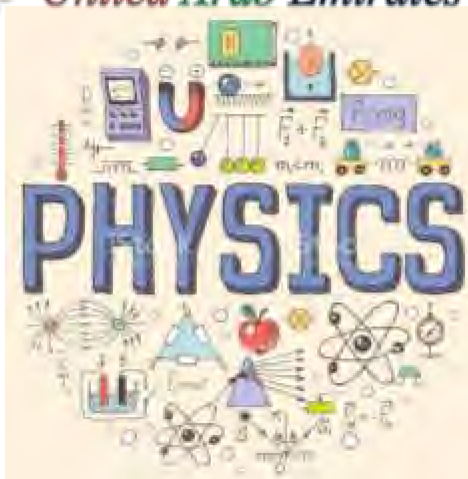
Al Dahma'a School C3

United Arab Emirates

Ministry of Education



الإمـــارات
THE EMIRATES

وزارة التـربيـة والتـعليـم
MINISTRY OF EDUCATION

Grade 10 Advanced

Prepared by: Osama Awny

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Chapter 5: Sound

Section 1: Properties and Detection of Sound

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Properties and Detection of Sound

Sound Waves

Pressure variations

- **A pressure variation that is transmitted through matter is a sound wave**
- **Sound waves move through air because a vibrating source produces regular variations, or oscillations, in air pressure.**
- **High pres – compressions, Low pres – rarefactions**
- **The air particles collide, transmitting the pressure variations away from the source of the sound.**

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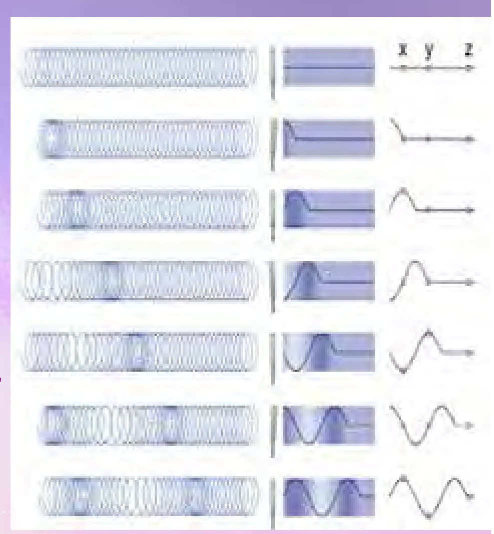
Properties and Detection of Sound

Sound Waves

Describing sound

- **The frequency of the wave** is the number of oscillations in pressure each second.
- **The wavelength** is the distance between successive regions of high or low pressure
- Because the motion of the air particles is parallel to the direction of motion of the wave, sound is **a longitudinal wave**



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Properties and Detection of Sound

Describing sound

- **At room temperature (20°C), sound moves through air at sea level at a speed of 343 m/s.**
- **The speed of sound in air depends on the temperature, with the speed increasing by about 0.6 m/s for each 1°C increase in air temperature.**
- **The speed of sound is greater in solids and liquids than in gases.**
- **Sound cannot travel in a vacuum because there are no particles to collide.**

Speed of Sound in Various Media

Medium	m/s
Air (0°)	331
Air (20°)	343
Helium (0°)	965
Water (25°)	1497
Seawater (25°)	1535
Copper (20°)	4760
Iron (20°)	4994

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Properties and Detection of Sound

Describing sound

- **Reflected sound waves are called echoes**
- **The time required for an echo to return to the source of the sound can be used to find the distance between the source and the reflective object**

$$v = \frac{2x}{t}$$

- **The frequency and wavelength of a wave are related to the speed of the wave by the equation $\lambda = v/f$**

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Properties and Detection of Sound

Detection of Pressure Waves

- Sound detectors convert sound energy—the kinetic energy of the vibrating air particles—into another form of energy
- A common detector is a microphone, which converts sound waves into electrical energy

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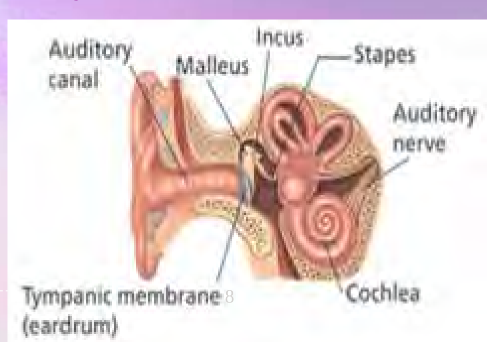
Properties and Detection of Sound

The Human Ear

- **The human ear is a detector that receives pressure waves and converts them into electrical impulses.**
- **Sound waves entering the auditory canal cause vibrations of the tympanic membrane.**



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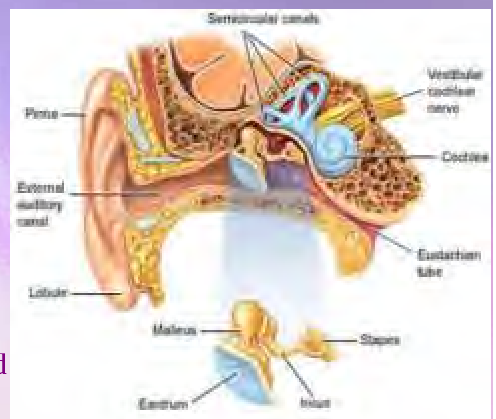
Properties and Detection of Sound

The Human Ear

- Three tiny bones then transfer these vibrations to fluid in the ***cochlea***.
- Tiny hairs lining the spiral-shaped cochlea detect certain frequencies in the vibrating fluid.
- These hairs stimulate ***nerve cells***, which send impulses to the brain and produce the sensation of sound.



