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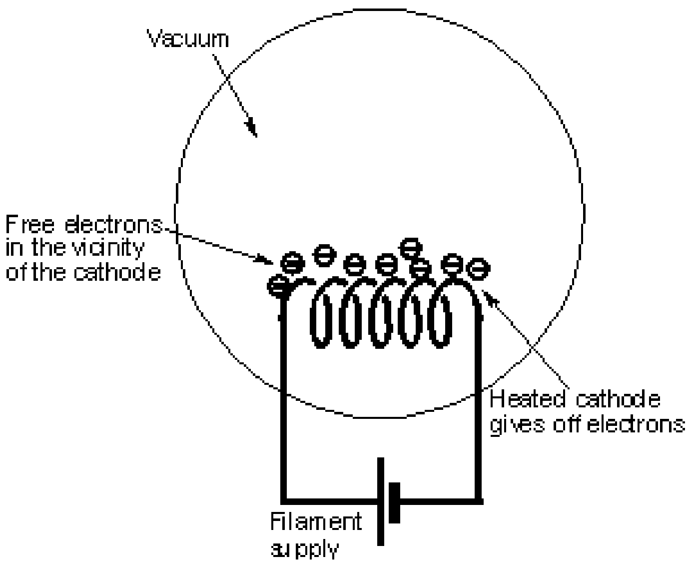
Vacuum Tubes or Thermionic Valves come in many forms including the Diode, Triode, Tetrode, Pentode, Heptode and many more. These tubes have been manufactured by the millions in years gone by and even today the basic technology finds applications in today's electronics scene. It was the vacuum tube that first opened the way to what we know as electronics today, enabling first rectifiers and then active devices to be made and used.

Although Vacuum Tube technology may appear to be dated in the highly semiconductor orientated electronics industry, many Vacuum Tubes are still used today in applications ranging from vintage wireless sets to high power radio transmitters.

Until recently the most widely used thermionic device was the **Cathode Ray Tube** that was still manufactured by the million for use in television sets, computer monitors, oscilloscopes and a variety of other electronic equipment.

Concept of thermionic emission



Thermionic basics

The simplest form of vacuum tube is the Diode. It is ideal to use this as the first building block for explanations of the technology. It consists of two electrodes - a **Cathode** and an **Anode** held within an evacuated glass bulb, connections being made to them through the glass envelope.

If a Cathode is heated, it is found that electrons from the Cathode become increasingly active and as the temperature increases they can actually leave the Cathode and enter the surrounding space.

When an electron leaves the Cathode it leaves behind a positive charge, equal but opposite to that of the electron. In fact there are many millions of electrons leaving the Cathode. As unlike charges attract, this means that there is a force pulling the electrons back to the Cathode. Unless there are any further influences the electrons would stay in the vicinity of the Cathode, leaving the Cathode as a result of the energy given to them as a result of the temperature, but being pulled back by the positive charge on the Cathode.

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The Diode – the simplest tube

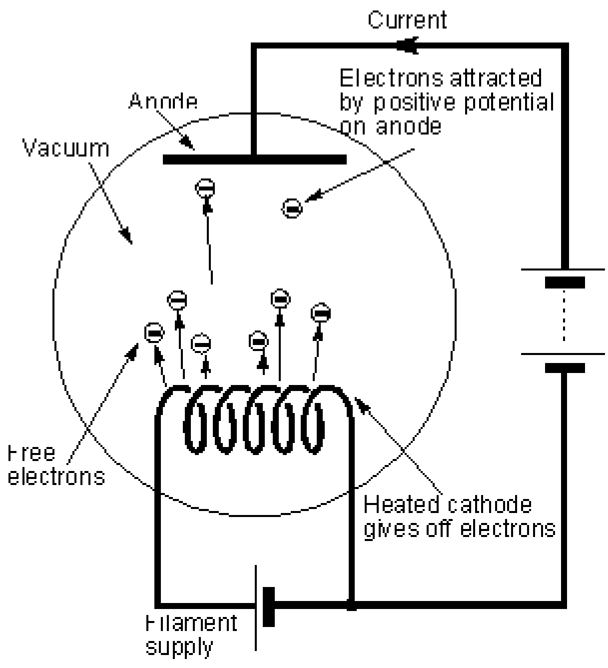
In a Diode Vacuum Tube there is also another electrode called the Anode. If a positive potential is applied to this electrode, the electrons will be attracted by this potential and will move towards it if it is at a higher potential than the Cathode.

