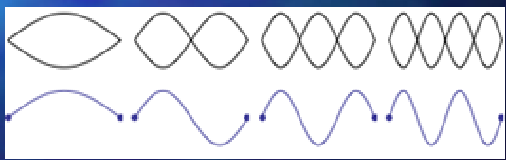
Standing Waves

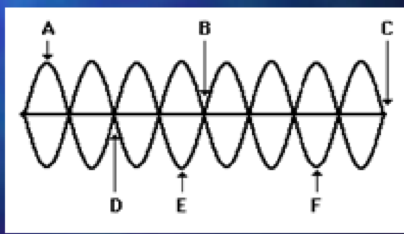
- A **standing wave** *is the result of two identical waves traveling in opposite directions. It has stationary* nodes *and* antinodes.
- Standing Waves
- Animation



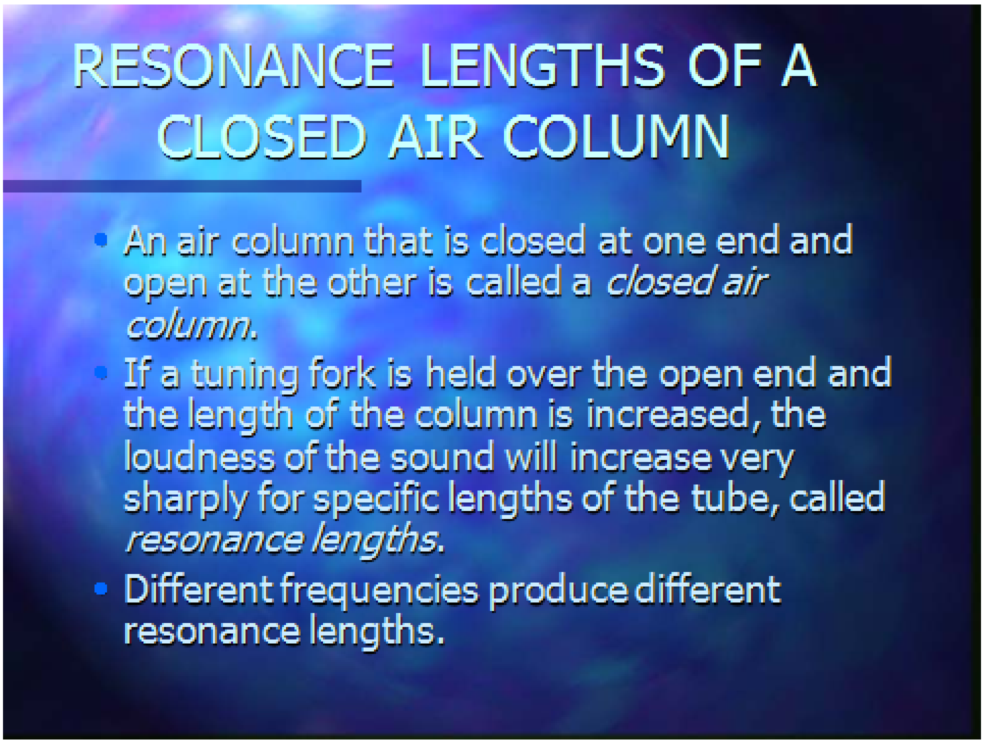
- *At a* node, *the medium is not displaced as the waves pass through each other.*

