A HISTORY OF ELECTRONICS

Bolded capitalized words are in the Glossary at the end.

I. How Electronics Began

In 1800, people the world over lived much as they had for millennia, with no electric lights, without running water, and without most other modern conveniences. **Before the Flood man may have had technology we are not aware of, and early peoples after the Flood had running water and some other conveniences.**

By around 2000 BC, however, much of this early post-Flood technology had been lost, and technology stayed pretty much on the same low level for generations. Then in the late 1800s, technology began changing rapidly leading to advances such as the ones listed in the table below.

After thousands of years of using horses and other animals as transportation, motorized cars came into use slightly over a century ago. In 1900, the Wright brothers still had three years to go before flying the first successful airplane. Who could have guessed that air transportation would be a worldwide industry only a hundred years later? Also in the last hundred years, common diseases such as diphtheria and cholera have become almost unheard of due to medical advances.

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Life-Changing Technologies Beginning in the 1800s

Air flight	Electric lights
Automobiles	Refrigeration
Canned foods	Running water
Disease cures	Sewers

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As much as these technologies have changed the way people live, perhaps the most significant technological changes have come about through the science of **ELECTRONICS**. Electronics is the science concerned with the workings of radio, television, computers, and computer-controlled devices such as VCRs (video cassette recorders), CD (compact disk) players, DVD (digital video disk) players, and calculators.

Since most modern machinery is at least partly computer controlled, electronics has to do with all but the simplest appliances. Without electronics, modern automobiles would not run; airplanes would not fly; and man would never have travelled to the moon.

Though electronic devices such as computers use electricity, **there is a difference between "electronic," and "electric current." Electric current is confined to a wire.** By the late 1800s, there were many inventions which used electricity.

Electronics involves controlling the movement of electrons without wires. In some electronic devices, electrons move through a vacuum, and in others, they move through a gas or a semiconductor. In any electronic device, the movement of electrons is carefully controlled. In computers, for example, the movement of electrons is controlled to copy documents, music or photographs with flawless accuracy. The chart below lists some of the electric inventions of the 1800s in contrast with electronic inventions of the 1900s.

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Electric vs. Electronic Inventions

Electrical inventions of the 1800s	Electronic Inventions of the 1900s
Electric motor	Radio (modern), TV
Electric generator	Computer
Transformer	Calculator
Telegraph	Cell phone
Telephone	VCR, CD, DVD players
Light bulb	Digital photography
Phonograph	Flat screens (LCDs)
Moving picture film	Internet

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When electrons move in a copper wire, there is friction between the electrons and the atoms of copper. This friction makes it hard for the electrons to move and causes electrical resistance

Like the heat from rubbing your hands together, the friction of electrical resistance also generates heat. This is why electrical resistance causes a "load" in a circuit to get warm. Even the wires in an electrical circuit generate a little heat because of their electrical resistance.

If electric current could move in a vacuum without wires, there would be no electrical resistance. Even as scientists of the 1800s were making wonderful electrical inventions, they wondered, Can we eliminate electrical resistance by making electrons move in a vacuum? Can we make a "wireless" electric current? **Efforts to make a "wireless" electric current in the 1800s led to the electronics of the 1900s.**

In 1838, Michael Faraday made the first known try at passing an electric current through a vacuum. He did not succeed because his vacuum pump was too weak to make a really good vacuum.

In 1854, Heinrich Geissler, a German glass blower, invented a better vacuum pump. Together with German physicist Julius Plücker, Geissler made a glass tube with all the air sucked out. We say that all the air was "evacuated" from the glass tube, or that the glass tube was evacuated. At each end of the glass tube, Plucker and Geissler installed a wire called an **ELECTRODE**.