For the optimum performance the space between the Cathode and the Anode should be a vacuum. If there are any gas molecules in the space in which the electrons travel, collisions will occur and this will impede the flow of electrons. If an appreciable amount of gas is present, the electrons will ionise the gas, giving rise to a blue glow between the electrodes. In the early days of valves, it was thought that a certain amount of gas was necessary in the envelope. Later this was discovered that this was not the case and new **"hard valves"** were made that had a superior performance to the older **"soft valves"**. Very early radio receivers often used a soft valve for the detector stage and hard valves for the other stages.

Space charge

The electrons flowing between the Cathode and the Anode form a cloud which is known as the **"space charge"**. It can tend to repel electrons leaving the Cathode, but if the potential applied to the Anode is sufficiently high then it will be overcome, and electrons will flow toward the Anode. In this way the circuit is completed and current flows.

As the potential is increased on the Anode, so the current increases until a point is reached where the space change is completely neutralised and the maximum emission from the Cathode is reached. At this point the emission can only be increased by increasing the Cathode temperature to increase the energy of the electrons and allow further electrons to leave the Cathode.



Concept of vacuum tube diode with cathode and anode

If the Anode potential is reversed, and made negative with respect to the Cathode it will repel the electrons. No electrons can be emitted from the Anode as it is not hot and no current flows. This means that current can only flow in one direction. In other words the device only allows current in one direction, blocking it in the other. In view of this effect, the inventor of the Diode vacuum tube, **Professor Sir Ambrose Fleming** called it an **"oscillation valve"** in view of its one way action ?.

Control of current flow

Although the basic concept of the vacuum tube enabled a rectifier to be made, it does not allow for another form of control of the flow of electrons in the Anode circuit. However it was discovered that is a further potential was placed between the Cathode and the Anode this could be used to control the flow of electrons between the Cathode and Anode. Once the theoretical idea was devised, it was necessary to implement a way of placing this potential in the right place. An electrode known as a Grid, in the form of a thin mesh or wire through which the electrons could pass, was inserted between the Cathode and Anode.

It was found that by varying the potential on the Grid, this could alter the flow of electrons. The Grid is normally placed at a voltage below that of the Cathode so that it repels the electrons and counteracts the effect of the pull on the electrons from the potential on the Anode. If the voltage on the Grid is varied then it will vary or control the level of current flowing between the Cathode and the Anode. As such, this form of grid is known as a **Control Grid**. It makes the vacuum tube into an active device that is capable of amplifying signals.

Further grids

The basic thermionic tube with three electrodes is called a **Triode** in view of the number of electrodes. To improve the performance of the tube, further grids may be added. These tubes are given generic names that describe the number of electrodes, and thereby giving an indication of the type of tube and performance.

Number of grids	Total number of electrodes	Generic name
1	3	Triode
2	4	Tetrode
3	5	Pentode
4	6	Hexode
5	7	Heptode
6	8	Octode

The basic concept of the vacuum tube outlined here enables signals to be rectified and amplified. Many refinements have been added in the form of further grids to enable much better performance to be obtained, but the principles involved are all the same.

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Vacuum tube electrodes

The Cathode

There is a variety of different types of Cathode that are used in vacuum tubes. They differ in the construction of the Cathode and the materials used.

One of the major ways in which Cathodes can be categorised is by the way they are heated. The first type to be used was what is termed **directly heated**. Here a current is passed through a wire to heat it. In addition to providing the heat it also acts as the Cathode itself, emitting the electrons into the vacuum. This type of Cathode has the disadvantage that it must be connected to both the heater supply and the supply used for use in the Cathode - Anode circuit itself. This has disadvantages because it limits the way the circuit can be biased unless each heater is supplied separately and isolated from each other. A further disadvantage is that if an alternating current is used to provide the heating, this signal can be superimposed upon the main Cathode - Anode circuit, and there is a resultant hum at the frequency of the heater supply. The second type of Cathode is known as an **indirectly heated** Cathode. Here the heater is electrically disconnected from the Cathode, and heat is radiated from the heater to heat the Cathode. Although as a rule it takes longer for these types of tubes to warm up, they are almost universally used because of the flexibility this provides in biasing the circuits, and in isolating the Cathode - Anode circuit from the effects of hum from the heater supply.