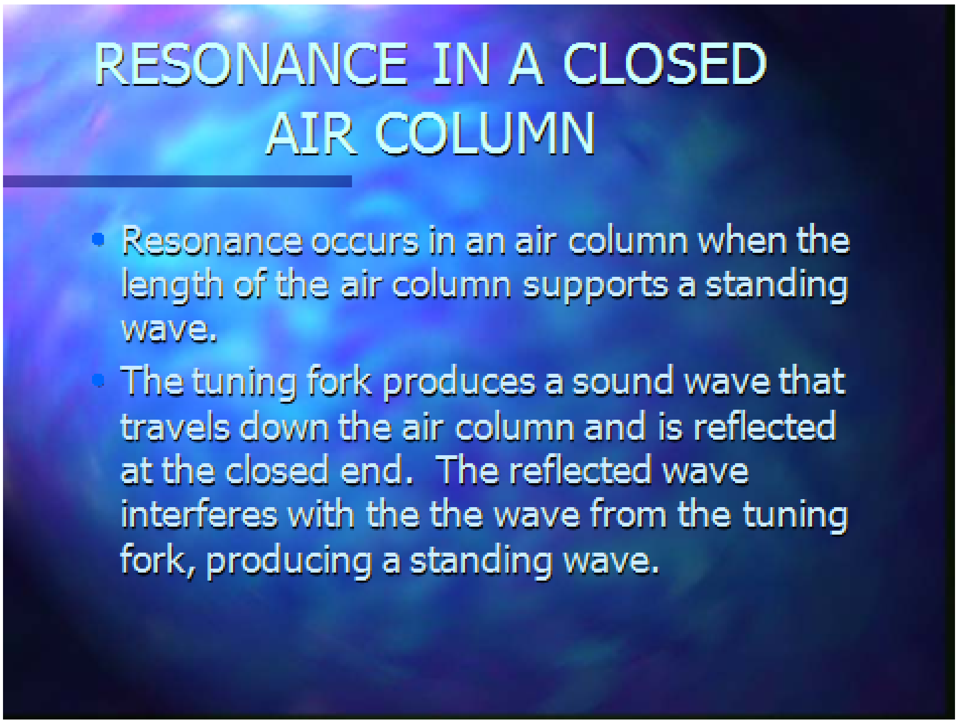
- *At an* antinode, *the displacement caused by the interfering waves is the largest.*