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Properties and Detection of Sound

Perceiving Sound – Pitch

- The ear is not equally sensitive to all frequencies

Human can hear:

- 20 Hz or above 16,000 Hz
- 20 Hz or above 16,000 Hz (Older people)
- 20 Hz or above 8,000 Hz (By age 70, most people cannot hear sounds well and loss the ability to understand speech).

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Properties and Detection of Sound

Perceiving Sound – Loudness

- **Amplitude** is physical characteristic of sound waves and the measure of the variation in pressure along a wave.
- **The loudness of a sound** is the intensity of the sound as perceived by ear, and interpreted by the brain.
- **The intensity depends on** the amplitude of the pressure wave.
- The human ear is extremely sensitive to **the intensity of sound waves, which is the amplitude of the wave.**

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Properties and Detection of Sound

Perceiving Sound – Loudness

- The ear can detect pressure-wave amplitudes of 2×10^{-5} Pa
- At the other end of the audible range, pressure variations of approximately 20 Pa or greater cause pain
- It is important to remember that the ear detects only pressure variations at certain frequencies

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Properties and Detection of Sound

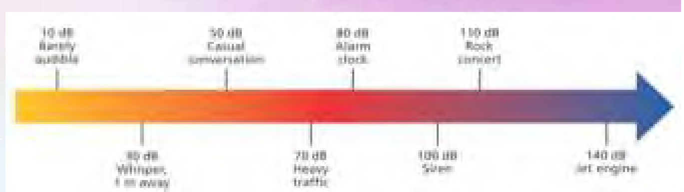
Perceiving Sound – Loudness

Sound level

- Logarithmic scale of pressure variation.

Decibel (dB)

- The unit of measurement for sound level
- This faintest sound is measured at 0 dB
- 10x higher pressure represents as an increase in 20 dB.
- Human preserve an increase of 10dB as being twice as loud as the original level.



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Properties and Detection of Sound

Perceiving Sound – Loudness

- The longer a person is exposed to loud sounds, the greater the effect. A person can recover from short-term exposure in a period of hours.
- Long exposure to 100-dB or greater sound levels can produce permanent damage
- The **ear's sensitivity** depends on both **pitch and amplitude**
- Cotton earplugs reduce the sound level only by about 10 dB
- Special ear inserts can provide a 25-dB reduction
- Specifically designed earmuffs and inserts can reduce the sound level by up to 45 dB.

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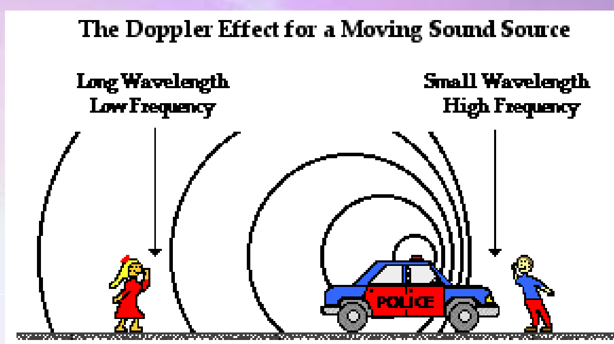
Properties and Detection of Sound

Doppler Efeect

- It is the change in frequency of sound caused by the movement of the source or the detector or Both.
- **The pitch was higher** when the vehicle was moving **toward** you, then it **dropped** to a **lower pitch** as the source **moved away.**



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Properties and Detection of Sound

Doppler Efeect

Doppler Effect $f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$

v = velocity of the sound wave

v_d = velocity of the detector

v_s = velocity of the sound source

f_d = frequency received by the detector

f_s = waves frequency emitted by the source

- This equation applies when the source is moving, when the observer is moving, and when both are moving

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Properties and Detection of Sound

The Doppler Effect

Defining the coordinate system:

Doppler Effect $f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$

For a *source* moving toward the *detector*:

- Positive direction, which results in a smaller denominator compared to a stationary source, (f_d), increases.

For a *detector* moving toward the *source*

- Negative direction and increased numerator compared to a stationary detector, the detected frequency, (f_d), increases.

If the source moves away from the detector or if the detector moves away from the source

- **(f_d) decreases**.

The velocity of sound is always positive!

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Properties and Detection of Sound

The Doppler Effect

Reducing Equations When an element in a complex equation is equal to zero, the equation might reduce to a form that is easier to use.

