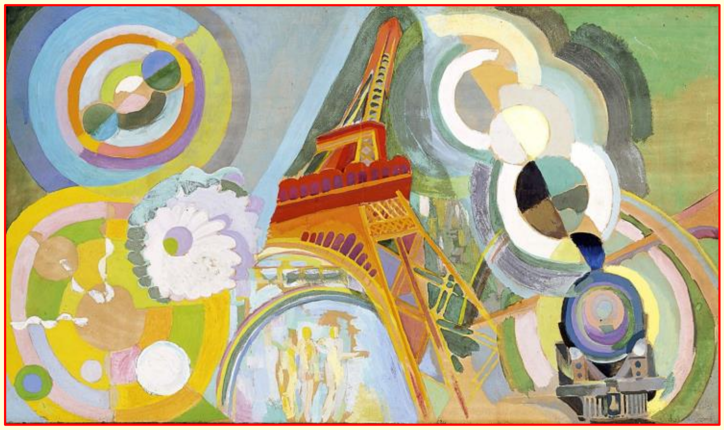
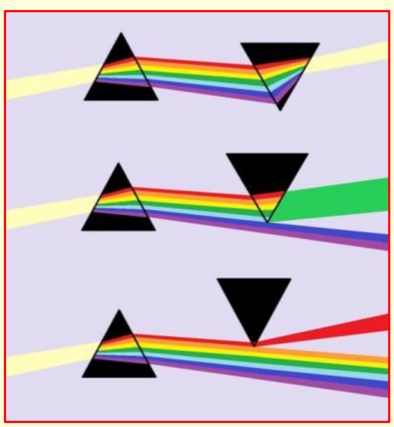
Communication



Robert Delaunay, *Air, fer, eau*, 1937

The painting is by Robert Delaunay. He and his wife Sonia and the Czech painter Frantisek Kupka were founding members of the Orphism movement in modern art. The painting uses colors from all regions of the visible spectrum. On the left are and right are various color wheels. In the center is the Eiffel Tower which was built in 1889 and which has transmitted radio signals since 1898. So the painting combines ideas of the electromagnetic spectrum and its use in communication.

Newton's Optical Experiments



In 1672, Isaac Newton wrote a letter to the Royal Society describing his experiments with a prism. In 1704 he published his book *Opticks*. Of his many experiments with the prism most readers concentrate on that described in the upper part of the illustration: white light passing through a prism is separated into seven colors and these can be recombined to form white light using an inverted second prism. His other experiments showing that light of a particular color could not be separated into other colors were equally important.

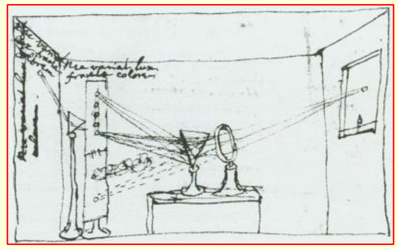
Unlike the Latin *Principia Mathematica* published in 1687, *Opticks* was published in English.

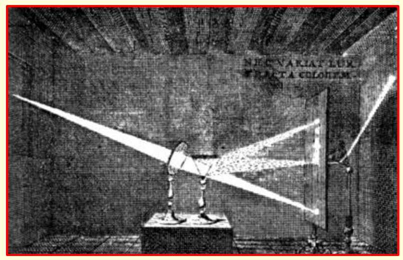
As well as the experiments illustrated in the middle and lower diagrams, Newton also used experiments wherein he limited his secondary analysis of the refracted colors by having these pass through a small hole in a screen. In this manner he could deal with light of any particular color in the spectrum.

The red end of the spectrum was refracted the least and the violet end the most. Later it was determined that this was because of the different wavelengths of the light, with red's wavelength being longer than blue's

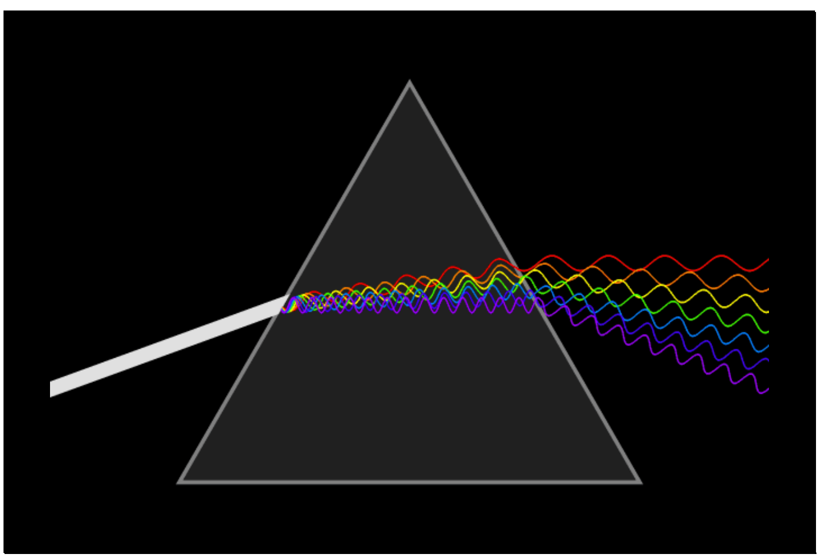
Newton's Diagram

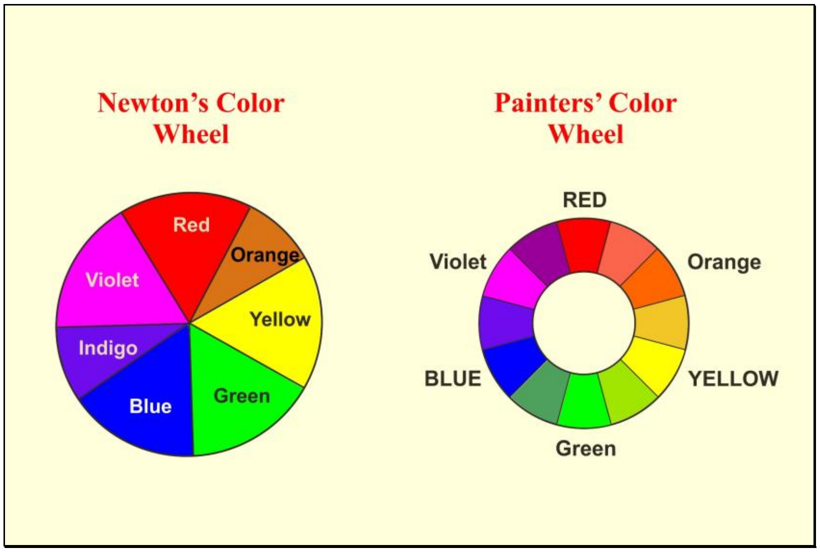
For the 1721 French edition of his *Opticks*, Newton submitted a diagram illustrating his experiments with prisms. The room was darkened and only a narrow beam of light came through a hole in the shutter, passed through a lens and then was broken up into colors by a prism. Allowing just one color to pass through another prism caused no further breakdown in the color. The handwriting on the drawing states *Nec variat lux fracta colorem* – "Separated light does not (further) change color."