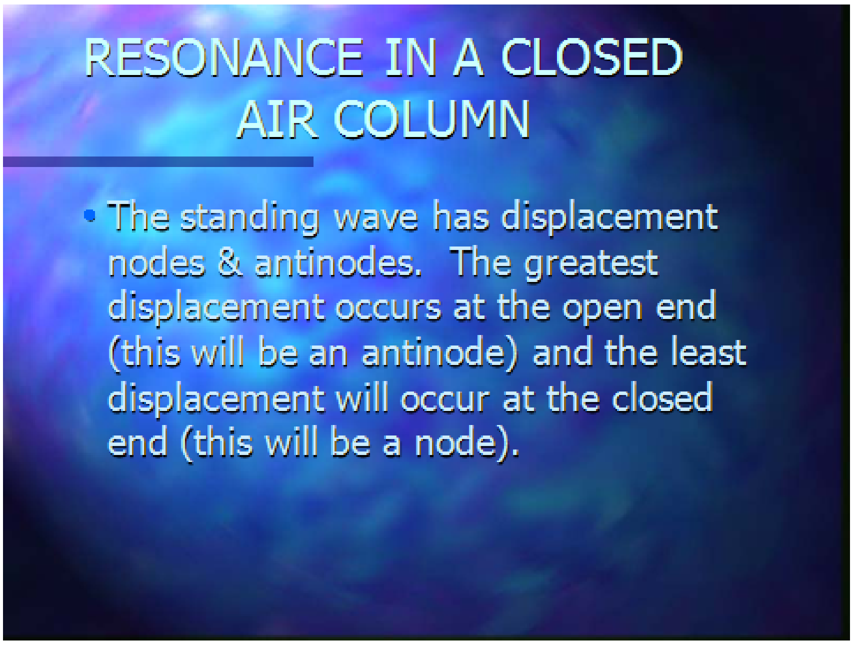
- Nodes: B, C, D
- Antinodes: A, E, F



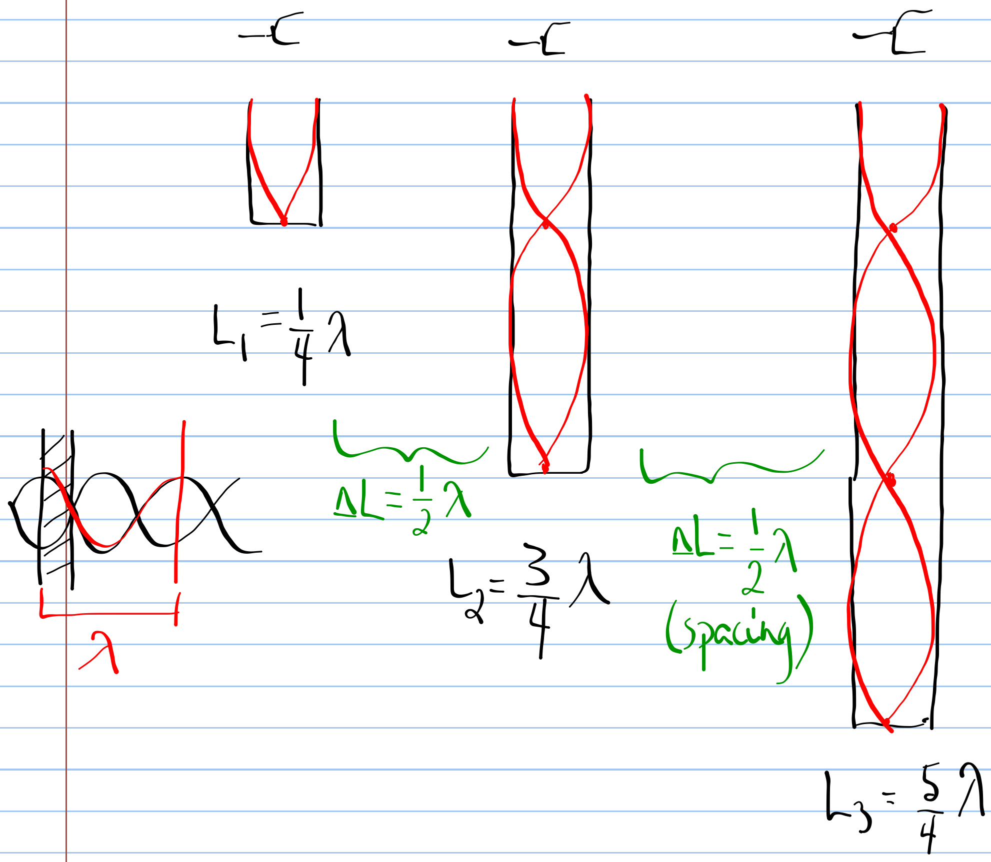
- *For every medium of fixed length, there are many* **natural frequencies** *of vibration that produce* **resonance**
- **Fundamental frequency** ~ *the lowest frequency (longest wavelength) that will produce resonance*
- **Fundamental mode** ~ *the standing wave pattern for the fundamental frequency; it has the fewest nodes and antinodes*
- **Overtones** ~ *natural frequencies higher than the fundamental frequency*


RESONANCE LENGTHS OF A CLOSED AIR COLUMN
An air column that is closed at one end and open at the other is called a *closed air column*.
If a tuning fork is held over the open end and the length of the column is increased, the loudness of the sound will increase very sharply for specific lengths of the tube, called *resonance lengths*.
Different frequencies produce different resonance lengths.


RESONANCE IN A CLOSED AIR COLUMN
Resonance occurs in an air column when the length of the air column supports a standing wave.
The tuning fork produces a sound wave that travels down the air column and is reflected at the closed end. The reflected wave interferes with the the wave from the tuning fork, producing a standing wave.


RESONANCE IN A CLOSED AIR COLUMN
• The standing wave has displacement nodes & antinodes. The greatest displacement occurs at the open end (this will be an antinode) and the least displacement will occur at the closed end (this will be a node).

Resonance in a Closed Tube



Shortest resonance length is $L_1 = \frac{1}{4}\lambda$

Spacing: $\Delta L = \frac{1}{2}\lambda$

RESONANCE IN A CLOSED AIR COLUMN

- The shortest tube that can have an antinode at one end and a node at the other is 1/4 of a wavelength
- Lengthening of the tube will give additional resonances for a given frequency (3/4 λ, 5/4 λ, 7/4 λ etc)
- The spacing between two successive resonances is 1/2 of a wavelength

RESONANCE IN A CLOSED AIR COLUMN

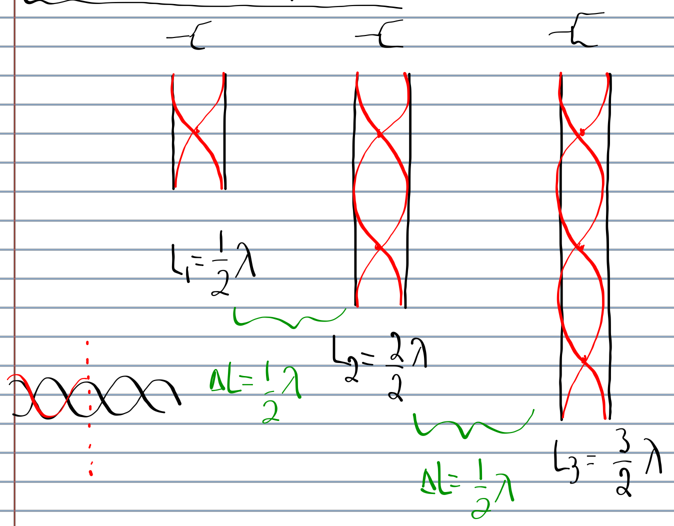
- Resonance lengths of a closed air column:

$$L_n = (2n-1)\frac{\lambda}{4}$$

- Resonance frequencies of a fixed-length closed air column:

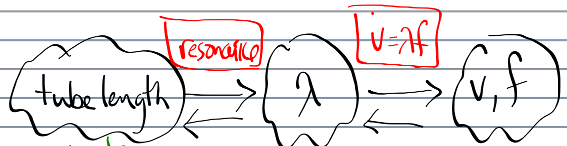
$$f_n = (2n-1)f_1$$

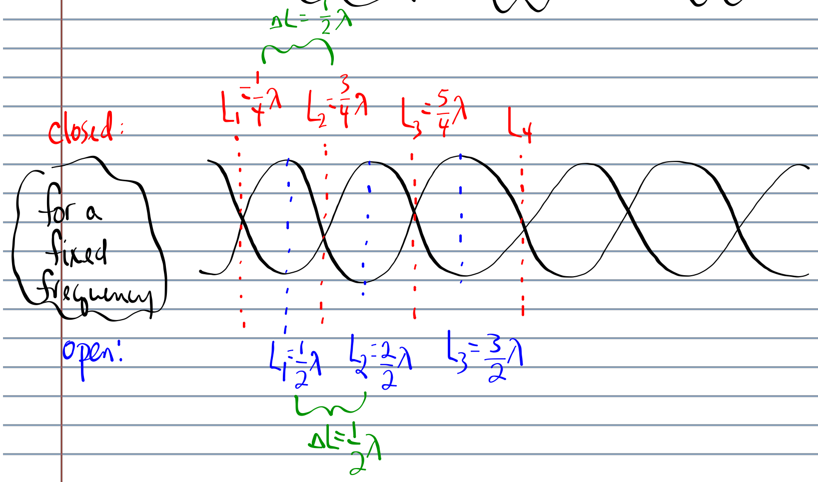
Resonance in an Open Tube

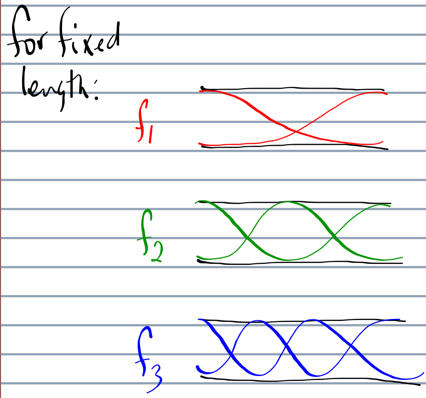


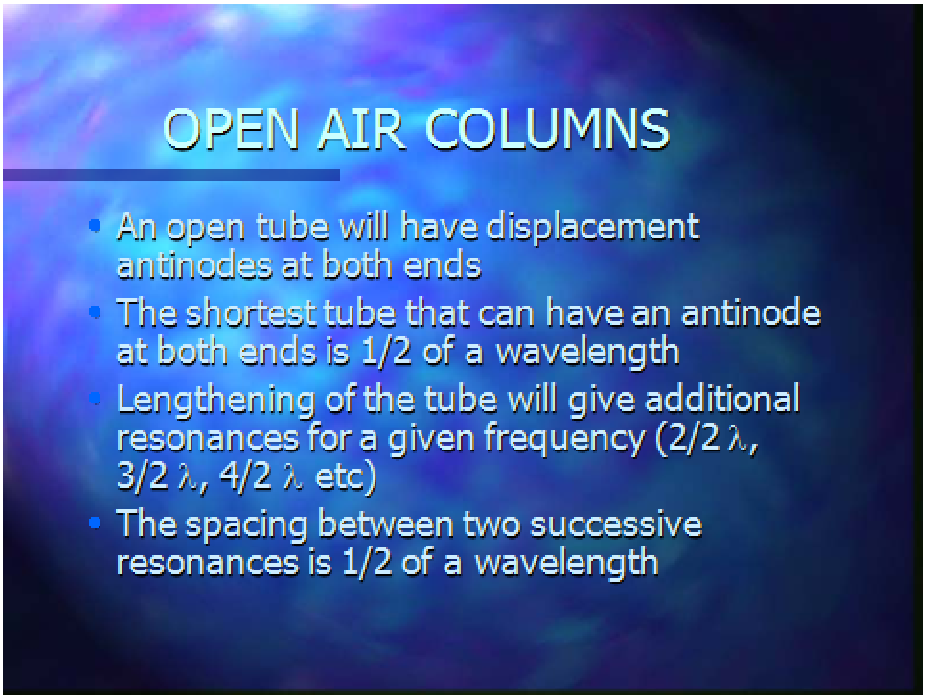
Shortest tube length: $L_1 = \frac{1}{2}\lambda$