Stationary detector, source in motion: $v_d = 0$	Stationary source, detector in motion: $v_s = 0$
$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$	$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right)$
$= f_s\left(\frac{v}{v - v_s}\right)$	$= f_s\left(\frac{v - v_d}{v}\right)$
$= f_s\left(\frac{\frac{v}{v}}{\frac{v}{v} - \frac{v_s}{v}}\right)$	$= f_s\left(\frac{\frac{v}{v} - \frac{v_d}{v}}{\frac{v}{v}}\right)$
$= f_s\left(\frac{1}{1 - \frac{v_s}{v}}\right)$	$= f_s\left(\frac{1 - \frac{v_d}{v}}{1}\right)$
	$= f_s\left(1 - \frac{v_d}{v}\right)$

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Properties and Detection of Sound

The Doppler Effect

- The Doppler effect occurs in all wave motion, both mechanical and electromagnetic.

It has many applications:

- **Radar** detectors use the Doppler effect to measure the speed of baseballs and automobiles.
- **Astronomers** observe light from distant galaxies and use the Doppler effect to measure their speeds and infer their distances.
- **Physicians** can detect the speed of the moving heart wall in a fetus by means of the Doppler effect in ultrasound.
- **Bats** use the Doppler effect to detect and catch flying insects.

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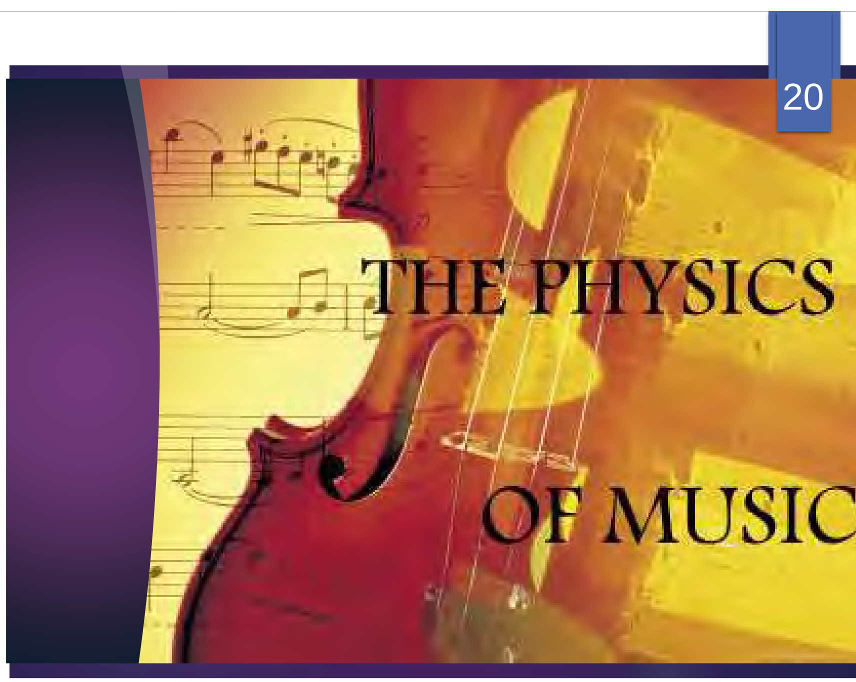

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The Physics of Music

Sources of Sound

The vibrations of the object create particle motions that cause pressure oscillations in the air.

Sound is produced by vibrating objects:

- Vocal cords
- Brass instruments
- Reed instruments
- Stringed Instruments
- Others

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The Physics of Music

Sources of Sound (cont.)

- The human voice is produced by vibrations of the vocal cords, which are two membranes located in the throat.
- Air from the lungs rushing through the throat starts the vocal cords vibrating.
- The ***frequency*** of vibration is controlled by the muscular tension placed on the vocal cords.
- The **more tension** on the vocal cords, **the more rapidly** they vibrate, resulting in a **higher pitch** sound.
- If the vocal cords are **more relaxed**, they vibrate **more slowly** and produced **lower-pitched** sound.

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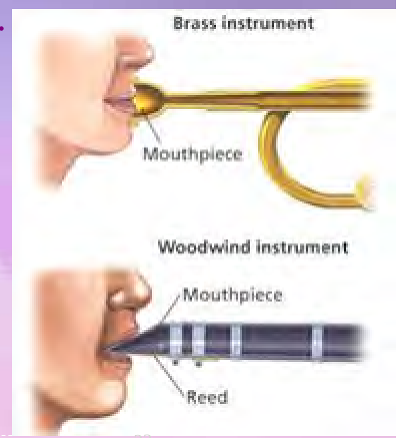
The Physics of Music

Sources of Sound (cont.)

- In brass instruments, such as the trumpet (بوق) and tuba, the lips of the performer vibrate.

- Reed instruments, such as the clarinet (مزمار) and saxophone, have a thin wooden strip (شريط خشبي), or reed (قصب), that vibrates as a result of air blown across it.



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The Physics of Music

Sources of Sound (cont.)

- In **stringed instruments** (الآلات الوترية), such as the piano, guitar, and violin, wires or **strings** are set into vibration.
- In the piano, the wires are struck (الضرب);
- In the guitar, they are plucked (النقر على الاوتار);
- In the violin, the friction of the bow causes the strings to vibrate.