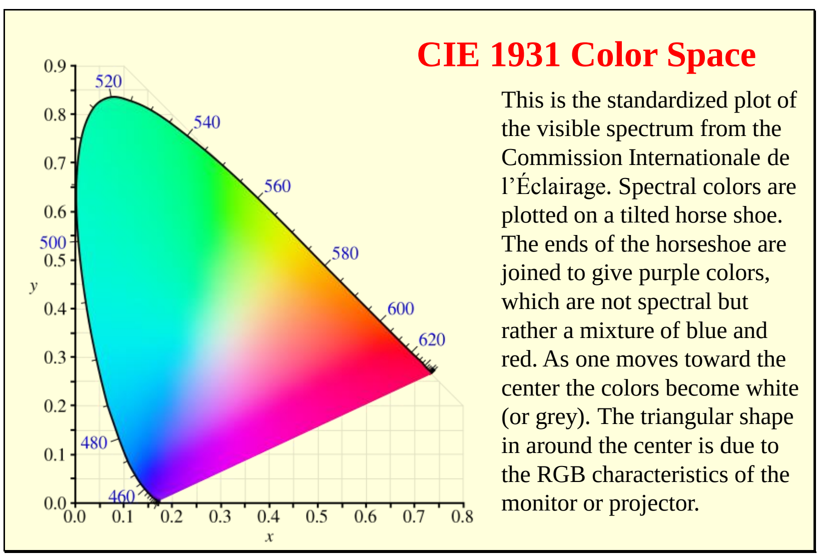
The illustration on the lower right shows the engraving that was included in the book. Like all engravings it is left-right reversed. The diagram shows the path of the light with and without the prism.
Many websites showing this figure incorrectly describe it as illustrating the separation of white light into colors by a prism and their recombination into white light by a second prism.





Newton identified seven colors. Most modern observers would not categorize indigo as a separate color. Newton was intrigued by the number 7 – there are seven planets, seven days of the week, etc. He also suggested that the lines between the colors could relate to the notes of the musical scale with A located between green and blue, B between blue and indigo, etc. Newton's idea of the color wheel is actually more complicated than that shown. The color in any of the sectors would become lighter as one approached the center.

The painter's color wheel on the right shows the primary colors in capitals and the secondary colors in lower case. The intervening colors are usually named using the format "reddish-orange."



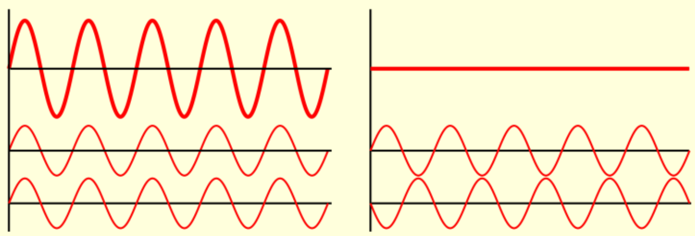
Projectors, printers and monitors are actually quite limited in their ability to represent colors. The range of greens and blues are particularly limited.

The axes of the CIE graph represent the human color system with two opponent processes one between red and green (y-axis) and one between blue and yellow (x-axis). The numbers on the graph represent the wavelength of the light in nanometers (10^{-9} meters)

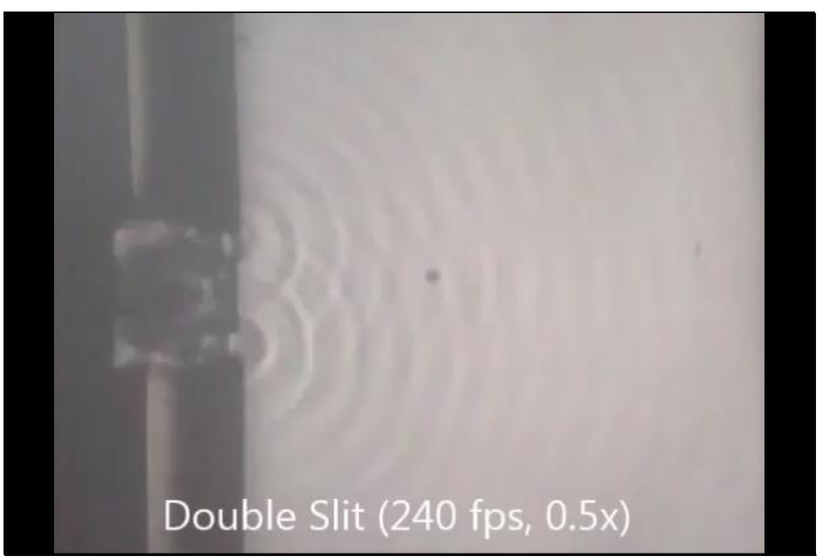
The color space is generally considered as a distorted three-dimensional sphere. The plot shows the sphere at the equator. The z dimension is brightness the colors go up to white light at the north pole and down to black at the south.

Waves and Particles

Newton thought that light was composed of particles. In his *Treatise on Light* (1690), Christiaan Huygens (1629-1695), a Dutch scientist, had proposed that light was composed of waves that travelled in space through an invisible "luminiferous aether." Waves from two separate sources characteristically interfere with each other. If they are in phase (below left) they add together, but if they are out of phase (below right) they cancel.

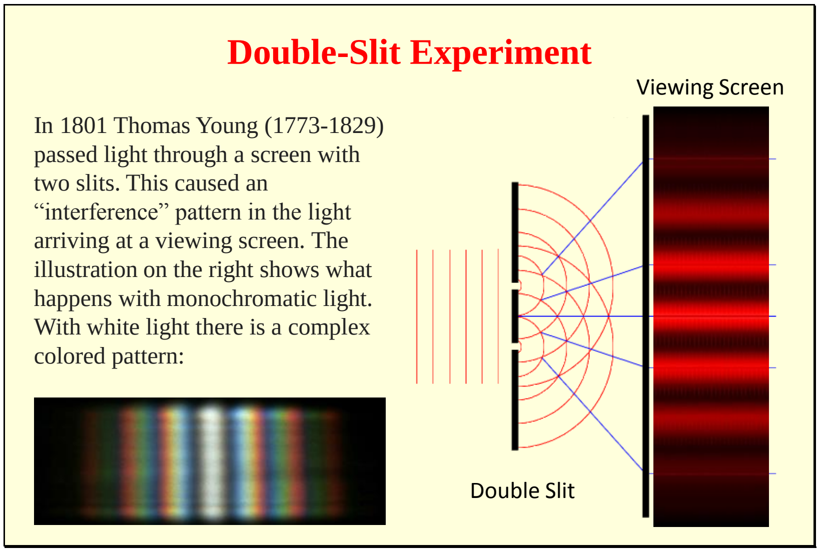


As well as his *Treatise on Light*, Huygens was the first to describe the rings of Saturn. He also worked extensively on the mechanics of time-keeping, designing a balance spring watch at about the same time as Robert Hooke in England.



https://www.youtube.com/watch?v=3p6iP7Oz_6w

One way to demonstrate the interference between waves is to have wave in water pass through two closely spaced openings (on the left). As the waves radiate out from each opening they add with or cancel each other so that a pattern of large waves and tiny waves reaches the right side of the tank.



In the diagram on the right the blue lines indicate paths where the waves from the two slits are in phase. Knowing the distance between the slits and the distance to the screen one could calculate the wavelength of the light:

for D the distance between slits and the viewing screen, d the distance between the slits (D>>d) y the distance between the maxima of the interference pattern, and m the number of the maxima away from the middle

$\lambda = yd/Dm$

Young calculated the wavelength of the light coming from a candle at 580 nm. Our modern measurements give yellow light between 560 and 590 nm.

