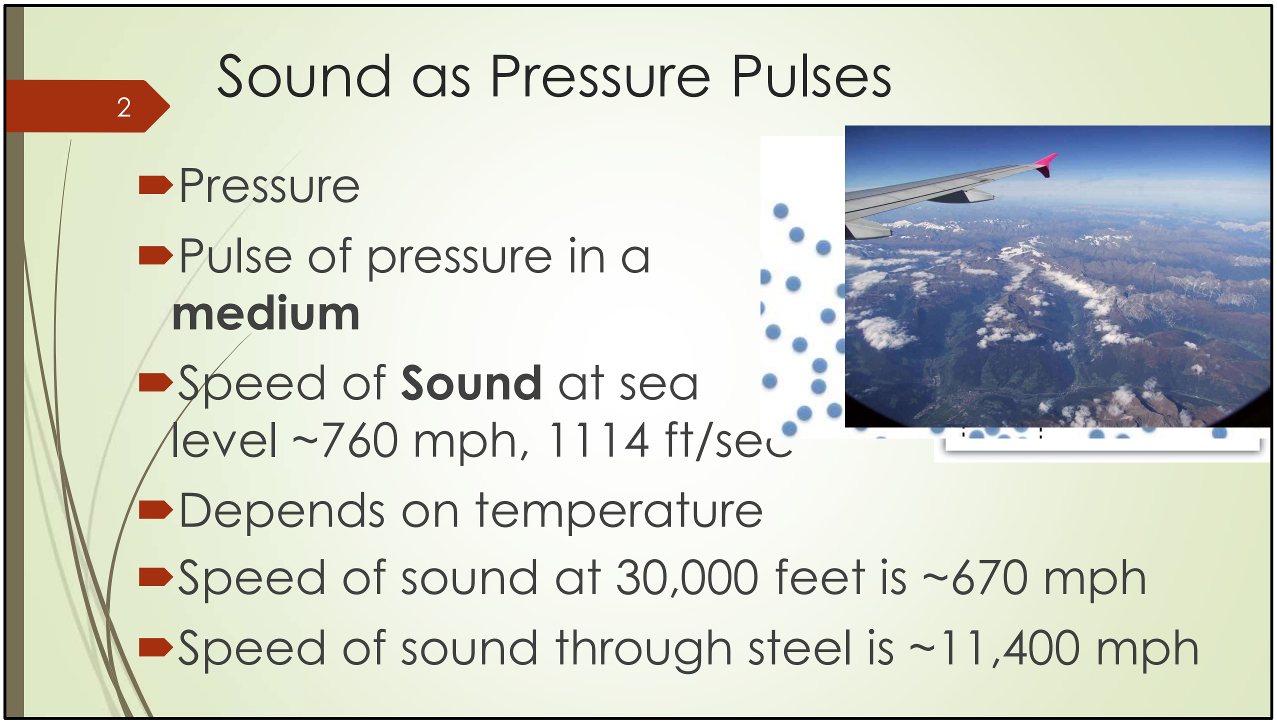
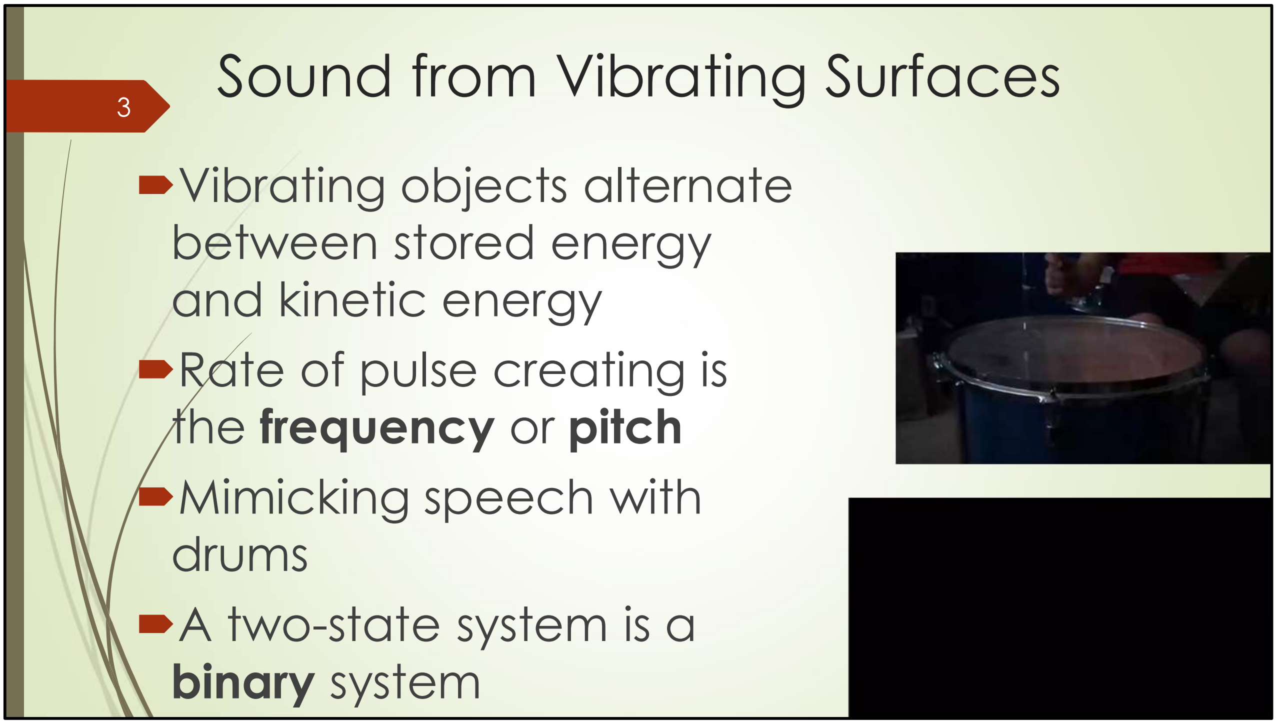
Communicating with Waves

John Michael Preston

While steam powered the industrial revolution, knowledge of waves created the communications revolution. In this session, we look at the nature of waves of air, water, electricity, magnetism, and light and how they are used to communicate.



*Recall that a gas consists of particles that move independently with a variety of speeds and directions and that pressure is the effect of those particles on their neighbors or on a container wall.
*Sudden motion of an object surrounded by air can cause a pulse of energy in the form of collisions between particles to propagate through the air. The material through which the pulses travel is the **medium**
*The individual particles only travel far enough to collide with their neighbors, but the pulse of pressure moves through the medium. We know this type of pressure pulse in air as **sound**. The speed of air particles at 70 degrees F is about 760 mph which is known as the **speed of sound**.
*At lower temperatures, the speed of sound is slower. *For example, at 30,000 feet altitude where jet airliners fly, the temperature is about -60 degrees F, and the speed of sound is about 670 mph.
*Pulses of sound pressure move through rigid solids faster than gasses. For example, the speed of sound through steel is about eleven thousand mph



Recall that energy can transfer back and forth between motion and storage like the gymnast on the trampoline. Any object that can vibrate back and forth, like a drumhead, can produce a series of energy pulses in the air.

*The rate at which the surface vibrates and produces pressure pulses is called its **frequency** which is described as vibrations per unit of time. If the drumhead is tightened, it vibrates faster, producing a higher frequency or pitch.

The Ashanti language uses two pitches and words can be represented by two drum pitches. (The video makes reference to high and low pitch that don't match the demonstration)

*When a communication system uses only two states, it is called a **binary** system.

Communicating Emotion with Sound

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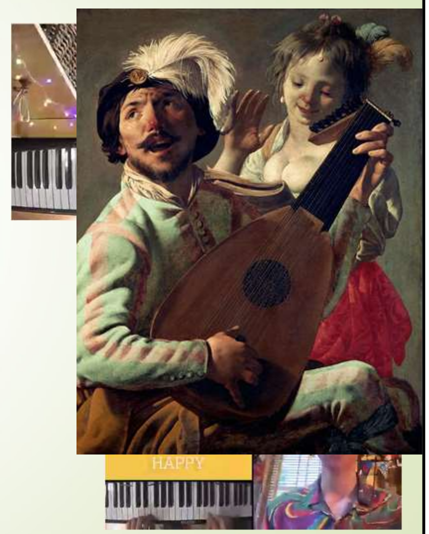
- Music and emotion
- Evoking emotion with intervals, chords and volume