- Often, the strings are attached to a sounding board that vibrates with the strings.
- The vibrations of the sounding board cause the pressure oscillations in the air that we hear as sound.

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The Physics of Music

Resonance in Air Columns

- When a reed instrument is played, the air within the long tube that makes up the instrument vibrates at the same frequency, or in resonance, with a particular vibration of the lips or reed.
- Remember that resonance increases the amplitude of a vibration by repeatedly applying a small external force at the same natural frequency.
- The length of the air column determines the frequencies of the vibrating air that will be set into resonance.

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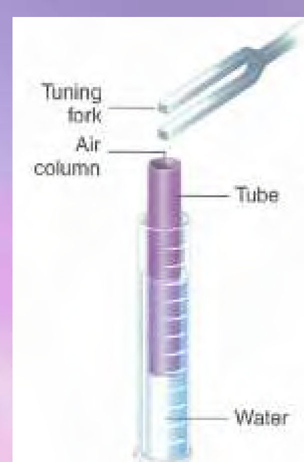
The Physics of Music

Resonance in Air Columns (cont.)

- A tuning fork above a hollow tube can provide resonance in an air column.
- A resonating tube with one end closed to air is called a **closed-pipe resonator**.
- **Open pipe resonator-** resonating tube with both ends open



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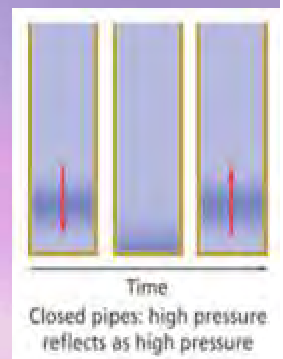
The Physics of Music

Resonance in Air Columns (cont.)

Standing pressure wave

- How does resonance occurs?
- The vibrating tuning fork produces a sound wave, alternate high- and low-pressure variations moves down the air column.
- When the wave hits the water surface, it is reflected back up to the tuning fork.
- If the reflected high-pressure wave reaches the tuning fork at the same moment that the fork produces another high-pressure wave, then reinforce each other, produces a standing wave, and resonance is achieved.



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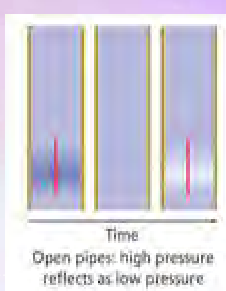
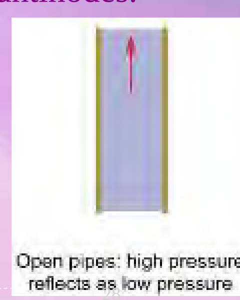
Resonance in Air Columns (cont.)

- **Open-pipe resonator**:
- The sound wave does not reflect off a closed end, but it is inverted.
- The standing waves have nodes and antinodes.





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Resonance in Air Columns (cont.)

Resonance lengths

- A node is the stationary point where two equal wave pulses meet and are in the same location.
- An antinode is the place of largest displacement when two wave pulses meet.
- In the pressure graphs, the nodes are regions of mean atmospheric pressure, and at the antinodes, the pressure oscillates between its maximum and minimum values.

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Resonance in Air Columns (cont.)

Resonance lengths

- **In the pressure graphs**:
- The **nodes** are regions of mean atmospheric pressure, and at the **antinodes**, the pressure oscillates between its maximum and minimum values.
- **In the case of the displacement graph**:
- **The antinodes** are regions of high displacement and **the nodes** are regions of low displacement.
- In both cases, two antinodes (or two nodes) are separated by **one-half wavelength**.

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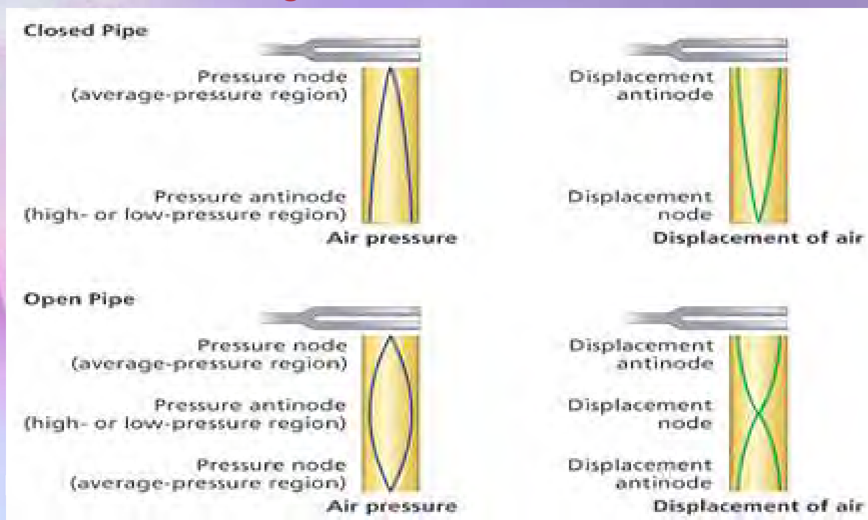
Resonance in Air Columns (cont.)

Resonance lengths



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Resonance in Air Columns (cont.)

