Diodes, Transistors and Tubes

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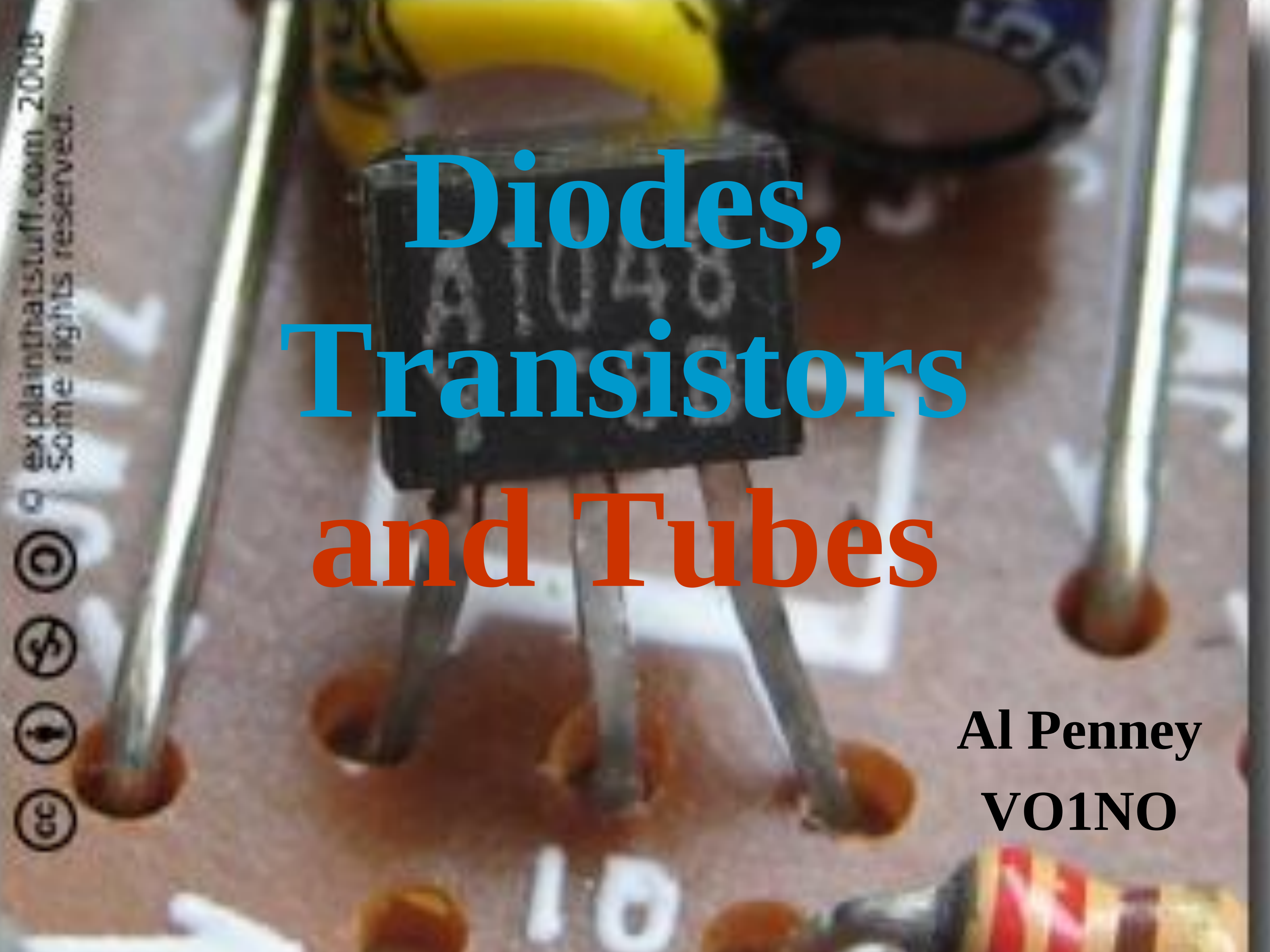
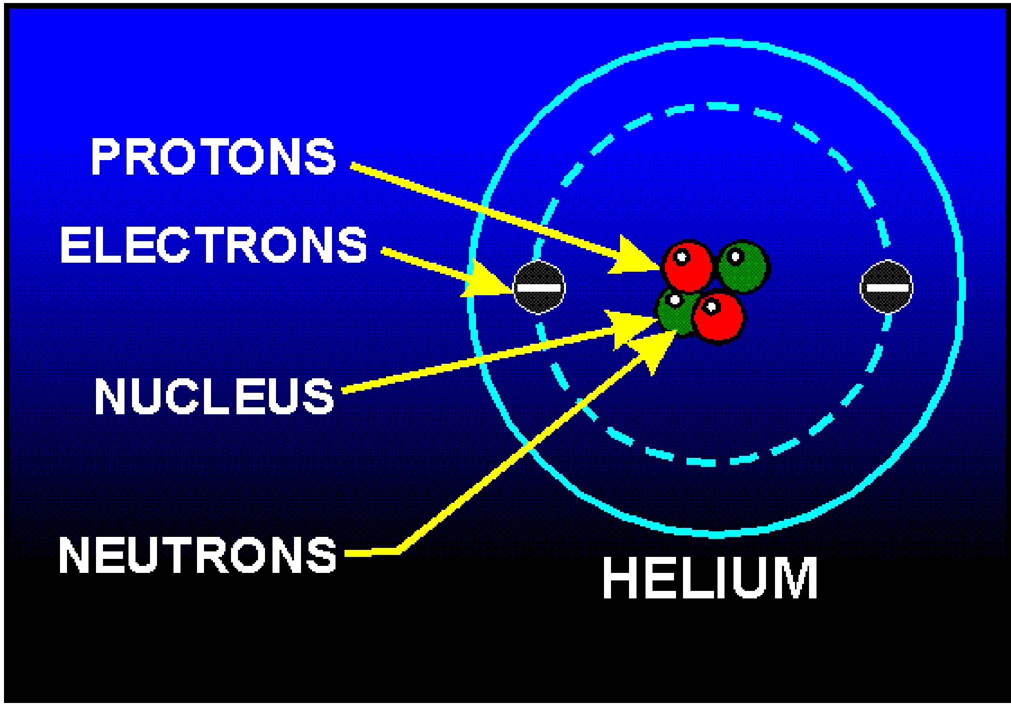