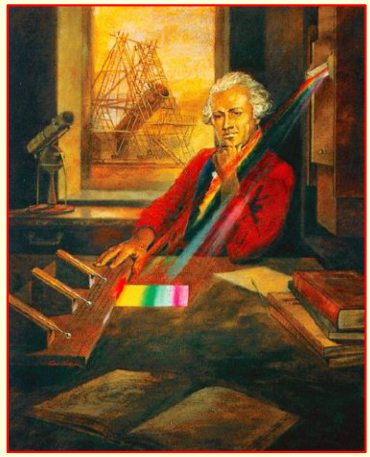
Thomas Young was a polymath. He contributed significantly to the understanding of Egyptian hieroglyphics, described how one could measure the elasticity/stiffness of materials, determined how the eye accommodates for near and far vision, measured the velocity of the cardiac pulse, and proposed the trichromatic theory of color vision.

Young's trichromatic theory – that human beings have three distinct color receptors – was expanded by James Clerk Maxwell, who used it to propose a way to take color photographs.

Infrared and Ultraviolet

In 1800, William Herschel (1738-1822), the astronomer who had discovered Uranus in 1781, measured the heat produced by light waves of different colors. He noted that a thermometer still registered an increase in heat when it was moved beyond the red end of the spectrum. He suggested that there must be invisible "calorific rays."

In 1801 Johann Ritter (1776-1810) observed that silver chloride turned black more quickly when placed just beyond the violet end of the spectrum. He called them "chemical rays."



In the background of the painting is shown one of Herschel's large reflecting telescopes.

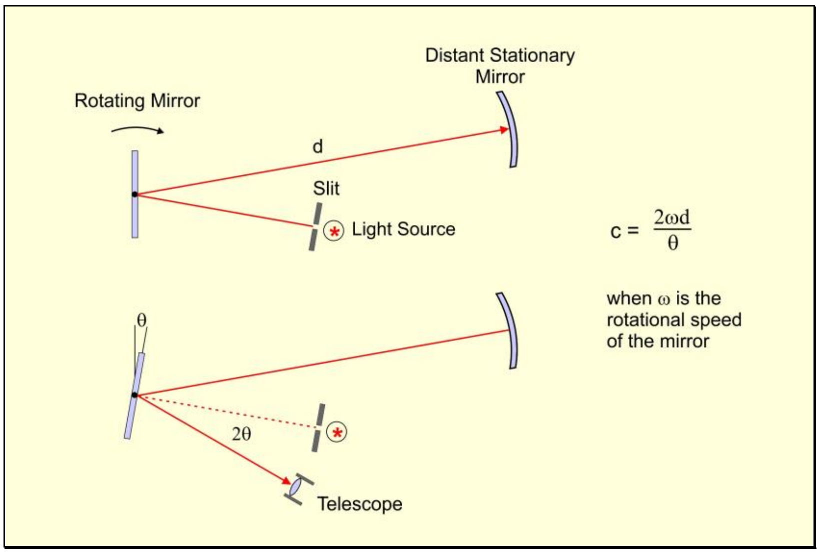
Early in the 20th Century Kodak made camera film sensitive to infrared region of the spectrum. Minor White took some striking photographs with this type of film. This photograph *Road and Poplar Trees in the Vicinity of Naples, New York* was taken in 1955. Minor White had just moved from the West Coast and wanted to make the more peaceful Eastern countryside more exciting.

Velocity of Light

Many scientists, such as Kepler, believed that the velocity of light was infinite. In 1676, the Danish astronomer Ole Rømer found that the duration of the eclipse of Io, one of Jupiter's moons was shorter when the Earth was moving toward Jupiter than when it was moving away – the difference caused by the longer time taken for the light to reach the Earth in the latter case.

Between 1849 and 1850 Hippolyte Fizeau and Léon Foucault measured the time taken for light to travel to a mirror many meters distant and back. They used rotating mirrors or cogwheels to give packets of light.

Léon Foucault (1819-1868)



This represents Foucault's experimental procedure. Light passed through a slit was reflecting using a rapidly rotating mirror and viewed in a distant mirror by an observer using a telescope. Measuring the angle at which the slit could be viewed relative to the source could then allow calculation of the velocity of light.

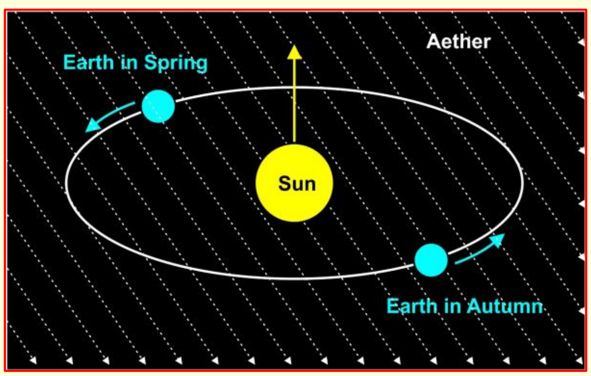
In 1880 Albert Michelson, at the time an officer in the US Navy teaching at Annapolis, used the technique of Foucault with a much longer distance between the mirrors (500 meters rather than 50). He published a velocity of 299,864 ± 51 kilometres per second for the speed of light in air.

The current standard values are 299,792 km/s in a vacuum. Light travels more slowly through a transparent medium than through a vacuum, with the ratio of the velocities being the "refractive index." The refractive index of air is 1.0003, water 1.333, glass 1.4-1.7, diamond 2.4.

Foucault's Pendulum in the Pantheon in Paris, guarded by Bastet, one of the Egyptian deities.

Foucault is more famous for his pendulum than for his measurement of the velocity of light. A swinging pendulum will slowly progress around a circle. This progression is caused by the rotation of the earth.

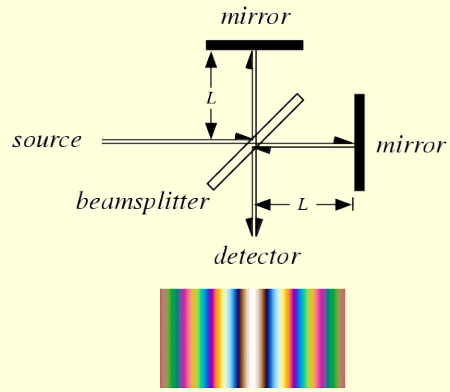
Lumini-ferous Aether



If light waves are indeed carried on the aether, then this must exist throughout the universe, and the earth must move through it as it rotates around the sun and as the sun itself moves in the galaxy. The velocity of light, aided or impeded the aether wind, should then vary with the time of day, the season and the direction in which the light travels.

Michelson-Morley Experiment

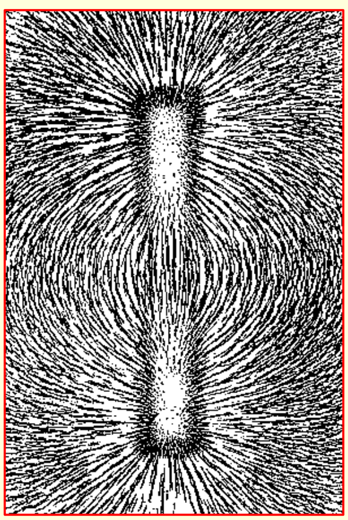
In 1887, Albert Michelson and Edward Morley conducted an experiment to measure changes in the velocity of light as the earth moved through the hypothetical aether. Light was split into two beams which travelled the same distance but on orthogonal pathways to meet again to cast an interference pattern on a screen. If the velocity in one path differed from the velocity in the other then the interference pattern would become distorted.