Resonance frequencies in a closed and open pipe

Closed-pipe resonator:

The shortest pipe length that will resonate is $\lambda/4 = L_1$

All Additional resonance occur with the addition of $\lambda/2$ to the pipe length.

$\lambda/4 = L_1$, $3\lambda/4 = L_2$, $5\lambda/4 = L_3$, $7\lambda/4 = L_4$, etc

Open-pipe resonator:

The shortest pipe length that will resonate is $\lambda/2 = L_1$

All Additional resonance occur with the addition of $\lambda/2$ to the pipe length.

$\lambda/2 = L_1$, $\lambda = L_2$, $3\lambda/2 = L_3$, $2\lambda = L_4$, etc

Measurements of the spacing between resonances can be used to find the velocity of sound in air.

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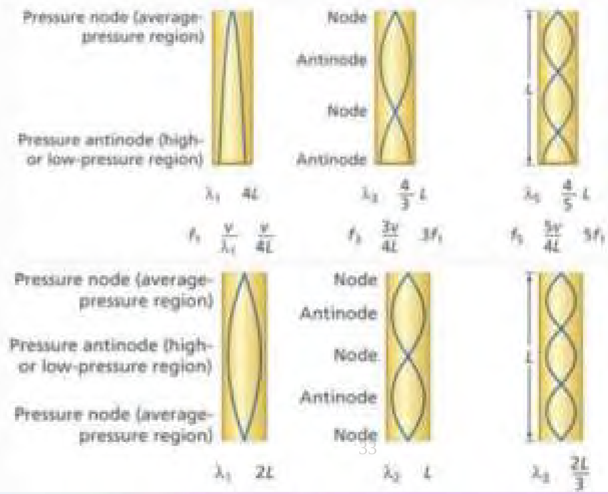
Resonance in Air Columns (cont.)

Resonance frequencies in a closed and open pipe

- Closed Pipe
- Open Pipe



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Resonance in Air Columns (cont.)

- If open and closed pipes of **the same length** are used as resonators:
- The **wavelength** of the resonant sound for **the *open pipe* will be *half* for the *closed pipe***.

- Therefore, **the frequency will be *twice* as high for the *open pipe* as for the *closed pipe***.
- For both pipes, ***resonance lengths*** are spaced by ***half-wavelength intervals***

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Resonance in Air Columns (cont.)

Hearing Resonance

- Musical instruments use resonance to increase the loudness of particular notes.
- Open-pipe resonators include flutes and saxophones.
- Clarinets and the hanging pipes under marimbas and xylophones are examples of closed-pipe resonators.
- The seashell also act as a closed-pipe resonator.

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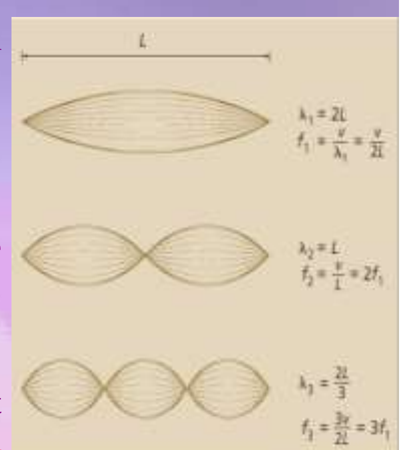
The Physics of Music

Resonance on Strings

- Striking strings produce variation in waveforms.
- Act as open-pipe resonators:
- First Resonance is at $\lambda = L_1$ **, not** $\lambda/2$
- Additional resonance occur with the addition of $\lambda/2$ to the pipe length: $\lambda = L_1$, $3\lambda/2 = L_2$, $2\lambda = L_3$, etc
- As with an open pipe, the resonant frequencies are whole-number multiples of the lowest frequency.



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Resonance on Strings (cont.)

- The **speed of a wave** depends on the **medium**.
- For a **string**, it depends on **the tension of the string** and its **mass per unit length**.
- The **tighter** the string, the **faster** the wave moves along it, and therefore, the **higher the frequency** of its standing waves.
- This makes it possible to tune a stringed instrument by changing the tension of its strings.

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The Physics of Music

Resonance on Strings (cont.)

- Because strings are so **small in cross-sectional area**, they **move very little air when they vibrate**.
- This makes it necessary to attach them to a sounding board, which transfers their vibrations to the air and produces a stronger sound wave.
- Unlike the strings themselves, **the sounding board should not resonate at any single frequency**.
- Its purpose is to transfer the vibrations of all the strings to the air, and therefore it **should vibrate well at all frequencies produced by the instrument**

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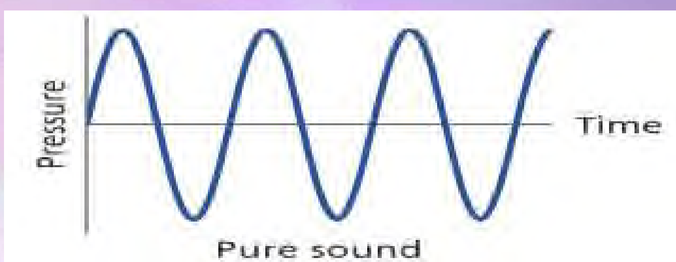
The Physics of Music

Sound Quality

- A tuning fork produces a soft and uninteresting sound.
- This is because its tines vibrate like simple harmonic oscillators and produce the simple sine wave shown in the figure.