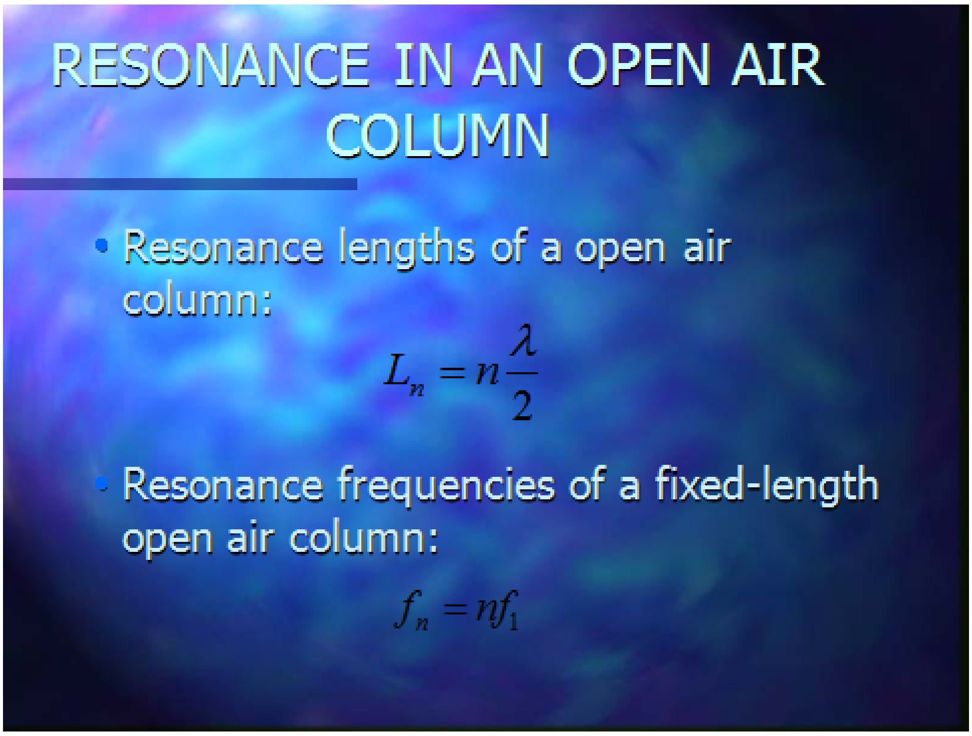
Spacing: $\Delta L = \frac{1}{2}\lambda$



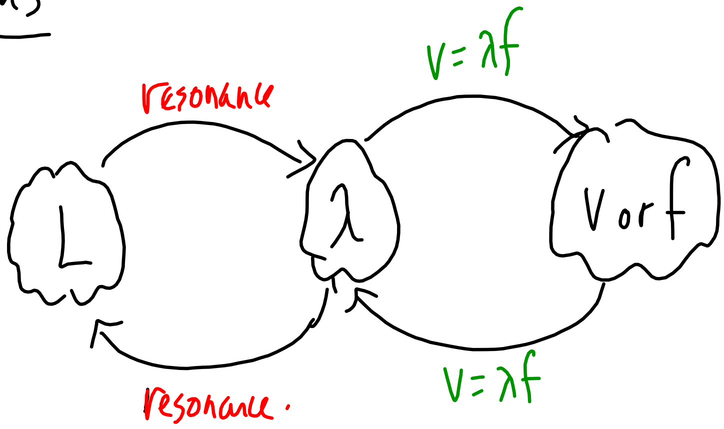





OPEN AIR COLUMNS
An open tube will have displacement antinodes at both ends
The shortest tube that can have an antinode at both ends is 1/2 of a wavelength
Lengthening of the tube will give additional resonances for a given frequency (2/2 λ, 3/2 λ, 4/2 λ etc)
The spacing between two successive resonances is 1/2 of a wavelength