*Musical instruments have been used for thousands of years to communicate emotion.
Certain intervals between pitches, combinations of pitches, and volume can evoke a variety of emotions. (see the references links at the end of this presentation)
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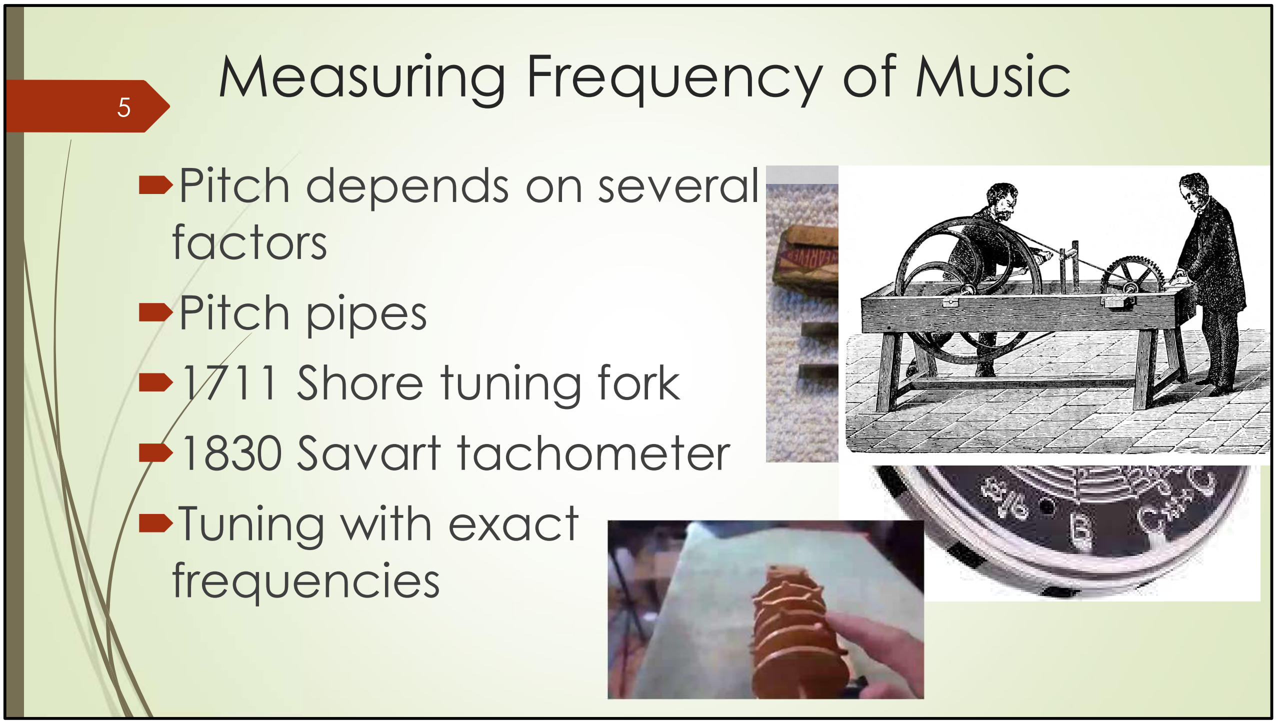

*The pitch or frequency of sound depends on the rate of vibration. Changes in temperature or humidity can alter the rate of vibration which makes it difficult to produce the same pitch each time.
*An early method of providing standard pitches was the use of a set of whistles, called pitch pipes. They can be cylinders of different length or * different size cavities within a round disk. Pitch pipes will change pitch slightly with changes in temperature.
*A better device called a **tuning fork** was invented in 1711 by John Shore who played trumpet and lute for the English royal court.
*In 1830, Felix Savart invented a machine that turned a toothed wheel that plucked a card. By using pulleys and gears connected to the wheel and then measuring the angular frequency of the wheel, close measurement of frequencies was possible. *
*Once frequencies could be measured, the issue of equal tempered musical scales could be addressed with greater precision.

Standard Pitches

- Pythagoras, Hippasus
- Equal temperament, equal multiples $\sqrt[12]{2}$
- Twelfth root of 2; **1.059463**
- 440 times 1.059463 twelve times equals 880
- Chords are slightly off

Pythagorean		Equal-tempered	
Note	*Hz*	*Note*	*Hz*
C	523.25	C	523.25
B	496.67	B	493.88
B^b	465.12	$B^b/A^\#$	466.16
A	441.49	A	440.00
A^b	413.42	$A^b/G^\#$	415.30
G	392.44	G	392.00
$F^\#$	372.52	$G^b/F^\#$	369.99
F	348.83	F	349.23
E	331.11	E	329.62
E^b	310.08	$E^b/D^\#$	311.13
D	294.33	D	293.66
$C^\#$	279.39	$D^b/C^\#$	277.18
C	261.63	C	261.63

*Recall that Pythagoras attempted to create a scale of twelve intervals between octaves using ratios of whole numbers like fifths and thirds, but his 12 intervals weren't equal multiples of the lower pitch, so they weren't equal. Also recall that his student, Hippasus, demonstrated that ratios of whole numbers were not sufficient to represent all relationships and made the case for irrational numbers like the square root of 2.
*To make a scale of twelve intervals that always add up to an octave (2x lower pitch) requires that each pitch be the same multiple higher than the one below (not the same number of vibrations). The correct number by which to multiply must be one that, when multiplied by itself twelve times equals 2.
*In other words, the twelfth root of 2.
*To calculate the pitch of the next note in an equally tempered scale, you multiply the frequency of its predecessor by the twelfth root of 2 which is about 1.059463. If this process is repeated twelve times you get a pitch that is exactly twice as high.
*This method yields octaves that are exactly double the frequency apart but the intervals for the other chords are not exactly right. *For example, the ratio of a perfect fifth is 3:2. *If the higher note is 440, *the lower note should be 293.33. On an equally tempered scale, it is 293.66; a small difference that usually goes unnoticed.

Standard Tuning

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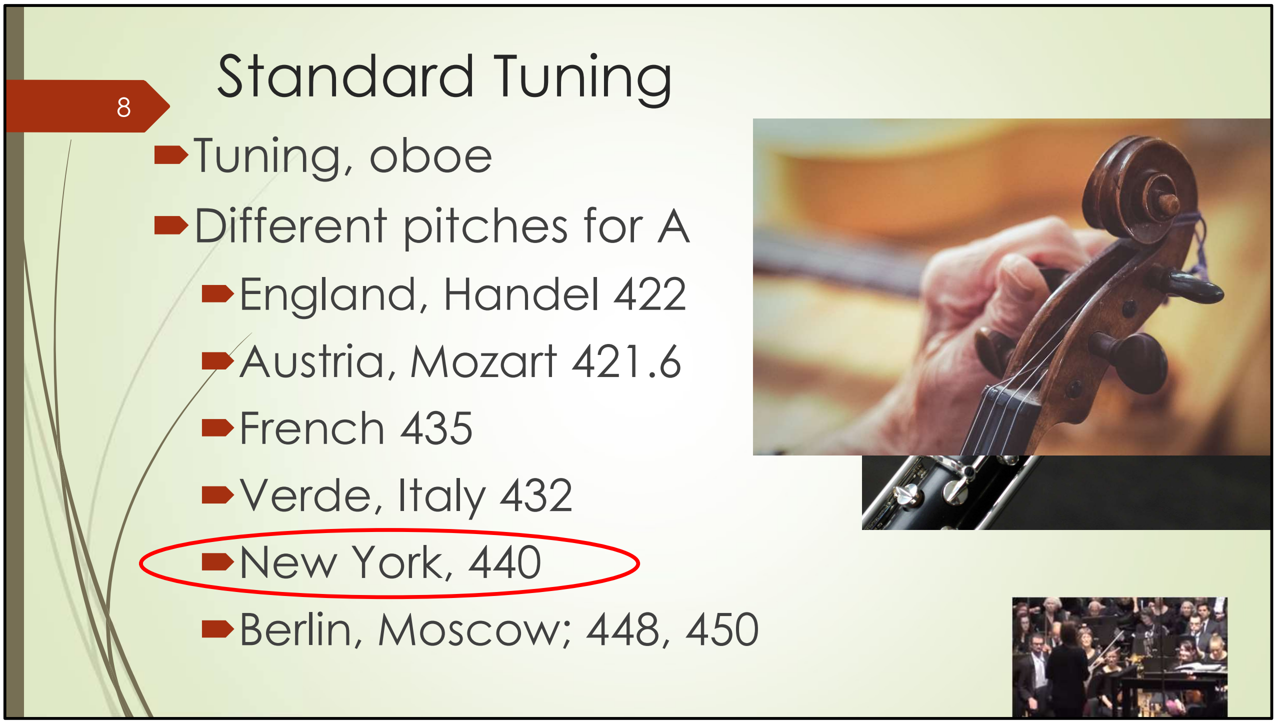
- Music notation
- Violin strings
- Orchestras tuned to A

*Pitches can be represented on paper as dots whose vertical position on the page corresponds to differences in pitch.
*The Romans only had seven letters; A-G, which were assigned to seven pitches and then repeated.
*The pitch that all the string instruments in an orchestra have in common is A
* so it is used as the common pitch for all the instruments in the orchestra to tune to.



*Strings were made from animal fiber and their pitch is affected significantly by changes in humidity and temperature so they must be adjusted for each new environment. *The oboe creates vibrations with a reed that is inserted in the mouth of the musician where there is a constant humidity and temperature and therefore less change from day to day. Different reeds might play slightly higher or lower pitches but the oboe itself does not have a pitch adjustment. It became customary to have the oboist play an A to which the orchestra tuned.*

*When steam power revolutionized travel, musicians and their instruments could travel easily between cities and the musicians discovered that orchestras in other countries tuned to different pitches for A. *In 1938, an international standard of 440 was adopted.