Basic Atomic Structure

- **Everything** in the Universe is made up of **Atoms.**
- To explain the behavior of atoms, we can **visualize atoms as solar systems.**
- The center, or **Nucleus,** of the atom is composed of **Protons** and **Neutrons.**
- In **orbit** around the nucleus are one or more **Electrons.**

Atomic Structure

- **Protons** have a **Positive** charge.
- **Neutrons** are electrically **neutral.**
- **Electrons** have a **Negative** charge.
- Protons and Neutrons are about **1800 times heavier** than Electrons.



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Valence Electrons

- Electrons are arranged in several **discrete orbits,** with a **maximum** number per orbit.
  - 1st 2 electrons
  - 2nd 8 electrons
  - 3rd 18 electrons
  - 4th 32 electrons
  - 5th 50 electrons
- The electrons in the **outermost orbit** are called the **Valence Electrons.**

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Atomic Bonds

- **Valence electrons** enable atoms to **bond** with other atoms.
- **Ionic Bond** – attraction based on oppositely charged ions eg: NaCl (salt).
- **Metallic Bond** – electrons are **loosely bound** and can **move freely** among the atoms eg: metals.
- **Covalent Bond** – each atom **shares its electrons** with other atoms, forming an **orderly network** called a **lattice structure.**

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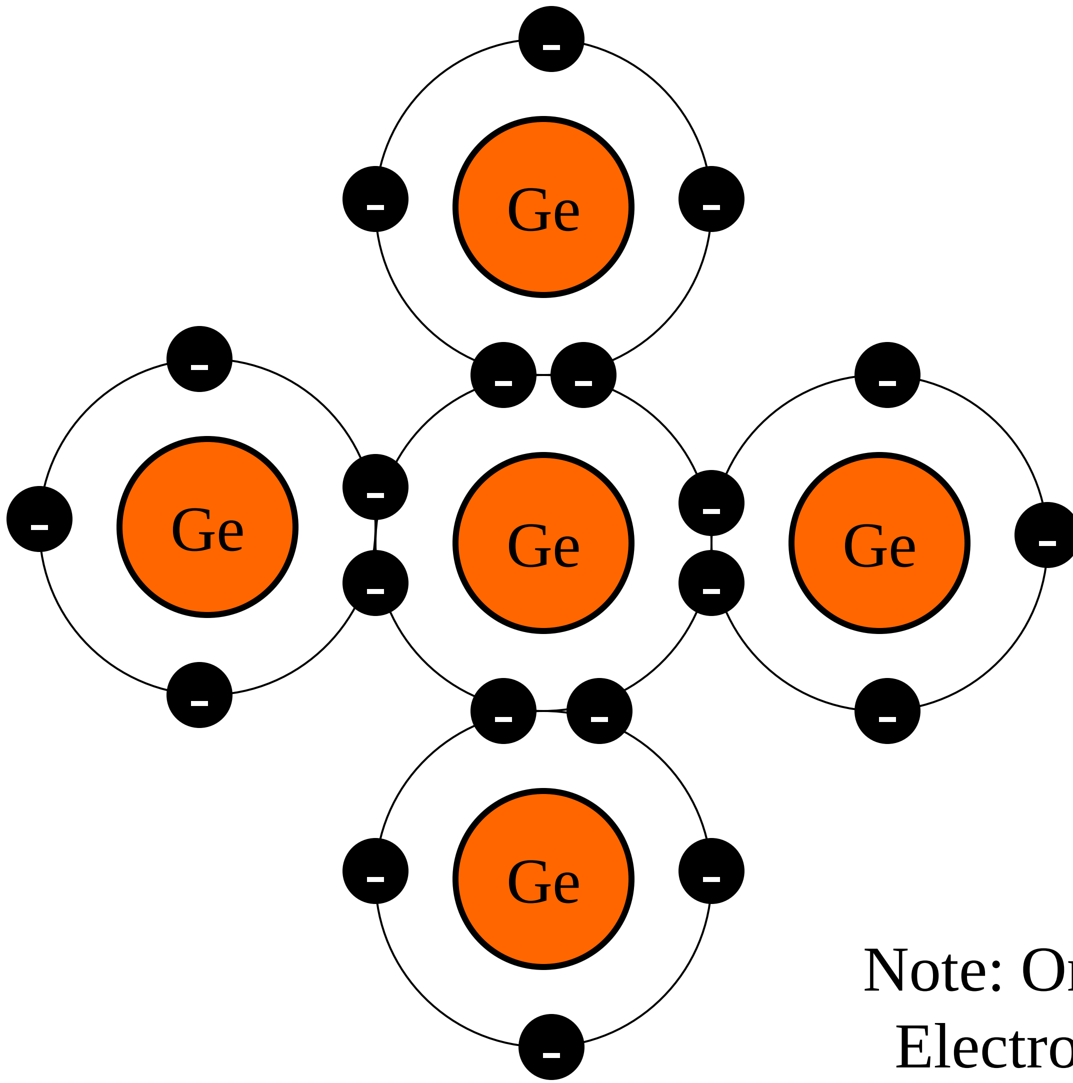
Germanium Covalent Bond



Note: Only Valence Electrons shown.

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Conductivity of Materials

- **Conductivity** is a measure of a material's **ability to conduct electricity.**
- Good **Conductors** have a large number of **free electrons.**
- **Insulators** have atomic structures where the **electrons are tightly bound,** and **cannot** be used to **conduct electricity**.