It was the “most famous failed experiment ever.” The interference pattern was completely stable. The only conclusion was that the aether did not exist. Michelson received the 1907 Nobel Prize in Physics.

The “beamsplitter” was a glass that had been coated with a thin layer of silver so that half the light went through the glass and half was reflected.

Fields of Force



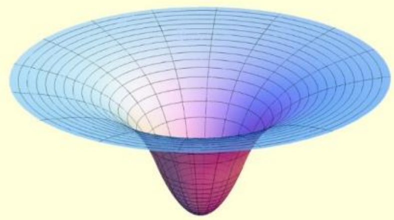
A force field represents the action of a non-contact force on an object in the space surrounding the origin of the force. Newton’s force of gravity (1687) can be represented as a field surrounding an object with mass. The electric field caused by charged particles obeys the law proposed by Charles-Augustin de Coulomb in 1785. In 1813 Carl Friedrich Gauss showed that the magnetic field was similar to the electric field but based on the separation of magnetic poles rather than electric charges.

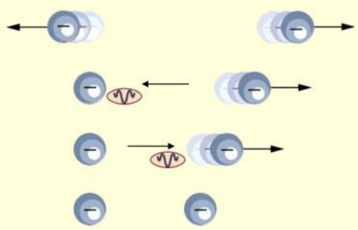
Iron filings in a magnetic field

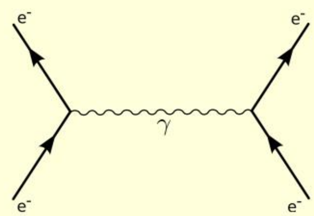
The usual demonstration of the magnetic field uses iron filings. These become like tiny weak magnets and align themselves to the field. The lines separate because of the magnetic repulsion between the filings

How Do Fields Work?

We still do not understand how forces act. Fields are often represented as a distortion of space (right). Modern atomic physics suggests that fields exert forces by the exchange of particles (below).



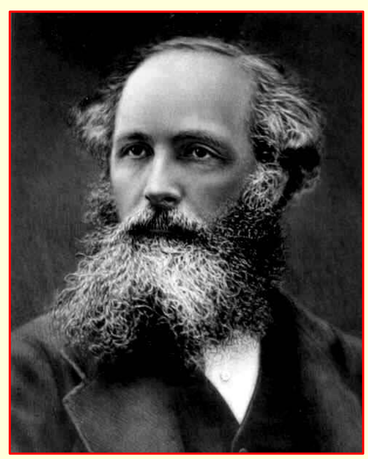




In the lower diagrams time is represented as proceeding upward. At the lower left, two negatively charged electrons exchange virtual photons which cause them to move apart. At the lower right this is represented in a Feynman diagram.

James Clerk Maxwell (1831-1879)

Maxwell was born in Edinburgh and educated at the Universities of Edinburgh and Cambridge. Between 1860 and 1865 at King's College in London and at his family home in Glenlair, he put together a mathematical formulation of electric and magnetic fields. In his 1865 *A Dynamical Theory of the Electro-magnetic Field* he demonstrated that changes in the electrical and magnetic fields cause electro-magnetic waves to travel through space at the velocity of light.



Anonymous Portrait, circa 1875

Maxwell also worked on the trichromatic theory of color, showing that a rotating wheel with only three colors (such as red, green and blue) would appear as white. He also contributed to thermodynamics and is famous for his 1867 thought experiment with Maxwell's demon. His 1868 paper "On governors" is foundational to cybernetics.

And God said, Let there be lights in the firmament of the heaven to divide the day from the night; and let them be for signs, and for seasons, and for days, and years: and let them be for lights in the firmament of the heaven to give light upon the earth:

$$\nabla \cdot D = \rho_f$$

$$\nabla \cdot B = 0$$

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times H = J_f + \frac{\partial D}{\partial t}$$

and it was so.

A new version of Genesis 1: 14-15 (Alexander Scourby)

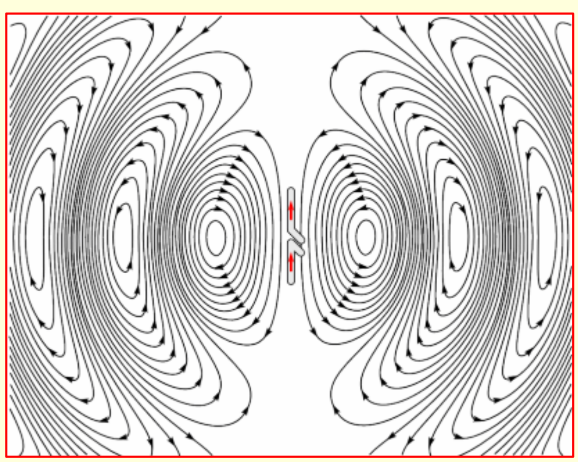
Maxwell used a series of laws to describe the electric and magnetic fields. These were recast from those previously proposed by Gauss. Faraday and Ampère.

The nabla symbol ∇ ("del") represents a three-dimensional gradient. "∇ dot" represents divergence and "∇ cross" represents curl. D and E are ways of expressing the electric field, and B and H measure the magnetic field. ρ and J represent the electrical currents. ∂ represents the partial derivative.

The crucial point about the equations is how the fields change with time and how the electric and magnetic fields necessarily interact.

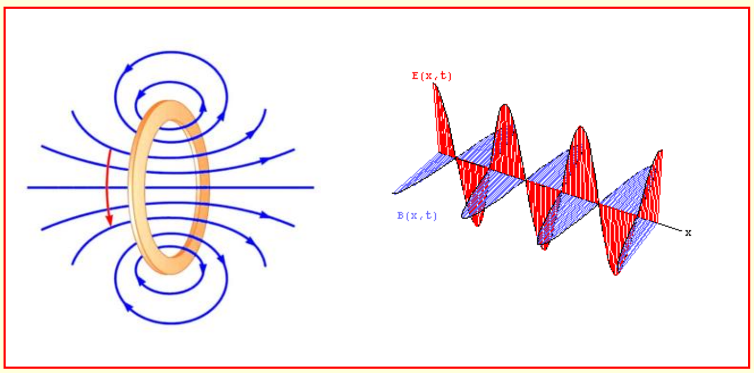
Radio Waves

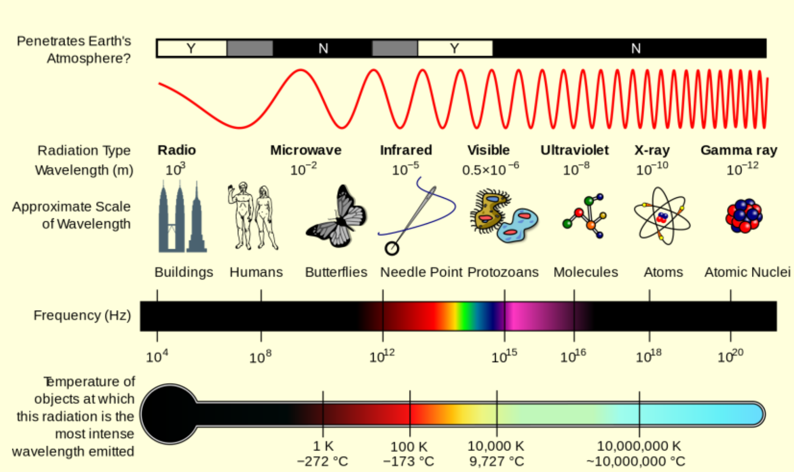
Maxwell realized that changes in the electric field around an oscillating current dipole would radiate out as electro-magnetic waves, and that these would travel at the speed of light.