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Standard Tuning

- 432 vs. 440
- The second case was tuned to 432

*There is still controversy over what pitch should be used as a standard when trying to perform music that was written by famous composers for a different pitch. See if you can tell the difference. Which of these two samples is tuned lower, to 432 instead of 440. *Did you like one better than the other?.**
*The second is tuned to 432

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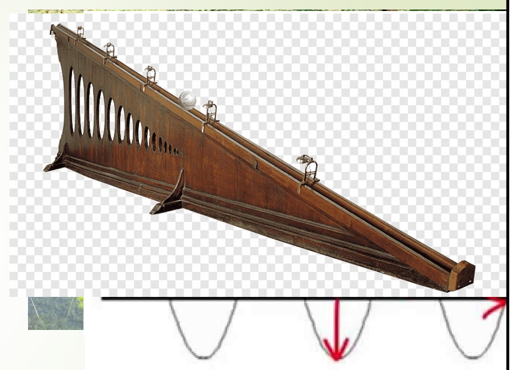
Visible Waves

- Sound waves are **longitudinal** waves
- Galileo slowed gravity, water waves are slower
- Water waves are **transverse** waves



*Sound waves are difficult to study because they move at high speed in a transparent medium and the waves consist of compression and rarefication along the direction of travel. This type of wave is called a longitudinal wave.
*Recall that Galileo slowed down the acceleration of gravity using an inclined ramp so he could study it more conveniently. *We will study waves in the surface of water that are much slower and easier to see. Fortunately, water waves have the same basic properties of all waves, including those that are very fast or invisible.
*Waves that occur at the surface of liquids where the wave motion is up-and-down are called **transverse** waves where their motion is at right angles to the direction of propagation.

Wave Measurements

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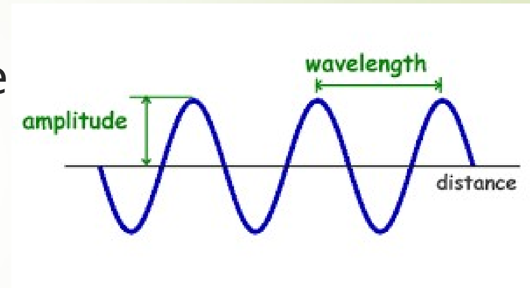
- Rate of creation is the **frequency**, F
- Time between waves is the **period**, T
- Distance between crests (or troughs) is the **wavelength**, λ
- **Amplitude** is the height
- **Speed** = F * λ or λ/T



*Repetitive disturbances in a body of water produces waves that are repetitive. The rate at which the waves are created is the **frequency**, represented by the letter f and
*the time elapsed between waves is the **period**, represented by the letter T.
*Frequency and period are inverses of each other. *For example, if the frequency is 10 waves per second, the period is 1/10 second per wave.
*The distance between similar parts of each wave such as the crests, is the **wavelength**. It is represented by a lower-case Greek letter, lambda
*The height of the wave is the amplitude
*The speed equals the wavelength times the frequency or the wavelength divided by the period

There are five wave properties that are important to know to understand how waves created a communications revolution. They are:

*Reflection
*Interference and standing waves
*Diffraction
*Refraction
*Internal reflection

Reflection

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- **Reflection**
- Ripple tank
- At the same angle

*If the media in which the wave occurs has a boundary, the wave can **reflect** or bounce off the boundary.*
To study water waves indoors, a ripple tank is used. A ripple tank has a shallow pool of water with a glass bottom and a light above. It has a piece of wood that moves up and down to produce straight waves. Waves in the tank cast shadows on a screen below. In the following video a barrier that extends above water level appears as a dark bar.
If the waves strike the barrier at an angle, the angle at which the waves reflect is the same, coming and going.

Interference

- Momentum is a vector
- Momentum can add to zero
- **Constructive** and **destructive** interference
- Transverse waves can pass through each other and produce the appearance of **standing waves**
- **Nodes** and **antinodes**

*Recall that momentum is a vector which means that a wave is the vector sum of the momenta of all the small particles of which it is composed.
Just like Newton's cradle, momenta in opposite directions can appear to pass through some particles that don't move.
*If the momentum vectors are in the same direction, they add together which is called **constructive interference**. If they oppose each other, they might add to zero which is called **destructive interference**.
*Transverse waves on a string moving in opposite directions can pass through each other where some spots on the string don't move. The pattern appears to be standing still and the effect is called a **standing wave**.*
*The points that don't move are called **nodes** and the parts between them that move the most are **antinodes**.

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Quantized Wavelengths

- Some things only come in integer multiples, e.g. children
- If only integer multiples are allowed, the behavior is **quantized**
- Only integer multiples of a half-wavelength will fit (1/2, 2/2, 3/2, 4/2…)

*The average number of children per family in the US might be 1.93 but we all know that children come in multiples of integers, e.g. 1,2,3, etc.
*If only integer multiples are allowed, we say something is **quantized**
Only integer multiples of the fundamental frequency will form standing waves

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Harmonics and Chords

- Several waves can share the same medium
- Shorter waves are called **harmonics**
- Chords
- Pythagoras was also right
- Equally tempered scales are a compromise

Pythagorean		Equal-tempered	
Note	*Hz*	*Note*	*Hz*
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B^b	465.12	$B^b/A^\#$	466.16
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D	294.33	D	293.66
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*Several different waves can exist at the same time in the same medium.
*The shorter standing waves that also fit on the string are called **harmonics**. They give each instrument its characteristic sound.*
When two notes are played together that have common harmonics, it "sounds right". These combinations are played as chords.
*Even though Hippasus was right about the need for irrational numbers to create an equal tempered scale, Pythagoras was also right. The chords that sound right are have integer multiples of the fundamental wavelength in common.
*Tuning a piano to equal multiples of the twelfth root of two (equal temperament) avoids the problem of the wolf fifth but it is a compromise that makes the chords slightly out of tune. *For example, if the higher note in a perfect fifth is 440, *the lower note should be 2/3 that frequency or 293.333, but if we use an equally tempered scale, the note is 293.66. This small difference usually goes unnoticed.

Interference from Two Overlapping Sources

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- Nodes occur where the wave momentum is zero

*If there are two sources of waves, they can interact to create a pattern of nodes and antinodes. Areas where crests from one source arrive when the troughs from the other arrive are nodes where the water is still. *

Diffraction

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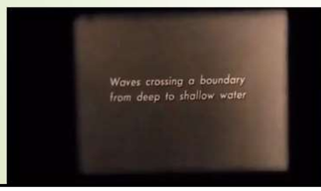
- Each segment of a wave front is composed of circular waves
- Beach erosion patterns
- Waves passing through an opening behave as a source of circular waves that bend round corners

*Waves passing through a barrier demonstrate how straight wave fronts are the sum of many circular waves. If a small portion of the wave front is allowed through a barrier it behaves like a point source of circular waves. This effect explains why sounds can be heard around a corner. This property is **diffraction**.
*Ocean waves diffract around offshore barriers and affect the shape of beaches
*Waves bend around barriers like these islands. The depth of the water is not a factor.

Wave Refraction in a Slower Medium

- Change of direction due to a change of speed is **refraction**
- Waves move slower in shallow water.
- Wavelength shortens as waves slow down
- Refraction and reflection



*Refraction** is a change in direction of the waves due to a transition from one media into another where the waves move at different speed.
*When waves travel from deep (fast) into shallow (slow) water, the direction becomes more perpendicular to the transition boundary
*In the following video of waves in a ripple tank, the thick black shadow is caused by a barrier that extends above the water surface. At the bottom of the screen is an area where a glass plate, supported by two round pegs creates shallow water. Its edge is below the surface. Notice how the wavelength shortens as the waves slow down in the shallow water.
*When the waves encounter the shallow water at an angle, the direction changes to become more perpendicular to the edge of the shallow water and some of the waves reflect creating an interference pattern of squares, even though the edge is entirely below the surface.

Refraction when Speed Increases

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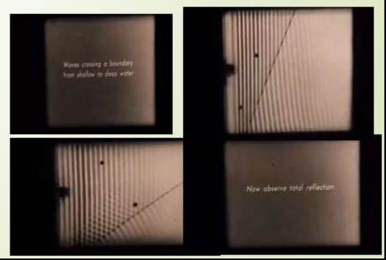
- Abrupt change to deeper, faster water, wavelength increases
- Waves become more parallel to the underwater edge
- At the **critical angle**, refracted waves are parallel to the edge
- Beyond the critical angle, all the waves are reflected
- Key to global communications



When the water gets deeper abruptly at an underwater edge and the speed increases, the waves lengthen.