Geissler found that an electric current went from one electrode to the other across the vacuum in the tube. For the first time, electric current had been made to travel without wires, and he "Geissler tube," as it came to be known, was the first "electronic" device. **The Geissler tube was a VACUUM TUBE, a sealed glass tube with a vacuum inside through which electrons could move.**

A Geissler tube filled with neon at low pressure is a neon light. Electric current passing through neon makes the neon glow red-orange. Other gases in a Geissler tube make other colors. Oxygen is blue-violet, carbon dioxide is pale blue, sodium vapor is bright yellow, and mercury vapor is blue-green.

"Sodium vapor" lights are Geissler tubes which illuminate interstate highway intersections and other busy highways which need brilliant lighting at night. Less expensive and dimmer "mercury vapor" lights, another type of Geissler tube, are used for lighting parking lots and roadways.

In the 1860s English chemist and physicist William Crookes experimented with a modified Geissler tube. The "Crookes tube," as it was later called, was shaped like a horizontal ice cream cone. One end was narrow like the bottom of an ice cream cone. The other end was wide.

Crookes installed an electrode at the narrow end. He coated the inside of the wide end with a fluorescent material similar to that used in modern fluorescent bulbs or television screens. He also positioned another electrode in the wall of the tube midway from either end.

Crookes then connected the electrode at the narrow end to a source of electric current. Electrons in the electric current left this electrode, travelled across the vacuum, and lit up the fluorescent coating on the other end. **Crookes had made the first "television screen."** We say that the electrode giving off the electrons is the **CATHODE**. The other electrode is the **ANODE**. The stream of electrons travelling across the vacuum is called an **ELECTRON BEAM**.

When Crookes did his experiments, electrons had not been discovered. All Crookes knew was that connecting the cathode to a source of electric current made "something" travel straight from the cathode to the opposite end of the vacuum tube where it lit up the fluorescent screen.

This "something" could not be current electricity because it did not travel from one electrode (the cathode) to the other electrode (the anode). Since this unknown came from the cathode, physicists called it "cathode rays." The Crookes tube became known as a **CATHODE RAY TUBE (CRT)**.

After more experimentation, physicists concluded that cathode rays were actually tiny particles of some kind. In 1897, British physicist Joseph John Thomson discovered that these were the particles we now call electrons.

Based on his discovery, Thomson developed the model of the atom named after him, the "Thomson model." According to this model, the atom has a nucleus surrounded by electrons. Crookes' experiments are an example of how one scientific discovery can lead to another. Crookes did not start out to discover electrons, but his experiments led to this result.

Television screens and older computer screens are still sometimes called CRTs. Though more sophisticated than the original Crookes tube, they work on the same principle, by an electron beam striking a coating on the inside of the glass screen to make a picture. Flat computer screens are not CRTs, but use a different technology called "liquid crystal display" (LCD).

II. Practical Electronic Inventions

Discoveries in the 1800s were the beginning of electronics. By the early 1900s, electronics was about to make a big change from focusing on basic discoveries to producing practical inventions.

Accidents, both good and bad, often influence research in science. When Crookes began experimenting with the vacuum tube named after him, he did not expect to stumble on evidence that cathode rays were really particles. This discovery was an accident, but it was a fortunate one -- an example of serendipity. It led to the discovery of electrons.

American inventor Thomas Edison made another fortunate but accidental discovery. It came about from his invention of the first practical incandescent light bulb in 1879. Over the next four years he tried to make the incandescent light bulb better.

He searched for a filament that would not burn out too quickly, trying hundreds of materials from string to human hair. Finally he found that carbon filaments lasted for several hours. (Modern incandescent light bulbs use tungsten filaments and usually last for weeks.)

However, long before the filament burned out, particles of carbon -- like the soot produced in a fire -- would burn off the filament and coat the inside of the bulb, dimming its light. To prevent this, he positioned a small metal square called a "plate" near the filament. He then charged it by wiring it a source of electric current, reasoning that particles of soot would be attracted to it rather than the bulb.

This idea did not work. Carbon still coated the inside of the glass even with the metal plate installed, but there was also a faint blue light from the filament to the plate. This blue light was actually an electric current, somewhat like the electron beam in a Crookes tube.