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Sound Quality (cont.)

- Sounds made by the human voice and musical instruments are much more complex, like the wave shown in the figure.
- Both waves have the same frequency, or pitch, but they sound very different.

- **The shape of the wave** depends on the **relative amplitudes of these frequencies**
- In musical terms, the difference between the two waves is called timbre (ختم), tone color, or tone quality.

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The Physics of Music

Finding the Speed of Sound Using Resonance

When a tuning fork with a frequency of 392 Hz is used with a closed-pipe resonator, the loudest sound is heard when the column is 21.0 cm and 65.3 cm long.

What is the speed of sound in this case?

Is the temperature warmer or cooler than normal room temperature, which is 20°C? Explain your answer.

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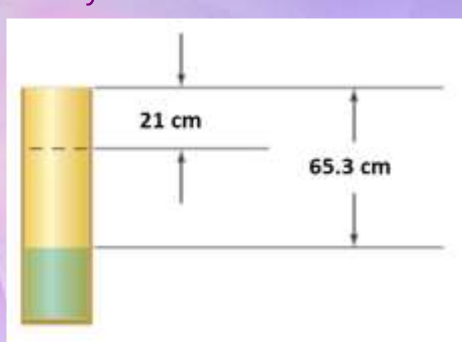
Finding the Speed of Sound Using Resonance (cont.)

Identify the known and unknown variables.



Known:

f = 392 Hz

L_a = 21.0 cm

L_b = 65.3 cm

Unknown:

v = ?

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Finding the Speed of Sound Using Resonance (cont.)

Solve for the length of the wave using the length-wavelength relationship for a closed pipe.

$$L_B - L_A = \frac{1}{2}\lambda$$

Rearrange the equation for λ: $\lambda = 2(L_B - L_A)$

Substitute $L_B = 0.653$ m, $L_A = 0.210$ m.

$$\lambda = 2(0.653\text{ m} - 0.210\text{ m})$$

$$= 0.886\text{ m}$$

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The Physics of Music

Finding the Speed of Sound Using Resonance (cont.)

Rearrange the equation for v.

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

$$v = f\lambda$$

Substitute $f = 329$ Hz, $\lambda = 0.886$ m.

$$v = 347\text{ m/s}$$

The speed is slightly greater than the speed of sound at 20°C, indicating that the temperature is slightly higher than normal room temperature.

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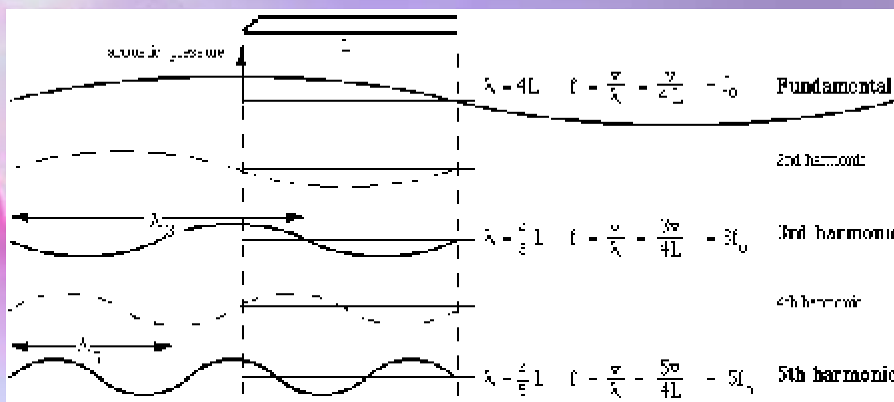
Sound Quality (cont.)

The sound spectrum: fundamental and harmonics



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The sound spectrum: fundamental and harmonic

- **Fundamental-** lowest frequency (f_1)
  - **Closed pipe-** $f_1 = \frac{v}{4L}$
  - **Open pipe-** $f_1 = \frac{v}{2L}$
- **Harmonics-** multiples of the lowest frequency

Closed pipe- odd multiples :	Open pipe- the next harmonic
$\lambda_3 \to f_3$ third harmonic ,	$\lambda_2 \to f_2$ third harmonic,
$\lambda_5 \to f_5$ fifth harmonic,	$\lambda_3 \to f_3$ third harmonic,
$\lambda_7 \to f_7$ seventh harmonic	$\lambda_4 \to f_4$ forth harmonic.

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The Physics of Music

Sound Quality (cont.)

The sound spectrum: fundamental and harmonics

- Different combinations of these harmonics give each instrument its own unique timbre (نغمة موحدة).
- Each harmonics on the instrument can have a different amplitudes as well.
- A graph of the amplitude of a wave versus its frequency is called a **sound spectrum**.