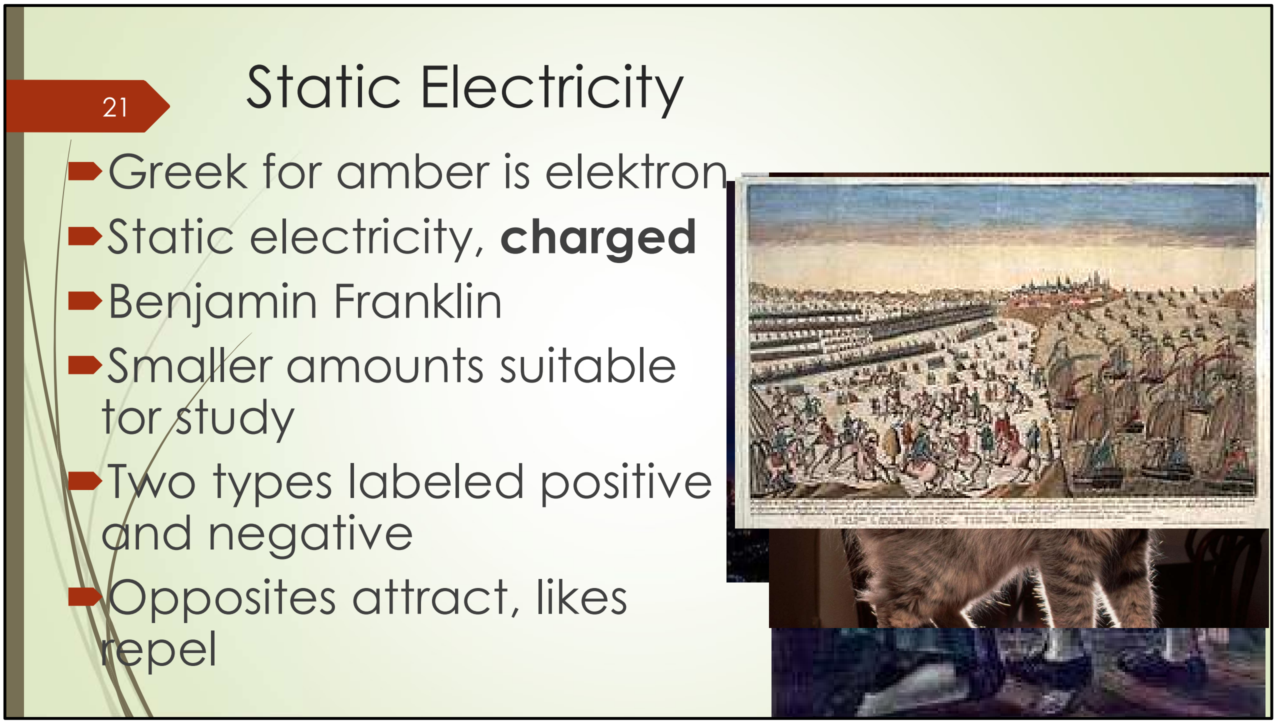
* If the waves encounter the deeper water at an angle, their direction of propagation becomes more parallel to the edge.*

At the critical angle the refracted waves are parallel to the edge and the reflection is strong

At a sharper angle than the critical angle, all the wave energy is reflected, even though the edge of the barrier does not extend above the surface.

*Total internal reflection explains why the surface of a fish tank appears to reflect like a mirrow when viewed from below

*The property of total internal reflection from the boundary of two media of different speeds is a key factor in our global communications network that will be explained later.



Now that you know several properties of water waves, we can recognize those same properties in other media where the waves might be longitudinal, invisible, extremely small, or extremely fast such as the waves associated with electricity and magnetism.
*Ancient Greeks recognized that amber had a special property that could be invoked by rubbing it with wool. The Greek word for amber is elektron and this property is called electricity.
*This type of electricity could build up and then jump, creating sparks, so it is called **static electricity** which means *not moving.* An object with a surplus of electricity is **charged**.
*For centuries, people speculated that lightning was the same effect but on a larger scale.
*This was proven by Benjamin Franklin in 1752. *This discovery made Franklin world famous and was an important factor in his acceptance at the French court, and ultimately with the French helping win our freedom from England.
In the mid-1700s, several inventors devised methods of producing smaller amounts of static electricity in the laboratory where it could be studied safely.
*Studies revealed that electricity came in two types that could be separated. The two types were labeled positive and negative because equal amounts added up to zero effect. They also observed that objects with the same type of charge repelled and that opposites attract, like the different charges on a balloon and cat hair

Magnetism

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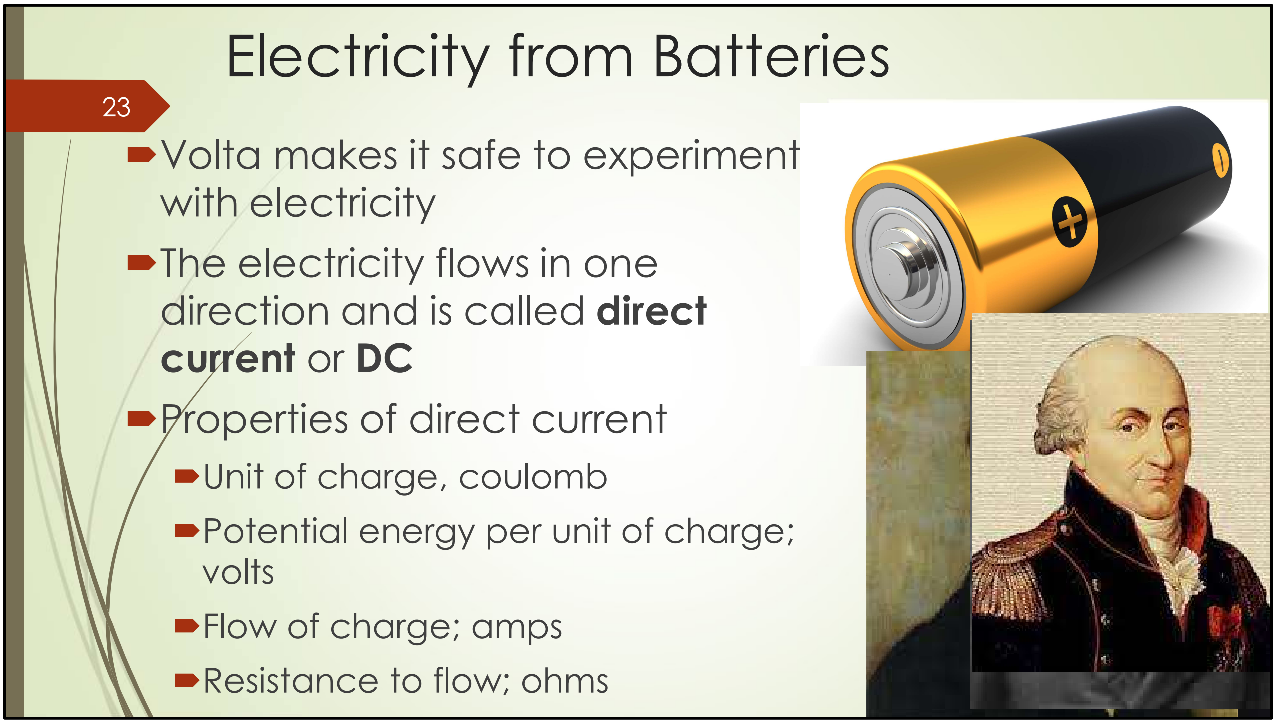
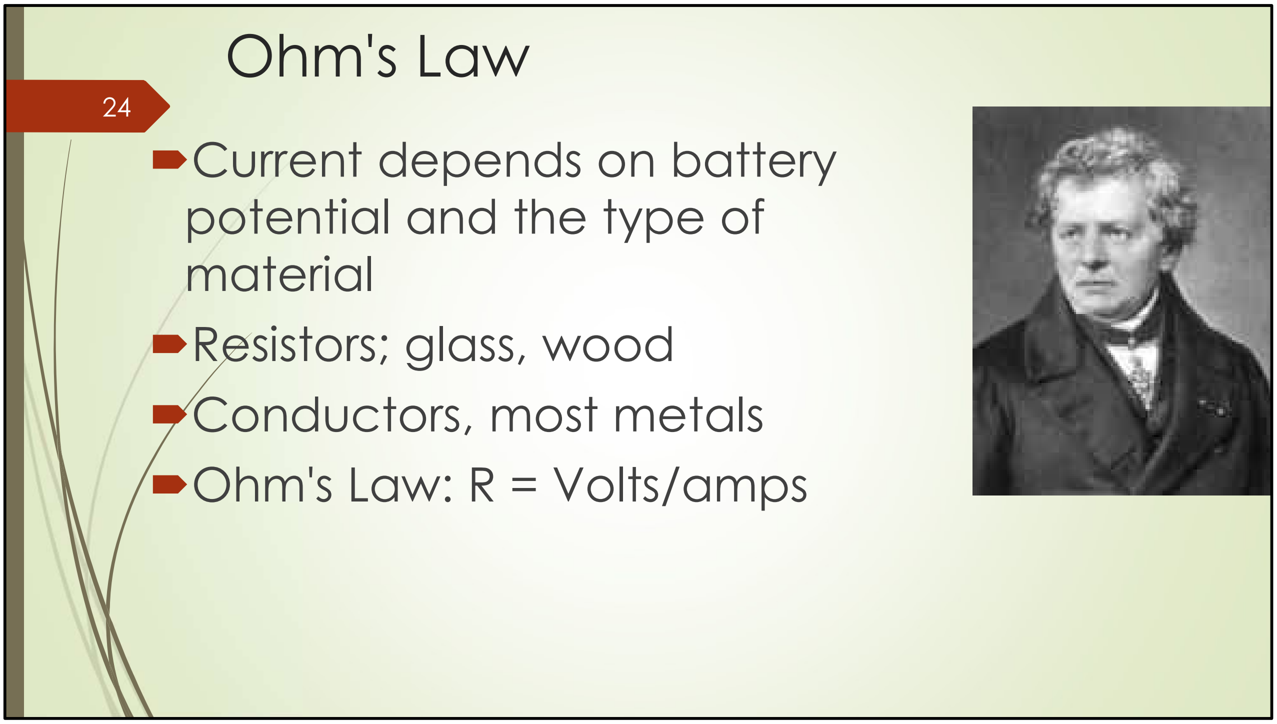
- Magnetism
- Static force on iron and nickel
- Properties of magnets
  - Iron, nickel, or cobalt
  - Aligns North/South
  - **Induction**
  - Pair of poles
  - Attraction in pairs