The earliest type of Cathode is known as a **bright emitter** Cathode. This type of Cathode uses a tungsten wire heated to a temperature of between 2500 and 2600 K. Although not widely used these days, this type of Cathode was used in high power transmitting tubes such as those used for broadcasting. It suffers a number of drawbacks, one being that it is not particularly efficient in terms of the emission gained for the heat input. The life of the Cathode is also limited by the evaporation of the tungsten with failure occurring when about 10% of the tungsten has gone.

A further type of Cathode is known as a **dull emitter**. These Cathodes are directly heated and consist of **thoriated tungsten**. They provide more emission than a tungsten Cathode and require less heat, making the overall efficiency of the tube greater. Typically they run at a temperature of between 1900 and 2100 K. Although these Cathode normally have a relatively long life, they are fragile and any valves or tubes using them should be treated with care and they should not be subjected to technical shocks or vibration.

The type of Cathode that is in by far the greatest use is the **oxide coated** Cathode. These may be used with indirectly heated cathodes, unlike the tungsten and dull emitter Cathodes that must be directly heated as a result of the temperatures involved. This type of Cathode is normally in the form of nickel in the form of a ribbon, tube or even a small cup shape. This is coated with a mixture of **barium and strontium carbonate**, often with a trace of calcium added. During the manufacturing process the coating is heated to reduce it to its metallic form and the products of the chemical reaction are removed when the tube is finally evacuated. In this Cathode it is the barium that acts as the primary emitter and it operates at a much lower than the other types being in the region of 950 - 1050 K.

A wide variety of electron tubes have used radioactive material as a **cold cathode** - voltage regulators, spark-gap tubes, voltage sensitive switching tubes, glow lamps, etc. In general, such tubes consist of a gas filled glass envelope, a radioactive source, an Anode and an unheated (cold) Cathode. An interesting cold cathode tube was the 0Z4, a rectifier tube that was often used in tube car radios in the 1950's. This tube did not use a radio active Cathode, it utilised a starter electrode and an Ionically heated cathode

More information on radio active cold Cathode devices on this web site:

https://www.orau.org/ptp/collection/consumer%20products/electrontubes.htm

The Anode (called the Plate in the early days of tube technology)

The Anode is generally formed into a cylinder so that it can surround the Cathode and any other electrodes that may be present. In this way the vacuum tube can be constructed in a tubular fashion and the Anode can collect the maximum number of electrons.

For the smaller tubes used in many radio receivers, the Anodes are generally made of nickel plated steel or simply from nickel. In some instances where larger amounts of heat need to be dissipated it may be carbonised to give it a matt back finish that enables it to radiate more heat out of the tube.

For applications where even higher powers are required, the Anode must be capable of dissipating even more heat, and operating at higher temperatures. For these tubes, materials including carbon, molybdenum, or zirconium may be used. Another approach is to build heatsink fins into the Anode structure to help radiate the additional heat. This approach is naturally limited by the construction of the device and the fact that the tube needs to be contained within its glass envelope. However a large heatsink structure will require the glass envelope to be much bigger, thereby increasing the costs.

To overcome this problem the Anode may be manufactured so that heat can be transferred outside the valve and removed using a forced air or a water jacket. Using this approach the envelope of the tube can be made relatively small, while still be able to handle significant levels of power.

The Grid

We have already discovered the Grid is the electrode by which the current flowing in the Anode circuit can be controlled by another potential. In the most basic form a vacuum tube may have one Grid. It is possible to use more than one to improve the performance or to enable additional functions to be performed. Accordingly tubes are named by the number of electrodes they contain that are associated with the electron flow. In other words the filaments or heaters and other similar elements are omitted.

A Grid is normally constructed in the form of a gauze mesh or a wire helix. If made of wire, it normally consists of nickel, molybdenum or an alloy and is wound using supporting rods that keep it clear of the Cathode. As such they may be wide, possibly oval in shape and they are generally made from copper or nickel.

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To achieve a high level of performance that is repeatable, the tolerances within the vacuum tube must be maintained from one device to the next. In addition to this it is often necessary to mount the Grid only fractions of a millimetre away from the Cathode or other Grids. To be able to maintain these dimensions one approach that is adopted is to use a stiff rectangular frame and then wind the grid wire onto this under tension. This structure then needs to be fixed by the use of glazing or even gold brazing so that it remains firmly in place. Under some circumstances it may even be necessary to grind the cathode surface coating to ensure its flatness. This form of Grid is known as a **Frame Grid**. Look inside most tubes and you will see mica structures the support the elements.