Edison had accidentally discovered that a hot glowing filament gives off electrons in the process now known as THERMIONIC EMISSION of electrons. In a normal light bulb, the electrons stay in a cloud around the filament. In Edison's special light bulb equipped with the metal plate, charging the plate caused it to attract electrons provided the charge was positive. A negative charge on the metal did nothing.

The blue light between the filament and a positively charged metal plate is called "Edison effect." Knowing that the blue light was really an electric current of moving electrons, we can understand why a positively charged plate would generate thermionic emission. Electrons are negative. A positively charged plate has the opposite charge. Since like charges attract, electrons would stream to the plate. A negatively charged plate could not attract electrons since like charges repel.

By accident Edison had stumbled on the first "electronic switch." A switch turns electric current on or off, but before Edison's chance discovery, all switches were mechanical -- a person had to physically move a contact into an "on" or "off" position, as when using a wall-mounted electric light switch.

Edison's "electronic switch" was not mechanical. The current between the filament and the plate could be turned on by making the plate positive. Making the plate negative turned the current off again. The switching was completely electrical with no moving parts.

Edison failed to see the significance of his discovery. Indeed, he thought it was impractical -- and so it was for many years. He put his experimental bulb away and continued to search for the perfect incandescent light bulb. Twenty-one years would pass before the importance of the Edison effect was recognized.

III. The Diode

In the 1870s German physicist Heinrich Hertz was the first to send radio waves across space. He beamed radio waves several meters across his laboratory.

Not many years later, in the 1890s, Italian electrical engineer Guglielmo Marconi showed that radio waves could be sent long distances through the air. A radio "receiver" could pick up these radio waves at a great distance from a radio "transmitter."

It is sometimes said that Marconi invented radio. This may be true in the most basic sense, but Marconi's radio was nothing like modern radio. It could not transmit speech or music, and few stores sold radio sets. Most people wishing to listen to radio built their own receivers.

In fact, Marconi's invention was used only for transmitting telegraph messages, but at the time this was a remarkable invention. Previously, all telegraph messages were transmitted over wires similar to modern telephone wires hung from telephone poles. **Marconi's invention allowed telegraph messages to be transmitted without wires, and ships at sea to send and receive "wireless" messages.**

These early "radio-telegraph" systems were not very sensitive. Even with headphones, incoming signals were extremely weak and hard to hear. How could incoming telegraph messages be strengthened to be clearer?

English engineer John Ambrose Fleming set out to solve this problem. He had been a consultant to Edison in the 1880s, and he knew of the Edison effect. Fleming wondered if the type of bulb producing the Edison effect might be used to strengthen radio signals.

In 1904, Fleming retraced Edison's steps. Since Edison had evacuated the air from the bulb, it was really a kind of vacuum tube. Fleming built a vacuum tube similar to the special bulb Edison had made twenty-one years earlier. Like Edison's experimental bulb, Fleming's vacuum tube had two electrodes –- a filament and a metal plate.

Fleming had made a DIODE, a vacuum tube with two electrodes. He connected the filament to a source of current, and wired the metal plate to a radio antenna and headphones. Radio waves striking the antenna would then produce a weak electric current to the plate.

Fleming believed that the metal plate would act as an "electronic switch" to turn current on and off between the filament and the plate. Weak current coming into the plate from the antenna would attract electrons from the filament and become stronger. This stronger current would then go to the headphones producing a loud and clear signal.

IV. The Triode

Fleming's idea worked, but not well. The sound in the headphones was still too weak to be practical. Two years later, American inventor Lee De Forest finally solved the weak-signal problem. He invented a three-electrode vacuum tube called the **TRIODE**. The triode had a third electrode called a "grid," a small screen or spiral length of wire between the filament and the plate. A separate current to the grid controlled how many electrons went to the plate from the filament.