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Conductors

- **Metals** are good conductors.
- They include:
  - **Copper**
  - **Aluminum**
  - **Silver**
  - **Gold**

Insulators

- **Insulators** include:
  - **Plastics**
  - **Rubber**
  - **Dry Wood**
  - **Porcelain**
  - **Dry Air**

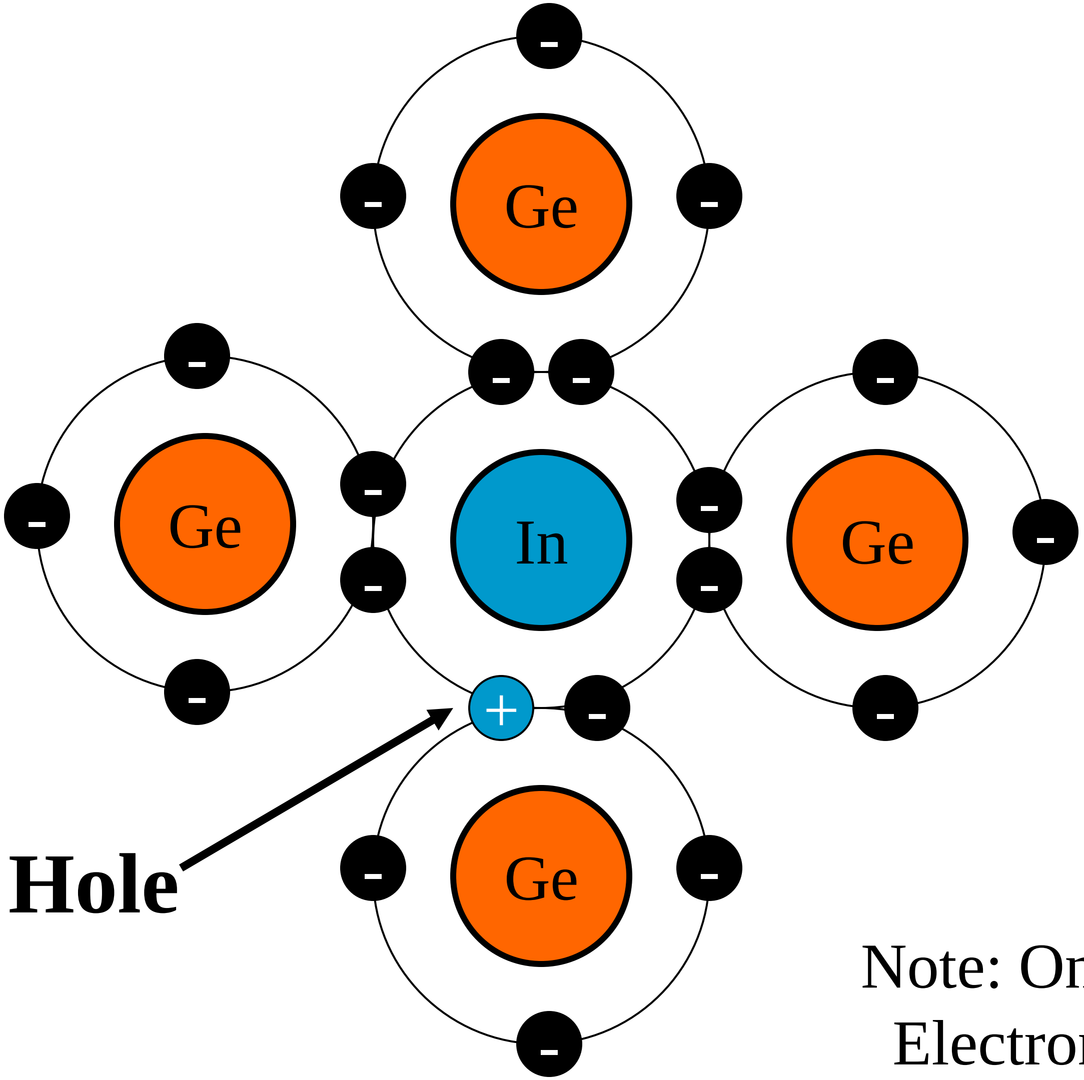
Semiconductors

- **Between** Conductors and Insulators is another category of materials classified as **Semiconductors.**
- They are **neither good conductors, nor good insulators.**
- Semiconductors include **Silicon** and **Germanium.**

Doping Semiconductors

- Ordinarily, semiconductors are poor conductors.
- When certain **impurities** are added however, their **conductivity improves.**
- The process of **adding impurities** is called **Doping.**
- Depending on the dopant, an **extra electron**, or a **Hole** ("missing" electron) can be added to the lattice structure.