One important aspect of the design of vacuum tubes is to ensure that the Grid does not overheat. This could lead to mechanical distortion and failure of the whole tube. To assist in the removal of heat the Grid wire may be carbonised, and often cooling fins may be attached to the Grid supporting wires. These supporting wires may also be welded directly to the connection pins in the base of the tube so that heat may be conducted away through the external connections.

A wide variety of vacuum tubes are available even today. Using the techniques that have been developed over many years they are able to offer excellent repeatability, performance and reliability.

The above information was adapted from the site http://www.radio-electronics.com/info/data/thermionic-valves/vacuum-tube-theory/tube-tutorial-basics.php

Naming the Grids

The first Grid is called the **Control Grid** (Grid 1), the second grid is called the **Screen Grid** (Grid 2) and in a Pentode the third grid is called a **Suppressor Grid** (Grid 3). With tubes with more than three Grids the other grids are usually named in the same way, Grid 4 Grid 5 etc. In many special purpose tubes with more Grids, some of the Grids may be internally connected to other elements.

The Triode

The Triode has a Cathode, a Control Grid and an Anode. Any where you have two conductors separated by an insulator you have capacitance, As a result, the Anode and Grid in a Triode Tube have capacitance, (referred to as **parasitic capacitance)** between them. Because the tube inverts the signal the capacitance appears to be much bigger than it actually is. This is known as the **Miller effect** and accounts for the increase in the equivalent input capacitance of an inverting voltage amplifier due to amplification of the effect of capacitance between the input and output terminals.

The Miller capacitance between the input and the output of active devices like Vacuum Tubes is a major factor limiting their gain at high frequencies. Miller capacitance was identified in 1920 in T vacuum tubes by John Milton Miller. The Miller Capacitance also can cause instability in high frequency/high gain circuits. This same effect also applies to Transistor circuits.

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The Tetrode, Pentode and Beam Tetrode

To combat the stability problems and limited voltage gain due to the **Miller effect**, the physicist **Walter H. Schottky** invented the **Tetrode** tube in 1919. He showed that the addition of a second Grid, located between the Control Grid and the Anode, known as the ***Screen Grid***, could solve these problems.

"Screen" in this case refers to electrical "screening" or shielding, not physical construction - all "Grid" electrodes in between the Cathode and Anode are "screens" of some sort rather than solid electrodes since they must allow for the passage of electrons directly from the Cathode to the Anode).

A positive voltage slightly lower than the Anode voltage was applied the Screen Grid, and was bypassed (for high frequencies) to ground with a capacitor. This arrangement decoupled the Anode and the Control Grid, essentially eliminating the Miller capacitance and its associated problems. Consequently, higher voltage gains from a single tube became possible, reducing the number of tubes required in many circuits. This two-Grid tube is called a ***Tetrode*****,** meaning four active electrodes, and was common by 1926.

However, the Tetrode had one new problem. In any tube, electrons strike the Anode with sufficient energy to cause the emission of electrons from its surface. In a Triode this so-called **secondary emission of electrons** is not important since they are simply re-captured by the more positive Anode. But in a Tetrode they can be captured by the Screen Grid also acting as an Anode, since it is also at a high voltage, thus robbing them from the Anode current and reducing the amplification of the device.

Since secondary electrons can outnumber the primary electrons, in the worst case, particularly as the Anode voltage dips below the Screen voltage, the Anode current can decrease with increasing Anode voltage. This is the so-called "**Tetrode kink**" and is an example of negative resistance which can itself cause instability. The otherwise undesirable negative resistance was exploited to produce an extremely simple oscillator circuit only requiring connection of the plate to a resonant LC circuit to oscillate; this was effective over a wide frequency range.

The solution was to add another Grid between the Screen Grid and the Anode, called the **Suppressor Grid**, since it suppressed secondary emission current toward the screen grid. This grid was held at the Cathode (or "ground") voltage and its negative voltage (relative to the Anode) electrostatically repelled secondary electrons so that they would be collected by the Anode after all.

This three-grid tube is called a **Pentode**, meaning five electrodes. The Pentode was invented in 1926 by **Bernard D. H. Tellegen** and became generally favoured over the simple Tetrode. Pentodes are made in two classes: those with the suppressor grid wired internally to the Cathode and those with the Suppressor Grid wired to a separate pin for user access.