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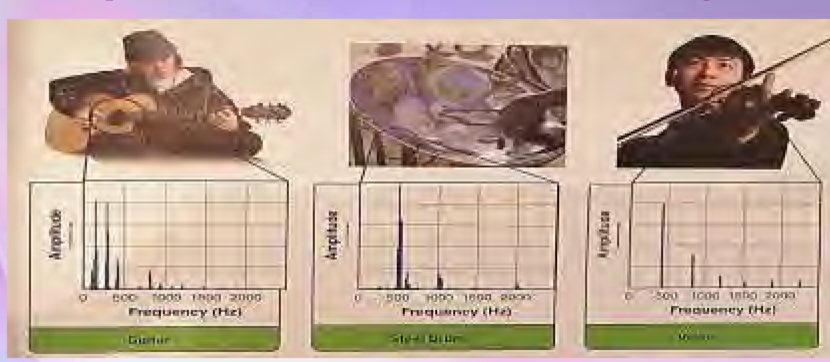
Sound Quality (cont.)

The sound spectrum: fundamental and harmonics

- The spectra of three instruments are shown in Figure:



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Sound Quality (cont.)

Consonance and dissonance التناغم والتنافر

- In musical terms, several pitches played together are called a **chord** (نغمات متآلفة).
- When sounds that have two different pitches are played at the same time, the resulting sound can be:
- **Consonance (ممتعا)**. If the combination is pleasant (pitches with small whole number ratios 1:2, 2:3 or 3:4)
- **Dissonance** (منفراً): An unpleasant set of pitches

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The Physics of Music

Sound Quality (cont.)

Musical intervals:

Octave:

- Two notes with frequencies related by the ratio 1:2
- For example, 1st note-440 Hz, octave higher would be 880 Hz
- The fundamental and its harmonics are related by **octaves**; the first harmonic is one octave higher than the fundamental, the second is two octaves higher, and so on.

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The Physics of Music

Sound Quality (cont.)

Musical intervals:

- The sum of the fundamental and the first harmonic is the ratio of two frequencies, not the size of the interval between them, that determines the musical interval.

In other musical intervals, two pitches may be close together.:

Major third:

- Two notes with frequencies related by the ratio **4:5**.
- A typical major third is made up of the notes C and E.

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Sound Quality (cont.)

Musical intervals:

Perfect Fourth:

- Two notes (C and F) with frequencies related by the ratio 3:4

Perfect Fifth:

- Two notes (C and G) have a ratio of 2:3.
- Graphs of these pleasant sounds are shown in Figure:

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Sound Quality (cont.)

Musical intervals:

- More than two notes sounded together also can produce consonance.
- The three notes called do, mi, and sol make a major chord.
- For at least 2500 years, this has been recognized as the sweetest of the three note chords; it has the frequency ratio of 4:5:6.

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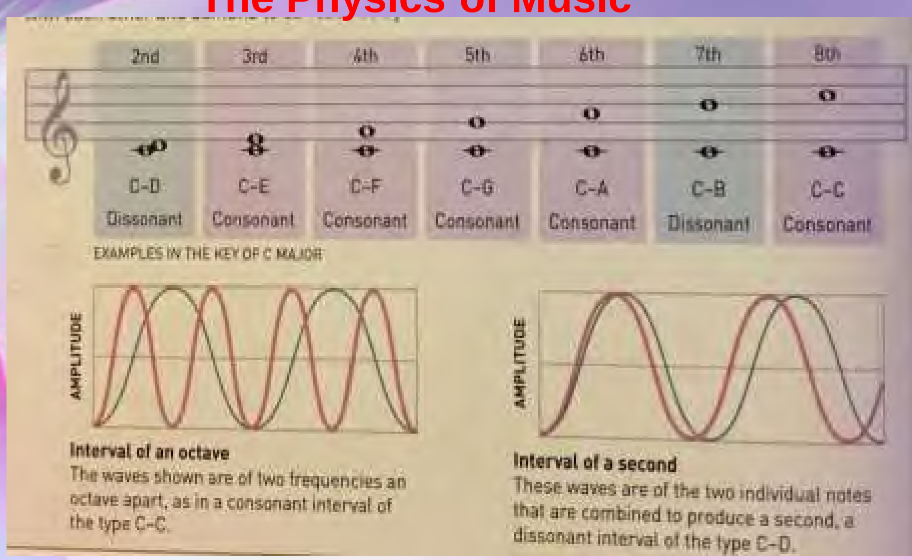

