}{f} - \frac{v_s}{f}}$$

$$f' = \frac{v}{\frac{v - v_s}{f}}$$

$$f' = f\left[\frac{v}{v - v_s}\right]$$

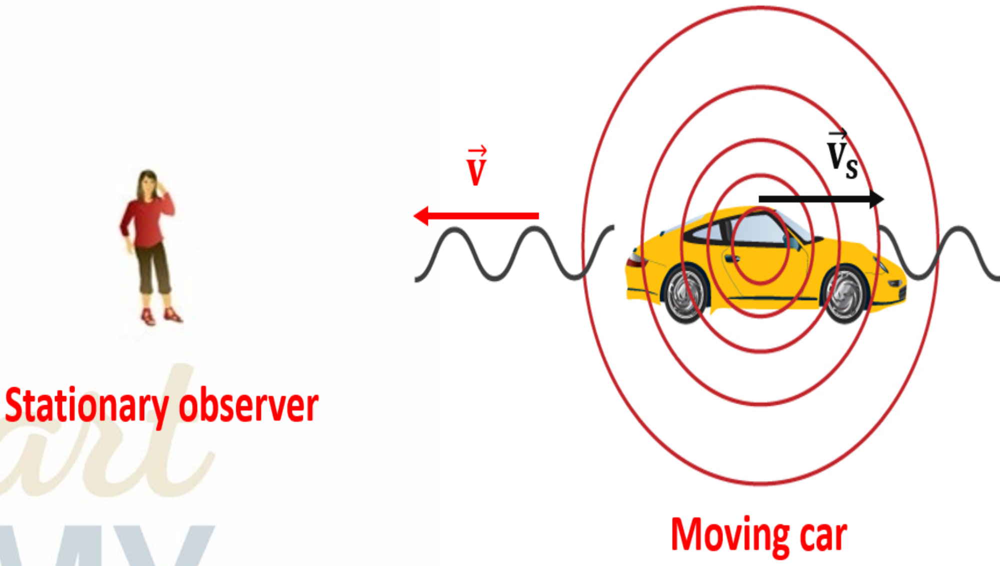
The observer hears a sound of frequency f′ higher than the frequency of the source

Doppler Effect

Case 4: The source is moving away from a stationary observer

A car is moving with a speed v_s away from a stationary observer.

The car emits a spherical sound of frequency f, of wavelength λ & speed v. ($v_s < v$) .



The apparent wavelength of the sound wave is: $\lambda' = \lambda + d$, where d is the traveled distance by the car.

The apparent frequency of the heard sound is $f' = \frac{v}{\lambda'} = \frac{v}{\lambda + d}$

Doppler Effect

But $\lambda = \frac{v}{f}$, **and** $d = v_s \times T$;

substitute in the last equation:

$$f' = \frac{v}{\lambda + d}$$

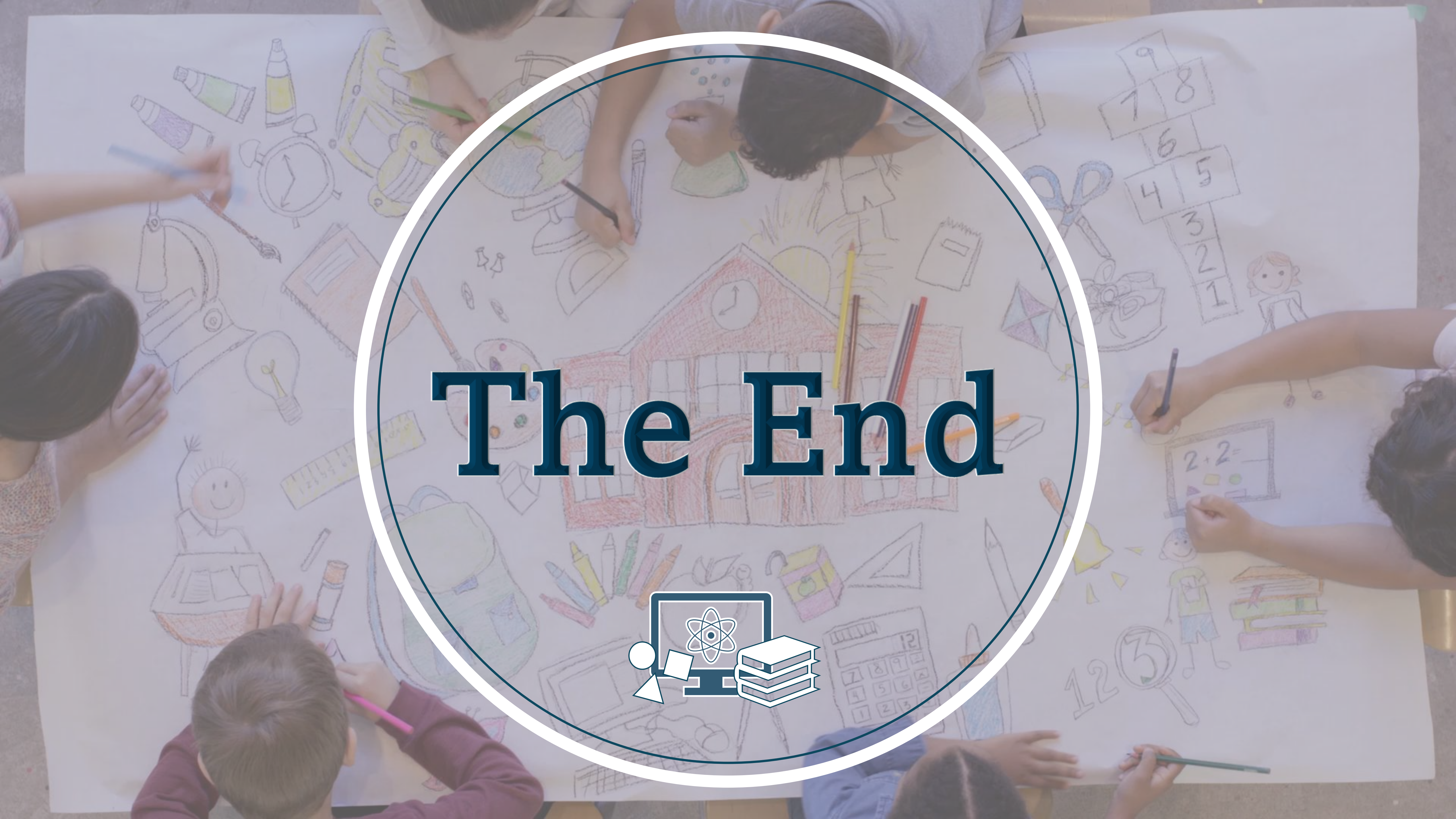
$$f' = \frac{v}{\frac{v}{f} + v_s \times T}$$

$$f' = \frac{v}{\frac{v}{f} + \frac{v_s}{f}}$$

$$f' = f\left[\frac{v}{v + v_s}\right]$$

$$f' < f$$

The observer hears a sound of frequency f′ lower than the frequency of the source.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