Germanium with Indium Doping



Note: Only Valence Electrons shown.

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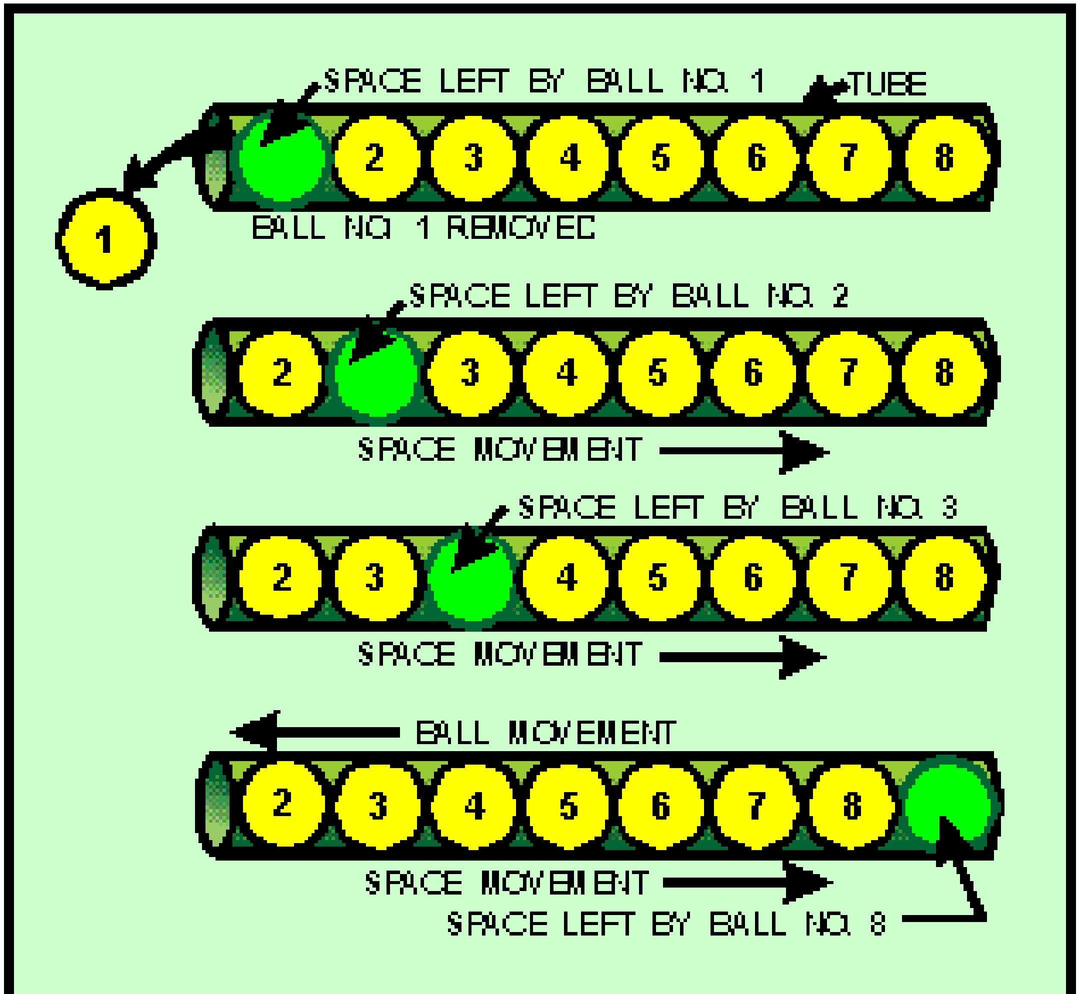
P-Type material

- The **absence of an electron** creates a **“hole”.**
- The **motion of this hole (Majority Carrier)** will support the **conduction of electricity,** as electrons are displaced to fill the hole.
- Because the conduction of electricity is primarily supported by **positive holes,** substances like this are called **P-Type material.**
- There are still some free electrons available for conducting electricity **(Minority Carrier).**