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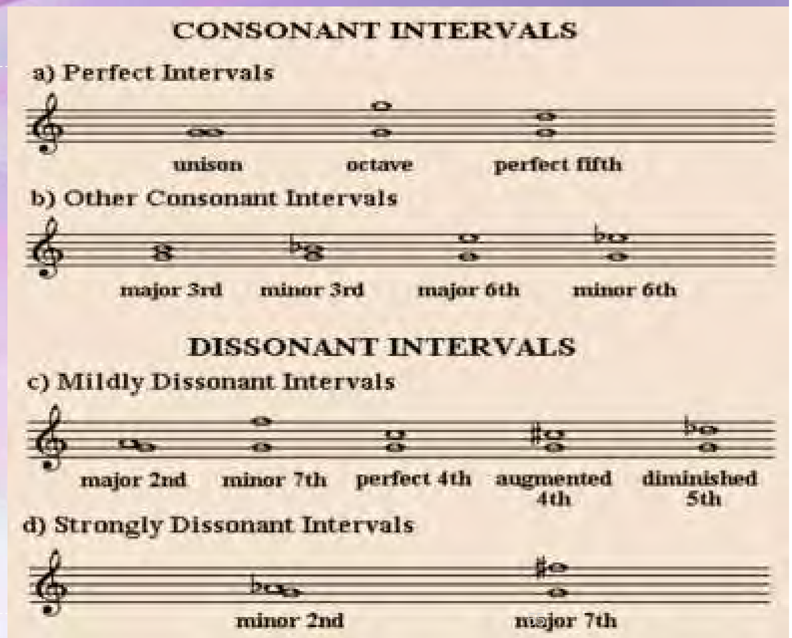

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The Physics of Music

Beats

- Two frequencies that are nearly identical interfere to produce oscillating high and low sound levels called a **beat** (الضربة)
- The frequency of a beat is the magnitude of difference between the frequencies of the two waves,

$$f_{beat} = |f_A - f_B|$$

- When the difference is less than 7 Hz, the ear detects this as a pulsation of loudness.

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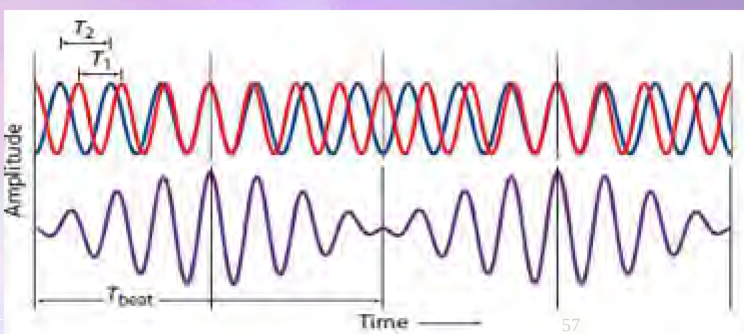
The Physics of Music

Beats (cont.)

- **Musical instruments often are tuned by:**
- **Sounding one against another** and **adjusting the frequency of one** until the beat disappears.



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Sound Reproduction and Noise

- Most of the time, the music has been recorded and played through electronic systems.
- To reproduce the sound faithfully, the system must accommodate all frequencies equally.
- Good stereo system keeps the amplitudes of all frequencies between 20 and 20,000 Hz the same to within 3 dB.
- Reducing the number of frequencies present helps **reduce the noise**

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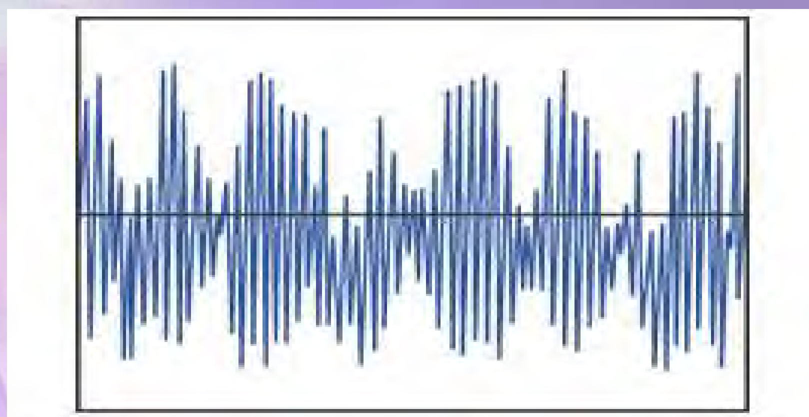
The Physics of Music

Sound Reproduction and Noise (cont.)



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The Physics of Music

Sound Reproduction and Noise (cont.)

- Many frequencies are present with approximately the same amplitude.
- While noise is not helpful in a telephone system, some people claim that listening to noise has a calming effect.
- For this reason, some dentists use noise to help their patients relax.

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Section Check

Which of the following statements about resonance in an air column is true?

A. In a closed-pipe resonator, if a high-pressure wave strikes the closed end, low-pressure waves will rebound.

B. In a closed-pipe resonator, if a low-pressure wave strikes the closed end, high-pressure waves will rebound.

C. In an open-pipe resonator, if a high-pressure wave strikes the open end, high-pressure waves will rebound.

D. In an open-pipe resonator, if a high-pressure wave strikes the open end, low-pressure waves will rebound.

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Section Check

Answer

Reason: In a closed-pipe resonator, if a high pressure wave strikes the closed end, high-pressure waves will rebound.

In an open-pipe resonator, if a high-pressure wave strikes the open end, low-pressure waves will rebound.

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Section Check

What is the length of the shortest air column in a closed pipe having a node at the closed end and an antinode at the open end?

A. one-half of the wavelength

B. one-fourth of the wavelength

C. same as the wavelength

D. double of the wavelength

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Section Check

Answer

Reason: In a closed pipe, the shortest column of air that can have a node at the closed end and an antinode at the open end is one-fourth of a wavelength.

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