RESONANCE IN AN OPEN AIR COLUMN
Resonance lengths of a open air column:
$L_n = n\frac{\lambda}{2}$
Resonance frequencies of a fixed-length open air column:
$f_n = nf_1$

Resonance Problems



Example

$L_1 = 9.0\text{ cm}$ (closed)

$T = 20°C \Rightarrow v = 343\text{ m/s}$

a) $\lambda = ?$

b) L_2 and $L_3 = ?$

c) $f = ?$

a) $L_1 = \frac{1}{4}\lambda$

$9.0\text{ cm} = \frac{1}{4}\lambda$

$\lambda = 36\text{ cm}$

b) $L_2 = \frac{3}{4}\lambda$

$L_2 = \frac{3}{4}(36\text{ cm})$

$L_2 = 27\text{ cm}$

$L_3 = \frac{5}{4}\lambda$

$L_3 = \frac{5}{4}(36\text{ cm})$

$L_3 = 45\text{ cm}$

c) $v = \lambda f$

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

$f = \frac{343\text{ m/s}}{0.36\text{ m}}$

$f = 9.5 \times 10^2\text{ Hz}$

Examples of Resonance

Barton's Pendulum - the pendulum that is the same length (i.e. has the same natural frequency) as the driven pendulum, has the largest amplitude.

Resonance in machinery (vehicle on a dirt road)

- loose components in the moving vehicle can vibrate and can do so with a large amplitude if their natural frequency is equal to the frequency of the car's vibration over the bumps.

(fasten loose things down!)

Singing Wine Glasses.

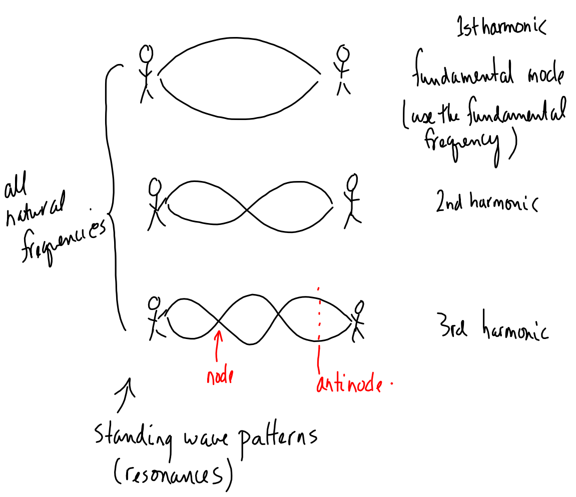
- the wine glass resonates with the periodic driving force (running your wet finger around the rim of the glass)
- opera singers can break glass!

Mechanical Structure

- structures like building + bridges must be strengthened to prevent damage due to resonance.
- strong winds / earthquakes can act as the driving force and the structure may resonate!
- resonance should be avoided
- Tacoma Narrows Bridge

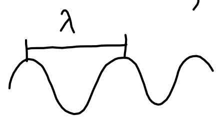
Music

- organ pipes, trumpets, bugles wind chimes (air vibrates in a tube with a resonant frequency)
- string instruments (piano, guitar, violin etc) (string that vibrates with a resonant frequency)



Microwaves

- water molecules have a natural resonant frequency of 2450 MHz
- microwaves are electromagnetic waves (wavelength λ is around 1cm or $f \approx 10^{10}$ Hz)



- microwaves are reflected by metal surfaces and can form standing waves
- microwave is designed to resonate the microwaves as they are radiated from the magnetron tube.
- microwaves are absorbed by the water molecules in the food and cause the electrons to oscillate.
- producing kinetic energy -> food gets hot.
- microwaves are useful!

Electrical resonance

- radio signals <-> frequencies must match (tuner used to match)

103.1 MHz
103.1×10^6 Hz

Quartz Oscillators

- quartz is a material that exhibits the piezoelectric effect.
- pressure on a quartz crystal causes one side to become positive + the other negative.
- used in AC circuit => resonance occurs in the circuit when the oscillating voltage matches the natural vibration of the crystal.
- used in microphones, + pressure sensors
- very precise (used in electronic clocks + watches)

Greenhouse Effect.

- resonance within the greenhouse gases like CO_2.