How did the grid work? Electrons from the filament had to pass through the grid on their way to the plate. A few electrons would strike the wire grid and be deflected, but most electrons would pass through as if

the grid were not there. However, a small electric charge on the grid made a large change in the number of electrons reaching the plate. A negative charge on the grid repelled electrons coming from the filament, and depending on the charge, few or no electrons reached the plate. In other words, **the size of the current between the filament and the plate depended on the amount of charge on the grid.**

A positive charge on the grid attracted electrons, and current would flow between the filament and the grid rather than between the filament and the plate. This reduced the current reaching the plate. Again, current to the plate depended on the charge on the grid.

By changing the amount of current falling on the plate, De Forest's triode functioned as an amplifier. A slight change in charge on the grid made a large change in the current flowing between the filament and the plate. **The triode made it possible to amplify weak radio signals**, and radio-telegraphy rapidly advanced. As mentioned earlier, however, radio-telegraphy transmitted only Morse code, not voice or music.

Several years earlier in 1875, Alexander Graham Bell had invented the telephone, and telephone technology became the key for introducing speech into radio. **A telephone mouthpiece converts the voice to an electrical signal sent over a wire.** Inventors wondered if a modified telephone could convert the human voice to a radio wave which could be transmitted to radio receivers far away.

In radio, the microphone in the radio studio is like the telephone mouthpiece. **The microphone changes sound waves into electrical impulses. The radio receiver is like the telephone receiver. It changes incoming electrical impulses into sound we can hear.** The radio waves are like the electrical impulses in the telephone wires.

The electrical impulses that a microphone produces have the same frequencies as the original sound waves. We say they have "audio frequencies." As discussed in Chapter 9, the frequency of audible sound waves ranges from about 20 Hz to 20,000 Hz. Radio waves have a much higher frequency, typically one million to 100 million Hz, as discussed in Chapter 10. We call these frequencies "radio frequencies."

To transmit audio frequencies -- speech and music -- by radio waves, the audio frequencies are impressed on a radio wave called a "carrier wave." A carrier wave modified by the audio frequency impressed on it is said to be "modulated." At the radio station, a device called a "modulator" combines the acoustic frequency with the carrier wave to form a modulated radio wave.

There are two types of carrier wave modulation. The first type is **AMPLITUDE MODULATION** (AM). With AM, the carrier wave is made to vary in amplitude according to the audio frequency impressed upon it. In the radio receiver, the amplitude variation is converted to electrical impulses which are sent to speakers or headphones. The speakers or headphones work like a telephone receiver to change the electrical impulses back into sound waves.

However, lightning, automobile ignition systems, and electric motors near an AM receiver can produce static interference. To avoid this problem, in 1933 American inventor Edwin Armstrong developed a second type of carrier wave modulation called **FREQUENCY MODULATION** (FM). Static does not affect FM.

With FM, the audio frequency is impressed on the carrier wave by changing the frequency of the carrier wave in step with the audio frequency. FM carrier waves have frequencies of about 100 million Hz, compared with typical AM frequencies around one million Hz). The frequency variations needed for audio frequencies (about 20-20,000 Hz) are an extremely small percentage of the carrier wave frequency. Thus the FM carrier wave always has practically the same frequency even with audio frequencies impressed upon it.

By law, a commercial radio station uses a carrier wave of a set frequency. **"Tuning" a radio means you are finding the carrier wave frequency assigned to the station you want to hear.** Radio stations often advertise the carrier wave frequency, though each station also has an official set of call letters.

Television broadcasters use FM radio waves in a slightly different range of frequencies from FM radio. A television "channel" corresponds to a certain carrier wave frequency. A television receiver processes the incoming carrier wave to retrieve both sound (the "audio signal") and picture (the "video signal"). Like radio stations, television stations have call letters.

By 1910 privately owned radio transmitters were broadcasting voice communications world wide. In the 1920s, commercial radio stations began broadcasting regularly, and most homes in the United States, Canada, and several European countries had at least one radio receiver. Though completely unexpected, vacuum tubes and modulated radio waves had revolutionized communication in just a few years.