An alternative solution for power applications is the **Beam Tetrode** or "**Beam Power Tube**. This is a type of Tetrode vacuum tube with auxiliary beam-focusing Plates designed to augment power-handling capability and help reduce unwanted emission effects. These tubes are usually used for power amplification, especially at audio-frequency.

Multifunction and multisection tubes

Superheterodyne receivers require a local oscillator and mixer, can use a tube that combines these two functions into a single **Pentagrid Converter tube**. Various alternatives such as using a combination of a Triode with a Hexode and even an Octode have been used for this purpose. The additional Grids include both Control Grids (at a low potential) and Screen Grids (at a high voltage). Many designs used such a Screen Grid as an additional Anode to provide feedback for the oscillator function, whose current was added to that of the incoming radio frequency signal.

To further reduce the cost and complexity of radio equipment, two separate structures (Triode and Pentode for instance) could be combined in the bulb of a single **multisection *tube***. An early example was the Loewe 3NF. This 1920s device had three Triodes in a single glass envelope together with all the fixed capacitors and resistors required to make a complete radio receiver. As the Loewe set had only one tube socket, it was able to substantially undercut the competition since, in Germany, state tax was levied by the number of sockets. However, reliability was compromised, and production costs for the tube were much greater. In a sense, these were akin to integrated circuits. In the US, Cleartron briefly produced the "Multivalve" triple triode for use in the Emerson Baby Grand receiver. This Emerson set also had a single tube socket, but because it used a four-pin base, the additional element connections were made on a "mezzanine" platform at the top of the tube base.

By 1940 multisection tubes had become commonplace. There were constraints, however, due to patents and other licensing considerations (see British Valve Association). Constraints due to the number of external pins (leads) often forced the functions to share some of those external connections such as their cathode connections (in addition to the heater connection). The RCA Type 55 was a Double Diode Triode used as a detector, automatic gain control Detector and audio preamplifier in early AC powered radios. These sets often included the 53 Dual Triode Audio Output.

Other early type of multi-section tubes, the 6SN7 and 6SL7 Octal based "Dual Triodes" performed the functions of two Triode Tubes, while taking up half as much space and costing less.

The Miniature Tube Bases

Early tubes used a metal or glass envelope fixed to an insulating Bakelite or a ceramic base. In 1938 a technique was developed to use an all-glass construction with the pins fused in the glass base of the envelope. This was used in the design of a much smaller tube outline, known as the miniature tube base, having 7 or 9 pins.

The introduction of these miniature tube bases, more than previously available, allowed other multi-section tubes to be introduced. The 12AU7, 12AT7 and 12AX7 dual triodes in a nine pin **Noval** miniature envelope, became widely used audio signal amplifiers. The 12AX7 was the "high mu" - highest voltage gain device of the three. Another popular combination was a Triode-Pentode such as the 6BL8, 6U8 and 6GH8. These tubes became popular in domestic radio and television receivers.

The desire to include even more functions in one envelope resulted in the **General Electric Compactron** which had 12 pins. A typical example, the 6AG11, contained two triodes and two diodes. Compactrons were used in the last tube television receivers, built mostly for the American market and was the "last gasp" of the tube technology.

Subminiature tubes

Many very small tubes were constructed for specialised functions, for example, tubes roughly the size of half a cigarette were used in hearing-aid amplifiers. These tubes did not usually have pins plugging into a socket but were soldered in place.

The **"Acorn"** tube (named due to its shape) was also very small, and was developed during the 1940's for very high frequency radio equipment being used during World War II.

There is also the metal-cased RCA **Nuvistor** from 1959, about the size of a thimble. The Nuvistor was developed to compete with the early transistors and operated at higher frequencies than those early transistors could. The small size supported especially high-frequency operation - nuvistors were used in UHF television tuners and some Amateur Radio receivers.

A look at this Wikipedia web site will show how tube sockets have evolved over the years – https://en.wikipedia.org/wiki/Tube_socket

Tube numbering

http://www.r-type.org/articles/art-170.htm
http://www.vintage-radio.com/repair-restore-information/valve_valve-numbering.html

List of vacuum tubes From Wikipedia, the free encyclopedia

https://en.wikipedia.org/wiki/List_of_vacuum_tubes