The animation of a half-wave dipole antenna transmitting radio waves, showing the lines of current in an electric field around the antenna. A radio frequency generator alternately charges the two ends of the antenna positive (+) and negative (−). Standing waves of current (red arrows) flow up and down the rods. The alternating voltage on the rods creates loops of electric field *(black lines)* and radiate away from the antenna at the speed of light. These are the radio waves. The radiated power is greatest in the horizontal direction, perpendicular to the antenna, and decreases to zero above and below the antenna, on the antenna axis. The action is shown slowed down drastically in this animation; real radio waves oscillate at rates of thirty thousand to a billion cycles per second.
https://commons.wikimedia.org/wiki/File:Dipole_xmting_antenna_animation_4_408x318x150ms.gif

Current loops in a changing electric field are associated with changes in the magnetic field perpendicular to the loops. Thus electromagnetic radiation has both electric (red) and magnetic (blue) components and these are oriented at right angles to each other:





Maxwell's equations indicated that there would be radiation at many different frequencies. The spectrum of electromagnetic radiation is generally divided into 7 sections. Everyone likes the number seven!
Discoveries:
Infrared – William Herschel 1800
Ultraviolet – Johann Ritter 1801
Radio – Heinrich Hertz 1886
X-Rays – Röntgen 1895
gamma waves – Rutherford 1914
microwaves – used in radar 1936 and heating 1933

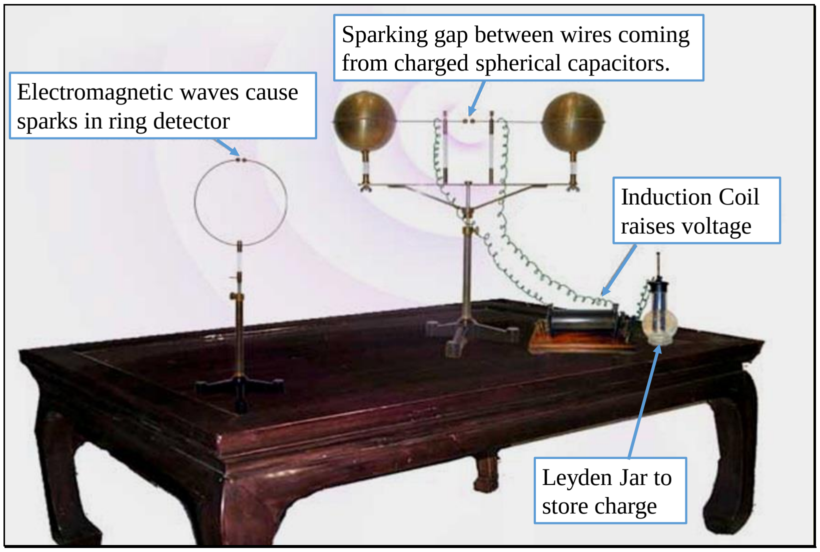
Etching circa 1886

Heinrich Hertz (1857-1894)

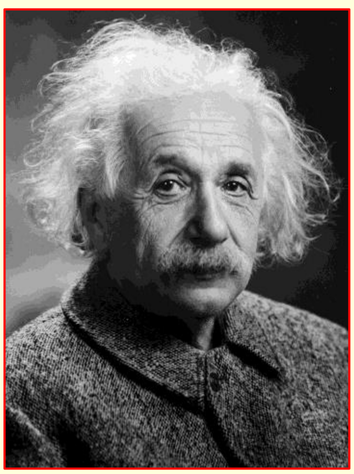
In 1879 Hermann von Helmholtz suggested to his student Hertz that he should attempt to test Maxwell's theories. It was not until 1887, however, that Hertz was able to demonstrate the generation of electromagnetic waves and their detection. For this he used a high-voltage circuit that generated sparks across a tiny gap. A distant circular antenna would show tiny sparks in synchrony with those in the generator circuit.

Hertz also demonstrated that the waves were deflected by a prism made of pitch just like light waves through a glass prism, and that that the detector had to be aligned in the plane of the waves.

In 1887 Hertz also discovered the photoelectric effect – the emission of electrons when light is shone on the material. His particular observations were related to his spark gap generator and receiver – sparks were greater when the electrodes were illuminated in ultraviolet light.



This illustration represents the equipment used by Heinrich Hertz to demonstrate radio waves. Charge was placed on the spherical capacitors which then discharged across a gap between the two wires. A tiny spark was seen at the same time in the ring detector. The faint purple shading suggests the electromagnetic radiation.



Portrait by Orren Turner, 1947

Albert Einstein (1879-1955)

Einstein graduated from the Swiss Polytechnic in 1900 and worked in the Swiss Patent Office from 1901-1908. While there he wrote many paper in theoretical physics. The most important concerned

(i) an interpretation of the photo-electric effect that proposed that light could be composed of discrete packets of energy – photons

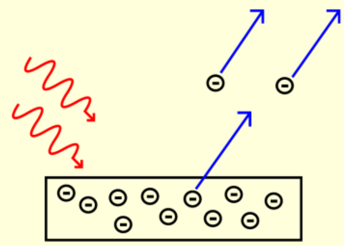
(ii) a theory of special relativity which considered the equivalence of energy and matter and provided the equation $e=mc^2$

After his papers were recognized Einstein became a professor of physics in Bern, then Prague, and then Berlin.

He received the Nobel Prize in Physics in 1921 mainly for his work on the photoelectric effect. His later theoretical contribution – general relativity (1911-1920) – attempted to provide a theory of gravitation as a warping of space-time by mass.

Photoelectric Effect

After its description by Hertz in 1887, numerous scientists investigated the photoelectric effect. By 1900 it was shown that this was related to the release of electrons.



However, certain characteristics of the effect did not fit with the wave theory of light. Most importantly electrons were release only when the light exceeded a certain threshold frequency (which depended on the material). If the light exceeded this frequency electrons were emitted regardless of how dim the light was. Einstein theorized that this could only happen if the incoming light consisted of discrete packets of energy – "photons." He thus confirmed Max Planck's proposal that the energy was equal to the product of frequency and a constant, later determined as Planck's constant: $E = h\nu$

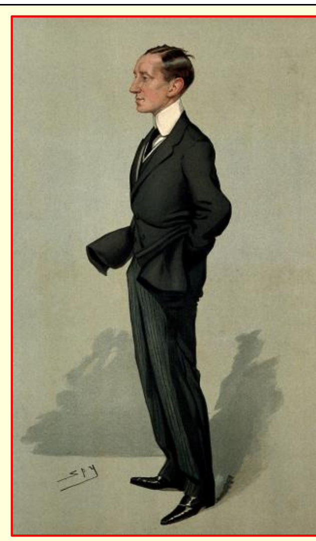
Max Planck received the Nobel Prize in 1918. Photons were initially called quanta by Planck and Einstein. The term "photon" came from Arthur Compton (1892-1962) who worked on the scattering of x-rays and gamma rays by electrons, further proving the particle nature of electromagnetic radiation. Compton received the Nobel Prize in 1927.

So light is both a wave and a particle. This idea led to the quantum physics of the early 20th Century.

But we should now return to Hertz's other discovery – radio waves.