*The Greeks were also familiar with an unusual stone that is rich in iron that derives its name from the region of Magnesia on the eastern coast of Greece. *Unlike lightning, natural magnets could be used and studied safely. *The following properties were observed:
*Only materials that contain Iron, nickel, or cobalt can be magnets.
*If allowed to rotate freely, a long magnet will align itself north and south and might be used for navigation, i.e. a compass
*A strong magnet can temporarily magnetize another piece of iron or steel (steel is mostly iron). This property is called **induction**
*Magnets always have two ends labeled North and South. Like poles repel and unlike poles attract, and *two magnets will pair up with opposite poles next to each other



*In 1800, another type of electricity was discovered when Count Alesandra Volta observed that *electricity would flow safely from a sandwich of different metals called a battery. The electricity flowed continuously and is called **direct current** or DC. *The two sides of the battery were labeled positive and negative.
*The units of measurement of electricity bear the names of the scientists who discovered their properties
*A unit of surplus charge is 1 coulomb (Charles-Augustin Coulomb)
*The potential energy per unit of charge is the volt
*The flow of a unit of charge per second is an ampere or amp (Andre-Marie Ampere)
*The resistance to current flow is the Ohm (Georg Ohm)



*Georg Ohm, recognized that the amount of current that flowed in a DC circuit depended on the energy of the battery and the type of material through which it flowed.

*Materials that resisted the flow of current like glass and wood were called **resistors** or **insulators**

*Materials that had little resistance, like most metals, were called **conductors**

*****Ohm observed that the resistance of a material was the ratio of the potential of the battery measured in volts to the current, measured in amperes

Electricity Creates Magnetism

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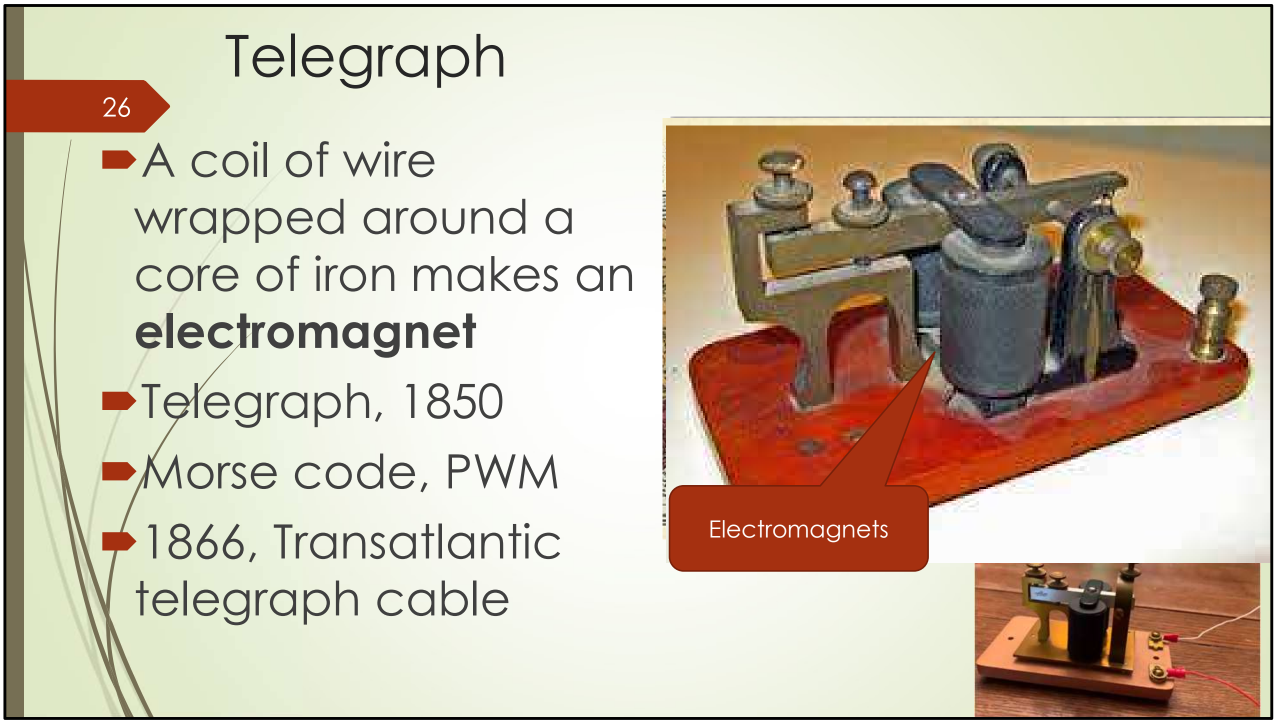
- Ørsted, 1820, Electric current creates magnetism
- Moving electric charge creates magnetism
- Reversing the direction of current reversed the magnetic polarity

*In 1820, Hans Christian Orsted discovered that electricity and magnetism were related by motion. *He connected a wire to a battery and the moving current created magnetism that could deflect a compass needle. *Reversing the current reversed the direction of the magnetism and he could turn the magnetism on and off by controlling the connection to the battery.



*If the wire was insulated so the wires can touch each other and be closer together, and then wrapped around a bar of unmagnetized iron, the magnetic force from an electric current in the coil could induce the inherent magnetism in the iron to appear and form a strong **electromagnet**. Unlike a permanent magnet, an electromagnet could be turned on and off.
This effect was used in 1850 to make a loud click by pulling down a bar of iron attached to a spring in response to an electric current to invent the telegraph sounder.
*These clicks could be used for communications using a code such as Morse code. Morse code uses long and short pulses of direct current to produce clicks separated in time. This type of encoding is called **pulse width modulation**, or **PWM**
*The sender and receiver of an electric telegraph could be about ten miles apart and communicate with each other in code. It was commonly used to coordinate train traffic.
*Improvements in wires and more powerful sources of direct current made it possible to communicate across the ocean by undersea cable. Instead of waiting for days to get news by ship, it took only seconds by telegraph.