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Radio Station Call Letters

Radio stations each have official call letters such as WEKU or WSM. Call letters are sometimes referred to as "call signs." Call letters for stations east of the Mississippi River start with W, and those west of the Mississippi start with K. Exceptions are made for call letters in use before this rule began. For example, the first commercial radio station began broadcasting in 1920. It was KDKA in Pittsburgh. Its call sign is still KDKA even though it is east of the Mississippi River.

Call signs are vital for radio bands in which many people may be sharing the same carrier frequency, such as ham radio and citizens band (CB) radio. The call sign is the only way to tell one operator from another.

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V. Television

Inventors began working transmitting pictures by television in the early 1900s. Three of these inventors were the American scientists Charles Ives, Philo Farnsworth, and Russian immigrant Vladimir Zworkin. Zworkin made a crude television system in 1923, but it did not transmit a clear picture. A viewer could not tell what was on the TV screen without being told. Ives' television system had the same problem.

Farnsworth invented the first clear-picture television system in 1929, a fact officially recognized in 1974 when a United States postage stamp commemorated his "First Television Camera."

Using Farnsworth's ideas, Zworkin, working for the Radio Corporation of America (RCA), prepared television for commercial marketing. The first TV sets for sale to the public were RCA sets on display at the 1939 World's Fair in New York. These TV sets had a black-and-white picture. Color TV came later.

The onset of World War II in 1940 ended the sale of TVs for time as RCA and other manufacturers went into weapons production for the war. With the end of the war, families began buying TV sets in huge numbers. By 1960, most American families had at least one black-and-white TV set. Color TV was perfected in the 1960s, and by the 1970s, nearly all American TV programming was in color.

We can illustrate the idea behind the workings of a television picture by looking at a newspaper photograph. You may have noticed that a newspaper photograph is made of many hundreds of tiny dots. From a normal distance, the brain blends the dots to form the picture. A television or computer screen uses the same principle, whether it is color or black-and white, a CRT or a flat screen LCD. **The screen contains many dots or "pixels." At normal viewing distance, the brain blends the pixels into a smooth image.**

With the exception of flat screens, a television screen is a vacuum tube, and like the Crookes tube, it is a CRT. The CRT is narrow at one end and flares into the television screen at the other end. Pixels of a zinc-sulfide compound are printed on the inside of the screen. The narrow end of the vacuum tube has an "electron gun" which shoots a beam of electrons at the screen.

When the electron beam strikes a zinc sulfide pixel, the pixel lights up for a fraction of a second. Hundreds of pixels lighting up in the right sequence make the TV picture. The order in which the electron beam strikes the pixels is called **SCANNING**.

What makes the brain "see" a smooth picture on a TV screen instead of individual pixels? First, the pixels on the screen are tiny. Television screens have thousands of pixels, and some computer screens have even more. It is impossible to see just one pixel from a normal viewing distance. Second, the scanning process is too fast to register on the brain. Each complete scan of the screen takes only 1/60th of a second.

Third, each pixel glows for a short time even after the electron beam has passed over it. This property is known as **PHOSPHORESCENCE**. A pixel glowing from one scan is not completely dark when the next scan happens. Phosphorescence blends the light from one scan with the light of the next scan to form a fairly continuous picture.

Finally, **the human eye has "persistence of vision." Even after the source of light has disappeared, our eyes continue to "see" the light for a fraction of a second longer.** Persistence of vision causes the brain to "see" an even smoother TV picture than would otherwise be possible.

VI. Solid State Electronics

Scientific theories regularly fail or pass away with new discoveries. For example, the "phlogiston theory" of combustion was in fashion until the late 1700s. Today no one believes in phlogiston, yet for several lifetimes most experts taught it as if it were absolutely true. Thermionic emission and vacuum tubes were wonderful discoveries, but these, too, have mostly faded away because of **SOLID STATE** electronics.