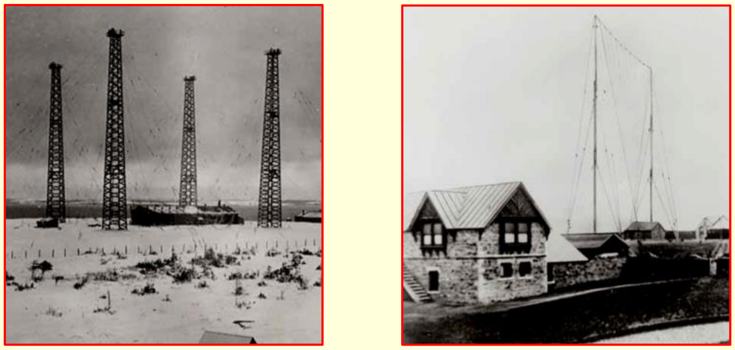
Guglielmo Marconi (1874-1937)

Born into the Italian aristocracy, Marconi was tutored in science but did not formally attend university. He decided to use a much longer antenna than that used by Hertz and found that the slower waves could travel longer distances. In the early years of the 20th Century Marconi set up radio transmission systems in England that could send signals across water and over mountains. He then decided to set up a transatlantic radio telegraphy.



1905 Caricature by Leslie Ward ("Spy")

Marconi received the 1909 Nobel Prize in Physics for his work with radio telegraphy.



The first clear transatlantic radio message was sent by Marconi from Glace Bay, Newfoundland (left) to Poldhu, Cornwall (right) in December 1902. Both photographs were taken at the time of the radio transmission. The aerial at Poldhu was much larger and more complex originally but this was blown down in a storm and only partially replaced.

Earlier transmissions from Poldhu to Glace Bay were claimed by Marconi but there is doubt about whether they really worked.In 1907 Marconi set up a regular transatlantic radio telegraphy from Ireland to Glace Bay. Extensive information about Marconi and his work is at http://www.marconicalling.com/introsting.htm

Willy Stöwer's 1912 magazine illustration of the sinking of the Titanic. One of Marconi's great contributions was to provide radio transmission between ships at sea. This was particularly helpful in the sinking of the Titanic since the Titanic was able to communicate with the Carpathia and this led to the rescue of the survivors.

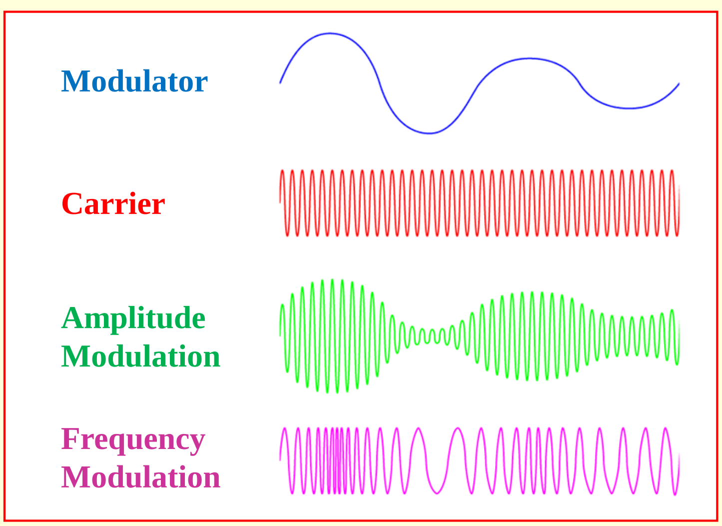
Marconi was technically very conservative. His transmission systems used the spark-gap antennae that were used initially by Hertz. This was far too noisy to transmit speech. Marconi could therefore only transmit dot-dash Morse code information. This was "wireless telegraphy."

Reginald Fessenden (1866-1932)

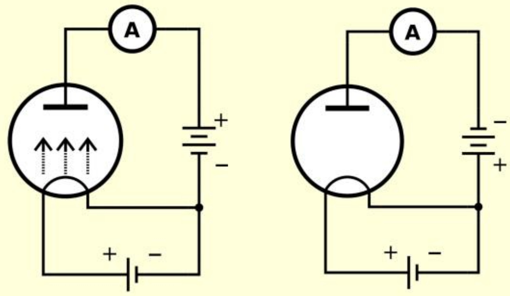
Fessenden worked for Thomas Edison in New York from 1886-1890 and then taught at Purdue University. He worked for the US weather bureau on setting up ship-to-shore radio contact from 1900-1902, and then set up his own company to see if radio could carry speech signals instead of the dots and dashes of Morse code. For this he used a high-speed continuous wave alternator and a detector that was able to rectify amplitude-modulated sound.

Fessenden was born in the Eastern Townships of Quebec but spent most of his working life in the United States. When Fessenden proposed his idea that continuous waves could carry speech signals, most other scientists working with radio, such as Marconi and Fleming, thought the idea was nonsense. He nevertheless persisted. Stubbornness is one of the main personality traits of successful scientists.

Fessenden claimed to have made the first radio broadcast in December 1906 sending out a phonograph recording of Handel's *Ombra ma fu* and his own violin rendition of *Silent Night*. *Ombra ma fu* is an aria from Handel's Xerses about the shade of a favorite tree. For some reason it has long been associated with Christmas. The sound is from a 1904 recording. Fessenden's claim has been disputed, and others have suggested that the first broadcast was by Lee de Forest in 1907.



Thermionic Emission



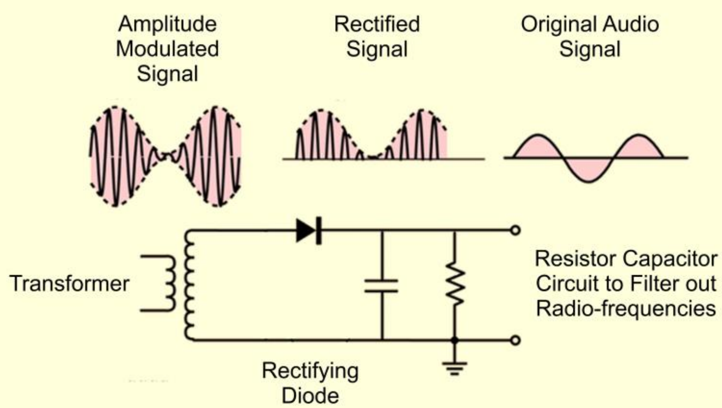
In 1880 Thomas Edison noted that a heated filament in vacuum tube would pass current to another electrode in the tube if that electrode was positively charged (left) and not if it were negatively charge (right).

In 1904 John Ambrose Fleming used a two-electrode tube (a "diode") to rectify current (allow it to pass in only one direction). This "Fleming valve" allowed the demodulation of AM radio signals.

In 1873 Frederick Guthrie (1833-1886) had earlier reported that a grounded white-hot metal ball would discharge a positively charged electroscope but not a negatively charged one – the ball emitted electrons. This was the first report of thermionic emission. Edison was not aware of this report when he did his work. The findings often go by the name of Edison's effect. The explanation of Edison's effect in terms of electrons would only come later. J. J. Thomson demonstrated the existence of electrons in 1897.

The emission of electrons could be increased by having a additional circuit to heat up the cathode (lower part of the diagrams), as opposed to having the passage of current through the cathode filament cause the heating.