Telephone

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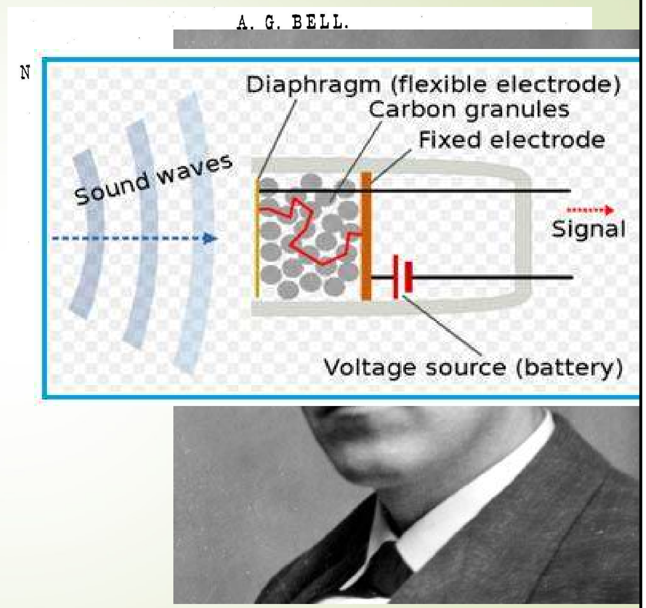
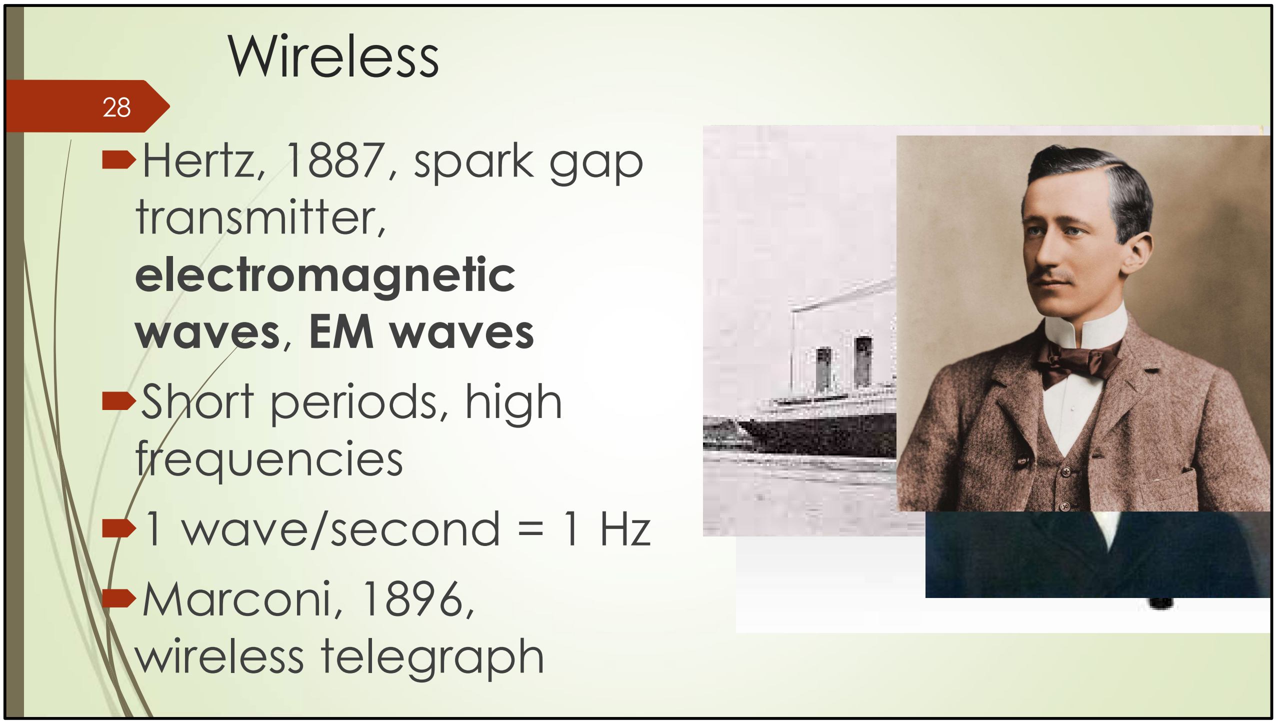
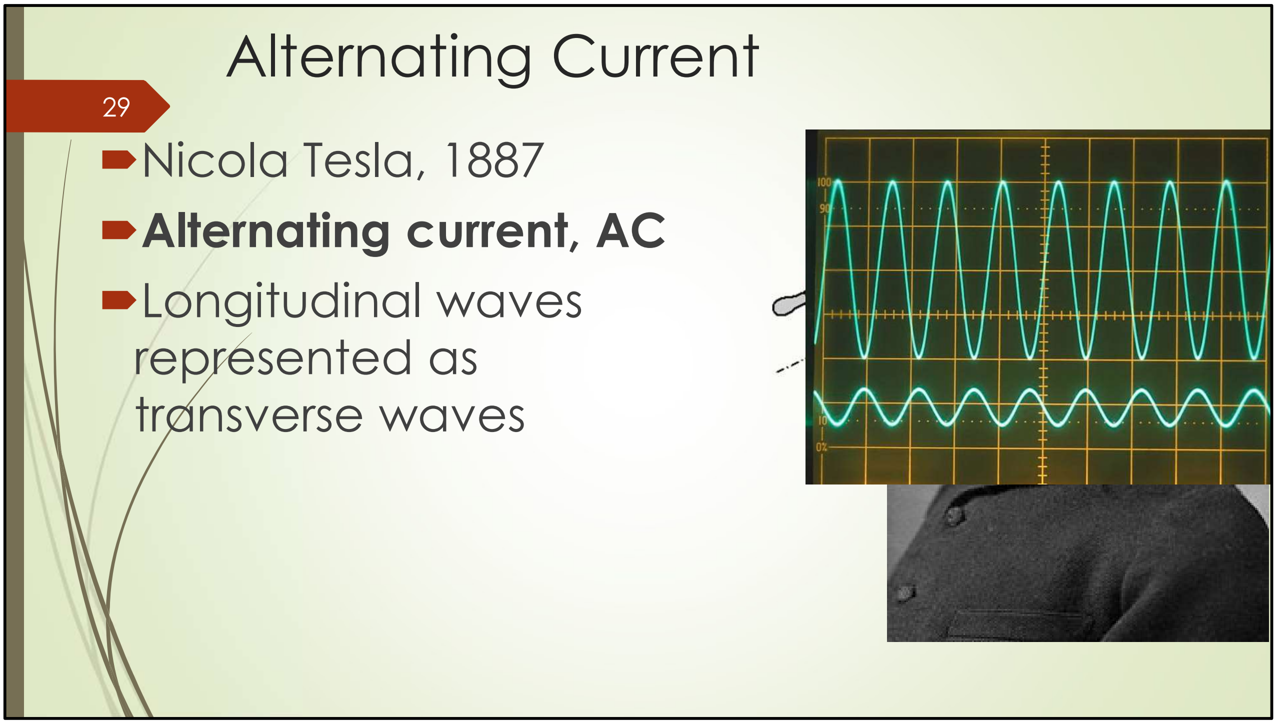
- Music and speech are sound waves
- Bell, 1876
- Microphone and speaker
- Edison carbon granule microphone, 1878



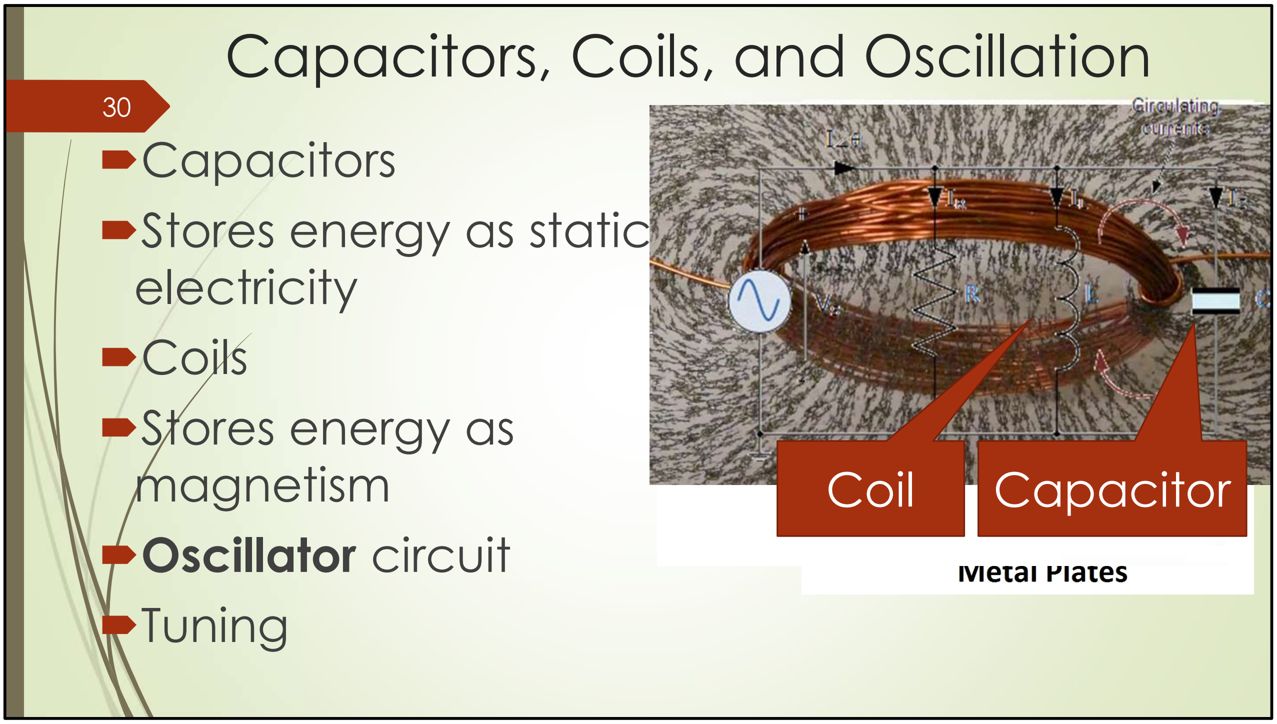
*Music and speech consist of longitudinal pressure waves that are more complex than a simple on/off signal in a telegraph
*Impressing the pattern of these sound waves on a direct electrical current was accomplished by Alexander Bell in 1876
*Bell's design used a coil of wire attached to a cone of paper that was near a strong magnet. When sound pressure waves pushed the cone and coil, it moved near the magnet creating an electrical current that simulated the variations of sound pressure. At the other end, the process was reversed where the varying current in a coil next to a magnet moved a paper cone that made air pressure waves.
*Bell's design had the advantage of using the same device as a microphone and as a speaker, but the cone-and-coil microphone didn't create much power and only worked over short distances.
* Thomas Edison improved on Bell's design by using a *container of carbon granules for a microphone. Sound pressure compressed the granules that reduced their resistance to the flow of a more powerful current supplied by a battery.