Vacuum tubes must have a hot filament which gives off the electrons that allow the vacuum tube to function. As with incandescent light bulbs, however, the filament in a vacuum tube also produces a lot of unwanted heat. This means that vacuum tubes get hot.

The first computers in the 1940s were operated with vacuum tubes, and had to be cooled by massive air conditioning systems because the vacuum tubes generated so much heat. CRT-type screens get warm for the same reason.

The CRT is a vacuum tube with a filament, and when the tube is on, the filament is hot. Put your hand near the back of an old-fashioned CRT-type TV or computer screen, and you can feel the heat the filament produces.

With solid state electronics, almost all vacuum tubes are replaced by TRANSISTORS and other electronic parts made of semiconducting solids. Semiconductors sometimes conduct electric current but under other conditions do not. When conducting, a semiconducting component is "on." Otherwise it is "off." By turning a semiconducting component "on" or "off," electron flow is controlled.

Transistors and other solid state parts do not generate nearly as much heat as vacuum tubes, and they last longer. When the filament of a vacuum tube burns out, the vacuum tube is useless. Solid state parts have no filament to burn out and can last for years.

American physicists John Bardeen, Walter Brattain, and William Shockley at Bell Telephone Laboratory made the first transistor in December, 1947. Like a triode, a transistor amplifies an incoming signal. Transistors eventually replaced vacuum tubes in most radios, televisions, and other electronic equipment. The only vacuum tube used much today is the CRT-type screen. Now even these are being replaced by flat screens that work by liquid crystal display (LCD) technology.

The most important advantage of transistors is that they are much smaller than vacuum tubes. An old fashioned vacuum tube was usually the size of a small incandescent light bulb. While this may sound small, electronic equipment requiring many vacuum tubes could be extremely bulky.

The first digital computer built in the 1940s used thousands of vacuum tubes and was the size of a small house. Known as ENIAC, it was capable of calculations no more sophisticated than those possible on a modern hand-held calculator. Desk-top and "notebook" computers never could have been developed without the reduction in size from vacuum tubes to transistors.

In the 1960s electrical engineers developed methods for printing hundreds or even thousands of transistors and other solid-state parts on a single small chip of material. The first "chips" were the size of a large postage stamp. They were actually complicated electrical circuits condensed into a very small space. Since they combined or "integrated" many electrical components, they were called **INTEGRATED CIRCUITS** (ICs). With old fashioned vacuum tubes, these same circuits would have taken up the space of a large room.

The first ICs could do thousands of mathematical calculations each second. Modern ICs are much smaller and faster still. In the newest personal computers, the "central processing unit" (CPU), often called a computer "chip," is an IC with many microscopic transistors and other electronic parts capable of billions of computations per second. Faster computer chips have given us faster computers.

Because they are so small, ICs have also made smaller computers, calculators, watches, and other electronic devices possible.

Since an IC is really a computer chip, ICs can be programmed to control the circuits of many appliances, including washing machines, dryers, microwave ovens, sewing machines, and cell phones. ICs also control engine operation in modern automobiles.

Glossary

AM = amplitude modulation
anode = an electrode which receives electrons
cathode = an electrode emitting electrons
CRT = cathode ray tube; a vacuum tube designed to produce a picture
diode = vacuum tube with two electrodes
electrode = the end of a current-carrying wire
electron beam = current of electrons, usually in a vacuum
electronics = science of controlling electron current without wires
FM = frequency modulation
integrated circuit = solid-state circuit printed onto a chip
phosphorescence = delayed production of light
scanning = sequence of pixel exposure to an electron beam
solid state = describes an electronic part made of semiconductors
thermionic emission = electrons ejected from an extremely hot wire
transistor = solid state amplifier
triode = a vacuum tube with three electrodes; a type of amplifier
vacuum tube = incandescent bulb designed to produce an electron beam