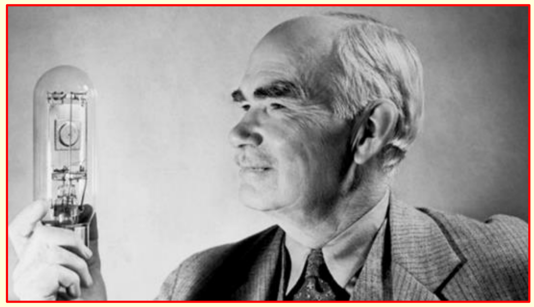
Demodulation of AM Radio Signals



The circuit diagram uses a semiconductor diode symbol. In this symbol the current passes in the direction of the arrow.

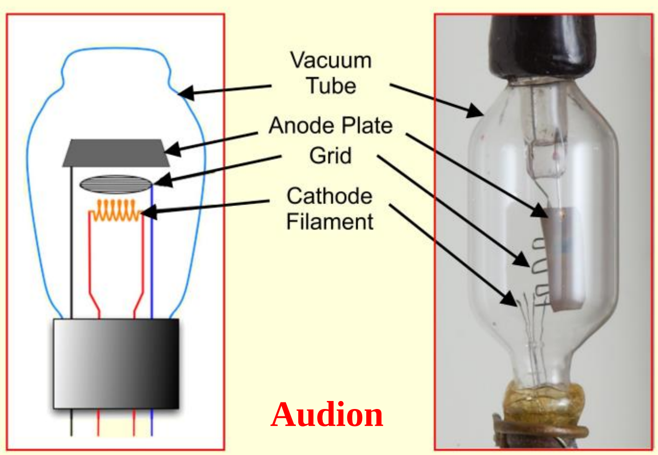
This rectification could be obtained with the Fleming valve, or with a special crystal which acted as a semiconductor allowing passage of current only in one direction. This was the basis of the “crystal radio sets.”

Lee de Forest (1873-1961)

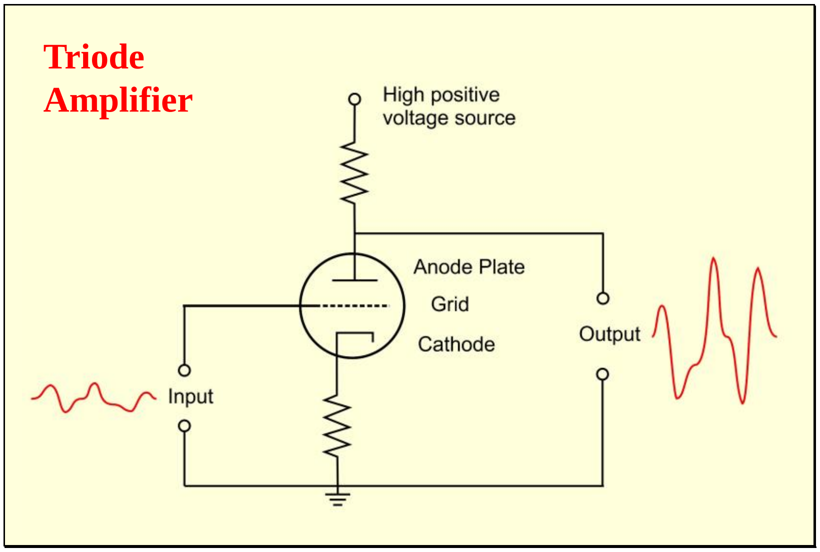


After studying at Yale University, de Forest set up his own wireless telegraphy company in 1902. One of the main problems with telegraphy and with the telephone was the low-level of the electrical signals. In 1906 de Forest invented a triode vacuum tube or Audion, containing a grid as well as the usual cathode and anode. This could be set up to amplify incoming signals from radio or telephone.

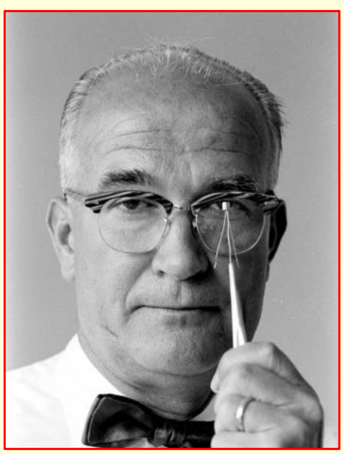
De Forest’s other achievements concerned recording sound on film. His phonofilm process was one of the first techniques used to record sound on film. For the first feature-length talkie – *The Jazz Singer* (1927) – the sound was recorded on disk and there were synchronization problems between film and disk. De Forest collaborated with another inventor Theodore Case, but they had a falling out, and Case went on to develop the Movietone sound-on-film system that was used by Fox.



The photograph on the right shows an actual Audion tube from 1908. The cathode filament in this tube has burned out. The diagram on the left shows the three main electrodes within the tube. The actual tube differs from the diagram in that the anode and the grid are connected through the top of the tube rather than the bottom.



The tiny voltages on the grid determines how much current passes between anode and cathode in a high voltage circuit. This is much like how small turns on a tap can control huge changes in the amount of water flow.



Portrait with transistor, Alfred Eisenstaedt, 1963 (Life Magazine)

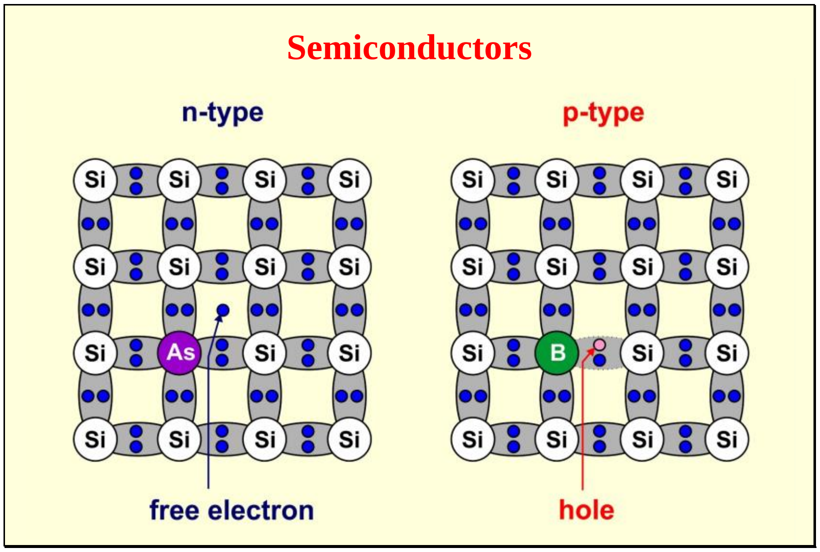
William Shockley (1910-1989)

Educated at both California and Massachusetts Institutes of Technology, Shockley worked on radar at Bell Labs during World War II. After the war he and his colleagues John Bardeen and Walter Brattain studied the properties of semiconductors. In 1954 Shockley moved from Bell Labs to Mountain View in California to set up his own company to commercialize semi-conductor devices. This was the beginning of Silicon Valley. Shockley, Bardeen and Brattain were awarded the 1956 Nobel Prize in Physics.

Semiconductors had first been considered (and patented) by Julius Lilienfeld in the 1920s, but the Bell Labs group was able to make them commercially viable.

Shockley was not a good administrator and his company did not do well.

Shockley became notorious for his racist views. In his opinion, black persons were inherently deficient. He also proposed that people with IQs below 100 be paid to undergo voluntary sterilization. Nobel Prizewinners are not always noble.