*Static sparks were also being studied in the late 1800s. In 1887, Heinrich Hertz discovered that a spark could induce an electric current in a nearby loop of wire. He inferred that the spark created invisible waves of energy that were a combination of electricity and magnetism that he called **electromagnetic waves** that are also known as **EM waves**.
*****Hertz recognized that the sparks had very short durations and the resulting waves would have short periods and high frequencies (recall that period and frequency are inversely related).
*The unit of frequency bears his name and is abbreviated Hz. The electromagnetic waves created by sparks had frequencies of thousands of hertz
***Guglielmo Marconi, created a system that created huge electric sparks as thick as a man's wrist, *that were connected to tall antenna. The electromagnetic waves from these wires could induce currents in *wires onboard ships hundreds of miles from land.** Marconi also modulated the pulses using pulse width modulation (PWM) and Morse code.



Marconi's wireless telegraph used sparks of short duration that couldn't be modulated to simulate speech or music.
*In 1887, Nicola Tesla invented a different method of generating electricity.
*He used a coil that rotated between the north and south poles of a strong magnet. The magnetic force created a current in the rotating wire that alternated direction as the wires passed each of the two different poles. This type of electric current is called **alternating current**, and is abbreviated as **AC**.
*The waves of electric current are longitudinal waves like sound, but they are usually represented on a device called an **oscilloscope** that displays the waves of electrical energy as transverse waves where it is easier to visualize frequency and amplitude.



There are two devices that respond very differently to alternating current and, when coupled together, they bounce electric current back and forth between them. They are capacitors and coils.
*A capacitor consists of two conductors separated by an insulator. *The conductors and insulator are typically thin, flexible materials wrapped in a cylinder.
*If an electric potential is applied to a capacitor, current flows readily onto the plates until the accumulation of charge builds up and opposes additional electric charge of the same type. It stores energy in the form of static electricity.
*When an electric current passes through a coil of wire, *some of its energy is initially transferred into magnetism that surrounds the coil until the magnetism is established so it resists the initial flow of current.
*If a capacitor and coil are paired together, they will pass electric energy back and forth between them and create a high frequency AC wave. This circuit is called an **oscillator**
*The frequency of the AC wave can be changed or **tuned** by changing the area of plates that are next to each other.

Modulating AC with Sound

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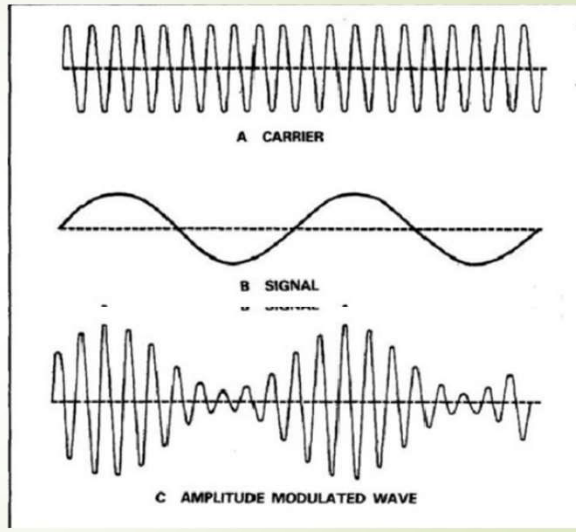
- **Carrier wave**
- Modulating the signal
- Amplitude modulation, **AM**
- Modulate the frequency, **FM**



*The continuous alternating wave from the oscillator is called the **carrier** wave. *It can be modulated with waves from a microphone, similar to the way a telephone circuit modulates DC current. There are two ways that are commonly used to modulate the carrier wave. The electrical waves from a relatively low frequency source *(the signal) can be used to change the strength or amplitude of the high frequency carrier wave. *This is called **amplitude modulation** , or **AM**

*Another option is to use the waves from the microphone to modulate the frequency which is called **frequency modulation**, or **FM**

EM Communication Spectrum

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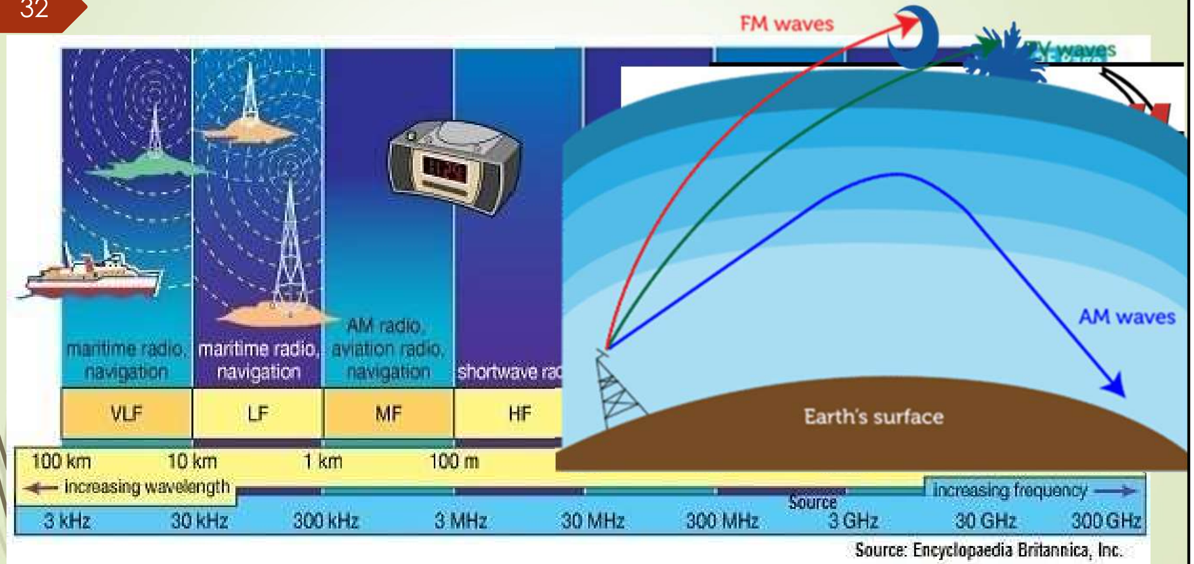

*The modulated carrier wave is connected to an antenna that emits electromagnetic waves that radiate outward. These waves are called **radio waves.** These waves induce similar waves in antenna wires that can be miles away. *The antenna is connected to a device with its own oscillator circuit that can be adjusted to respond to a particular carrier wave frequency out of the many that are inducing waves in the antenna. The lower frequency waves that represent music or speech, can be separated from the carrier wave and sent to a speaker.
Oscillator circuits can produce and detect a wide range of frequencies from 3,000 hz to 300,000,000,000 hz. *Government agencies have assigned specific ranges for different types of communication and *specific frequencies to individual broadcast stations.
*AM radio stations are assigned EM frequencies between 540 kHz and 1700 kHz while *FM stations are assigned frequencies between 88 megaHz and 108 mHz.
*The longer wavelengths assigned to AM radio, reflect from the ions in the upper atmosphere and travel over the horizon. The shorter wavelengths used for FM radio are line-of-sight

Two-way Radios; Cell Phones

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- Broadcast
- Personal transmitter/receivers
- Cell towers
- Frequency sharing technology generations; 4G, 5G

*Broadcast stations communicate in one direction from tall towers, and they have assigned frequencies.
*Personal two-way communication is possible if each person has a device that can transmit as well as receive but they must share the EM radio spectrum
*The solution to this problem is to limit the power of the transmitters and the height of the towers so the signals only travel a few miles. The same frequencies can be used by many people if they are far enough apart. The area around an antenna tower is called a **cell** that services about 10 square miles (radius of about 2 miles) and the two-way radios we have are called **cell phones**
*Very sophisticated methods are used to share the limited number of frequencies available, and they are known by a generation number. For example, a cell tower using 4G technology can communicate voice and text with up to 65,000 cell phones while a 5G system can handle up to 10 million devices. *Unlike the telephones of the late 1800s that could only handle a few calls that were sometimes shared on a party line, we now use EM waves to communicate personally with anyone who has a cell phone.

Waves without a Medium

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- Newton 1665
- Maxwell, 1864
- EM waves, 300,000,000 m/sec
- Speed of light >200,000,000 m/sec
- Light is an EM wave

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$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enc} + \boxed{\mu_0\varepsilon_0 \int \frac{\partial \vec{E}}{\partial t}}$$

*When Isaac Newton proposed his theory of gravity in 1665, he realized that he was proposing a force that could act through the vacuum of space. In a letter he wrote to a friend, he recognized the absurdity of this assumption. Similarly, electromagnetism has wave properties, but these waves could travel through a vacuum. It also seemed absurd that you could have a wave without a medium.
*In 1864, James Clerk Maxwell *wrote equations that described the behavior of electromagnetic waves in a vacuum. His equations even predicted the exact speed these waves would have in a vacuum; three hundred million meters per second!
*Almost 200 years earlier, Ole Romer, an astronomer, estimated the speed of light at roughly 200 million meters per second by observing the apparent eclipses of Jupiter's moons which seemed delayed when the earth and Jupiter were on opposite sides of the sun.
*Maxwell knew that Romer's data wasn't very accurate, so he made an intuitive leap and claimed that visible light is also an EM wave which turned out to be correct. However, it still seemed absurd that light could be a wave without a medium.

Waves without a Medium

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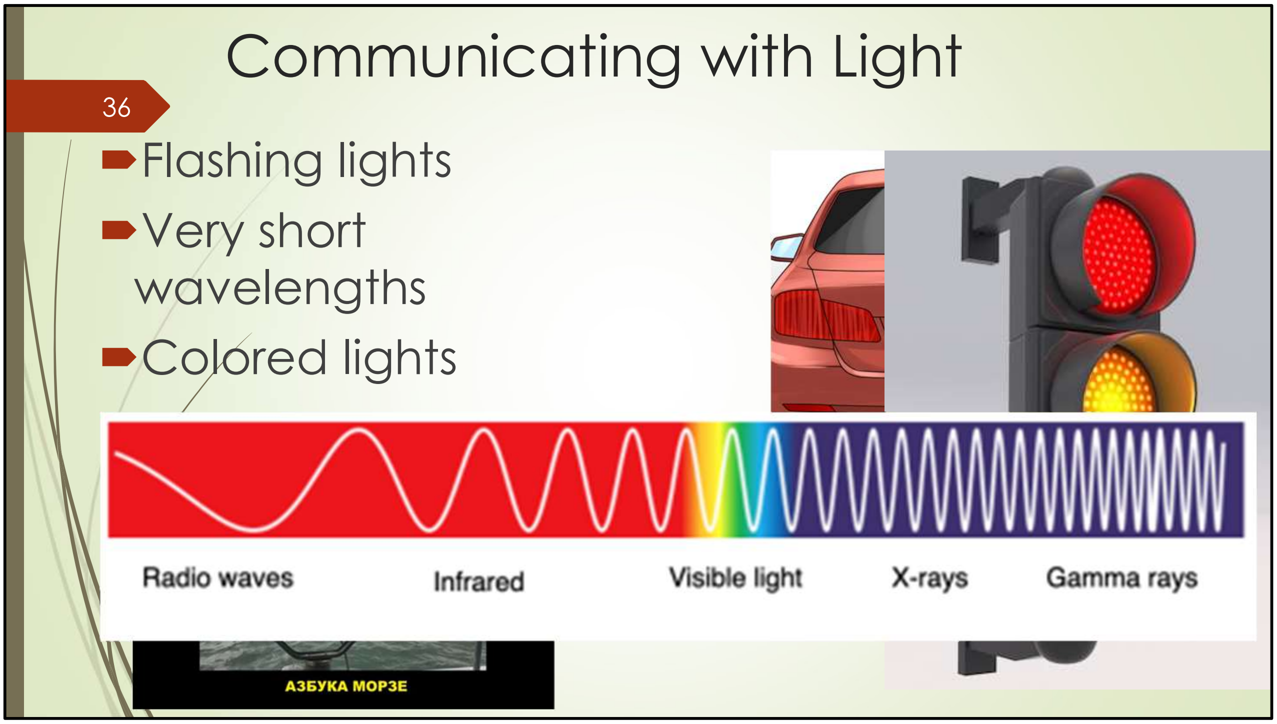
- Charles Dodgson (Lewis Carroll) 1965
- "We're all mad here"

*A mathematician who was a contemporary of Maxwell's, Charles Dodgson, preferred classical definitions of mathematics based on Euclid's original work. The year after Maxwell's equations were published, Dodgson wrote Alice in Wonderland under the pen name Lewis Carroll. Many consider his stories to be allegorical comments on the absurdity of the current state of mathematics. *For example, Alice in Wonderland included a grinning cat that could gradually disappear, leaving a "grin without a cat" reasoning that if you could have a cat without a grin, you could have a grin without a cat. When Alice objects that this is madness, the cat proclaims; "we're all mad here".



Even though the idea of light as a wave that didn't need a medium seems impossible, light waves are used every day for communication.
*Light can be used like a telegraph by flashing the light using a code and *by its position.
*Light waves are much shorter and higher frequency than radio waves. While the length of a radio wave at 100 megahertz might be about ten feet, the length of light waves is smaller than a human hair.
*Different wavelengths of light are perceived as different colors and these colors can be used for communication.

Images

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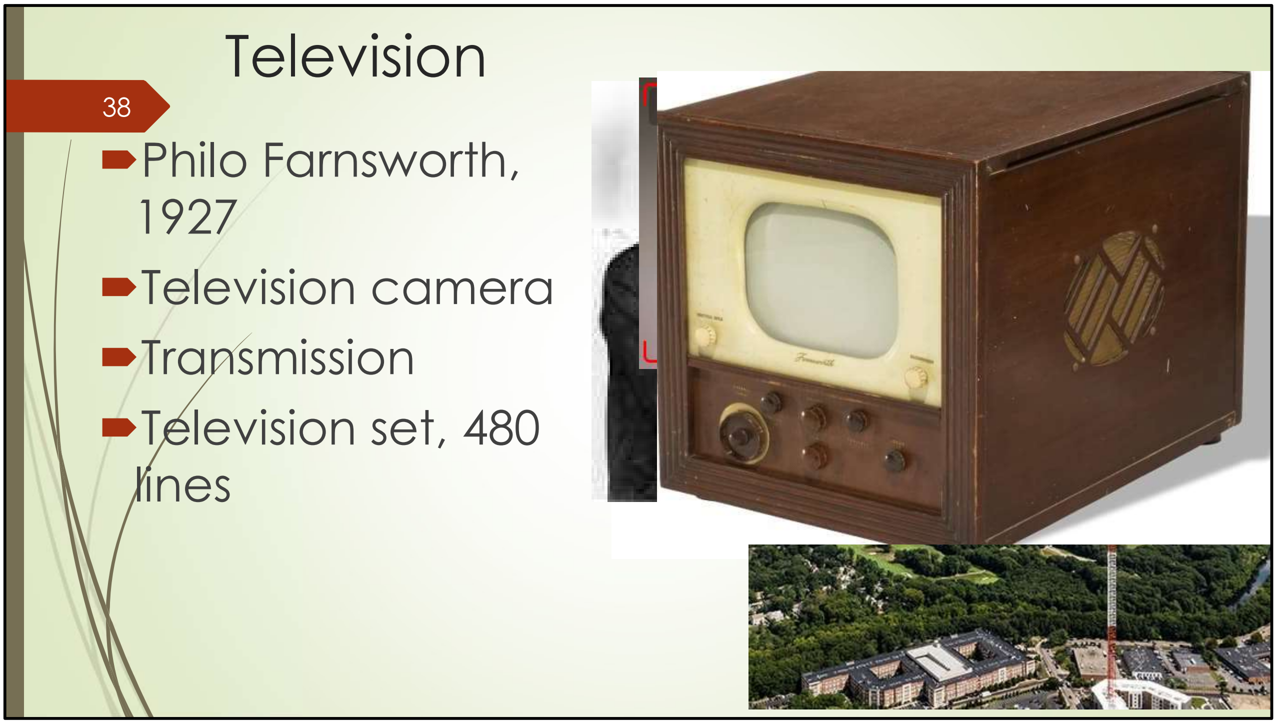
- Camera obscura
- Lenses
- Eyes and brain
- Resolution, Seurat 1886
- Motion pictures, 1896
- 24 still images per second

*Light can reflect from objects and then form images. If a small hole allows light into a darkened room, an image of the world outside can be seen on the wall that is upside down and reversed but the image is very dim.
*Light travels at a lower speed in glass. The wave property of refraction can be used to collect light from a larger aperture and focus it on a screen to create a much brighter image.
*Our eyes have a lens that forms an image on the back of the eyeball. Even though the image is upside down, our brains have learned to invert the image. The image at the back of our eyeball is small. If parts of the original object are close together, our brains merge them. *In 1886, Georges Seurat created a painting the consisted of dots of color, close together. *These dots can be seen when viewed up close, but from a distance, they appear to merge together.
*Our brains process images several times each second and changes between successive images is perceived as motion. Motion may be simulated by presenting a sequence of still images that show a progression of positions. By 1896, motion was simulated in theaters by flashing a sequence of still images on a screen. * A sequence of 24 different images per second is fast enough to give our brains the impression of continuous motion.*



*In 1927, Philo Farnsworth invented and patented a technology that could capture many images per second that consisted of dots and transform those images into EM waves the he could transmit, and then display rapidly enough to simulate live action that was called television.
*He used a camera that could convert small portions of an image on a screen into electrical current that varied with the brightness of the image at that spot.
*The variations in current were imposed on a carrier wave, and then transmitted to a receiver with a tuner.
*The variations that represented the image were imposed on a current that was projected on a screen that was covered with phosphors which emitted visible light in proportion to the strength of the current.
*Early televisions in the US divided the image into 480 lines. We now use 1080 lines or 4000 (4k) lines.
The use of radio and television revolutionized communications through sound and images.

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What experiences and insights can you share with us?

References

- Talking Drums: Link
- Tuning an A: Link, Link
- Music and emotions: Link
- Pitch standards: Link