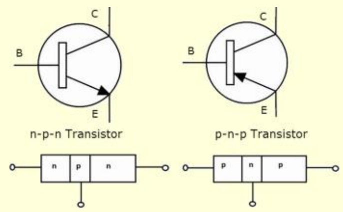
Semiconductors are materials that can conduct electric current but do not do so as readily as metals. They are usually made of crystals of elements like silicon or germanium. These have 4 electrons in their outer shell and form strong covalent bonds. The pure crystal will not conduct electricity because the electrons are firmly held in these covalent bonds. However if the crystals are “doped” with impurities they can become semiconductors. Impurities such as Arsenic or Phosphorus have 5 electrons in their outer shell. These impurities leave free floating electrons in the crystal that can carry electrical current. Boron, Aluminum or Gallium have only three electrons in their outer shell and so there are “holes” in the crystal that can take up electrons (and therefore carry current). The ability of the electrons or holes to move is facilitated by the crystal structure but is counteracted by the electric charge of the nucleus of the impurity.

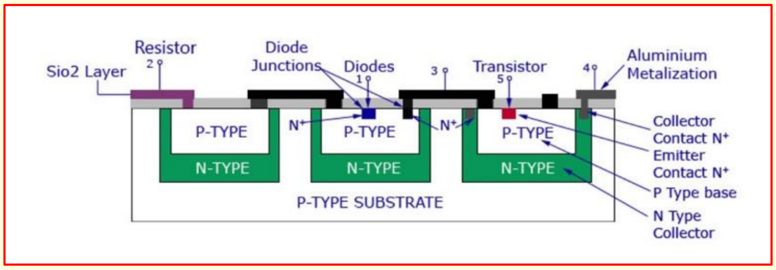
Semiconductors can also be made from compound crystals such as gallium arsenide – where the five electrons in one outer shell (arsenic) combine with 3 electrons from the other (gallium).

Semiconductor junctions work as simple diodes. Thus electrons more easily flow out of an n-type semiconductor than into it.

A triple junction (pnp or npn) – the transistor - can act like a triode amplifier. The current into or out of the base can increase or decrease the concentration of electrons or holes thereby modulating how much current flows from emitter to collector.

Transistors can function much the same as the old vacuum tube triodes (right). Their advantage is that they are much smaller and they lend themselves to making integrated circuits which can contain thousands of p-n and n-p junctions.



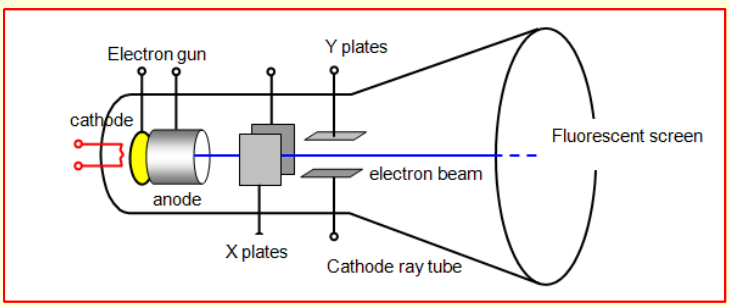


The base (B) of the transistor acts like the grid of a vacuum tube triode. It makes available more or less electrons or holes for current flow between the collector and the emitter.

Integrated circuits are made up of multiple layers of semiconductors. Etching on these lavers allows p-n and n-p junctions to be connected into complex circuits.

The first integrated circuits were developed in 1958 by Jack Kilby (1923-2005) while working at Texas Instruments. He won the Nobel Prize in Physics in 2000.

Cathode Ray Oscilloscope

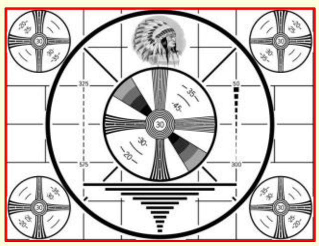


A beam of electrons is sent down a vacuum tube by an electron gun. This beam passes between two sets of deflecting plates and then strikes a fluorescent screen that glows when the beam hits it. The beam is directed by fields set up by the X and Y plates and the intensity of the beam depends on the current to the electron gun.

The first cathode ray oscilloscope was built in 1897 by the German physicist Karl Ferdinand Braun (1850-1918). It is still known as a Braun tube. Braun also was the first to use a crystal detector for receiving radio waves, and worked on the structure of radio antennas. He shared the Nobel Prize in Physics with Marconi in 1909.

Television

Many different scientists worked on the possibility of transmitting pictures via radio waves. The first commercial TV systems were made by RCA in the late 1940s using patents by Philo Farnsworth.



The first television broadcasts were intermittent and between the broadcasts all that was transmitted was the famous “Indian Head” test pattern. This was superseded by the color bar test pattern when color television arrived in the 1960s.

The signals on the X and Y plates of a cathode ray tube can be adjusted to move the electron beam in a raster fashion from the top to the bottom of the screen. By altering the intensity of the beam a picture can thus be traced out on the screen.

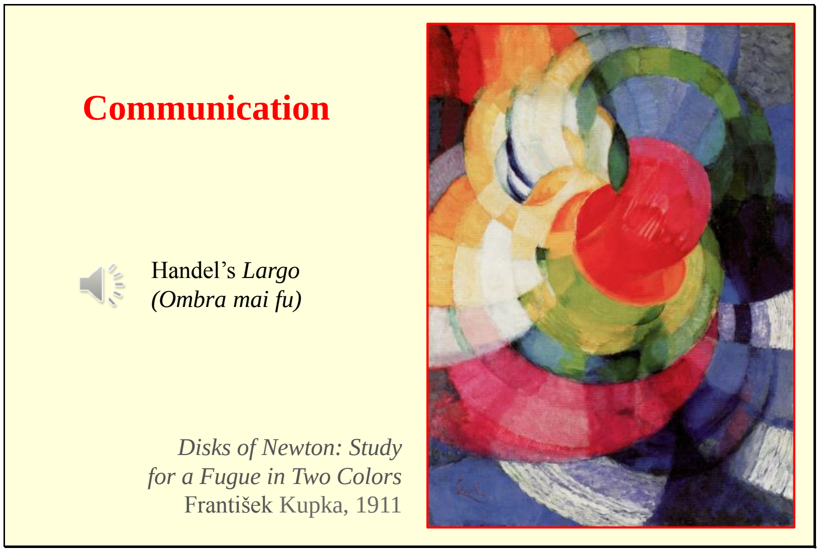
Martin Cooper (1928-)

Marty Cooper graduated from the Illinois Institute of Technology and went to work with Motorola in 1954. In the 1970s he developed the first mobile phone. The idea was that you could phone a person rather than a place. He has stated that his inspirations was Dick Tracy’s wrist radio.

Smartphones that include computer operating systems, web-browsing capability and cameras came into being in the 2000s.

https://www.theverge.com/2012/2/20/2811861/marty-cooper-interview

The illustration on the lower right shows the evolution of the mobile phone. The first goal was to decrease the size. With the advent of smartphones which use visual displays, mobile phones became larger.



The painting is a study of Newton's disks – the first attempt to understand electromagnetic radiation.

The sound is Handel's *Ombra mai fu* played by a Sousa Band recorded in 1904. This may have been the sound of the first radio broadcast on December 24 1906. Imagine what it might have been like to be a radio operator listening for the dots and dashes of Morse code and hearing the faint strains of Handel's Largo. The piece has been long associated with Christmas though I am not sure why. It comes from the opera *Xerxes* and it records the singer's love for the shade of a particular tree.

Recording is from the National Jukebox at the US Library of Congress which presents old recordings:
http://www.loc.gov/jukebox/recordings/detail/id/5488/