Conduction with Holes



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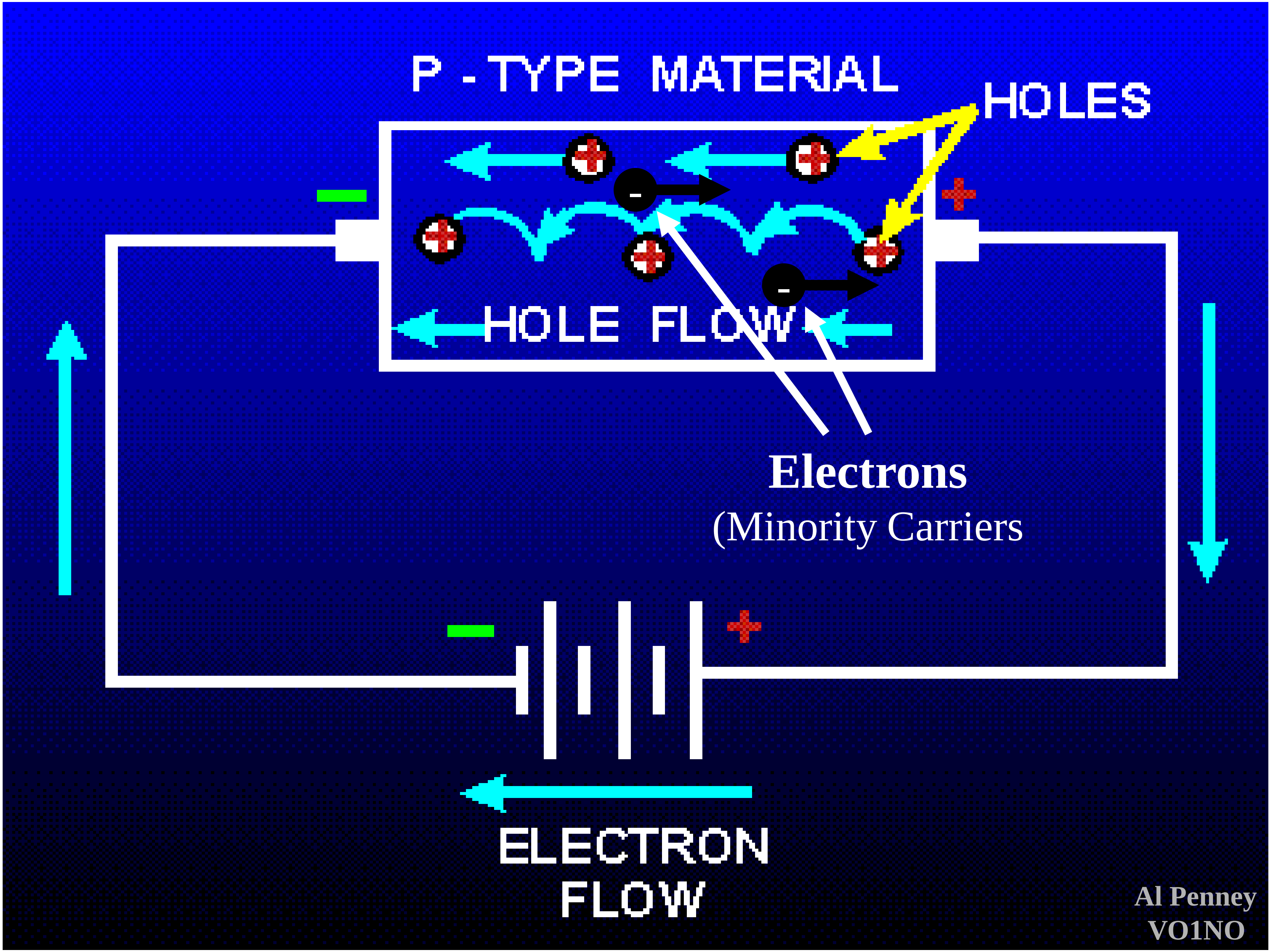

P - TYPE MATERIAL
HOLES
-
+
HOLE FLOW
Electrons
(Minority Carriers
-
+
ELECTRON
FLOW
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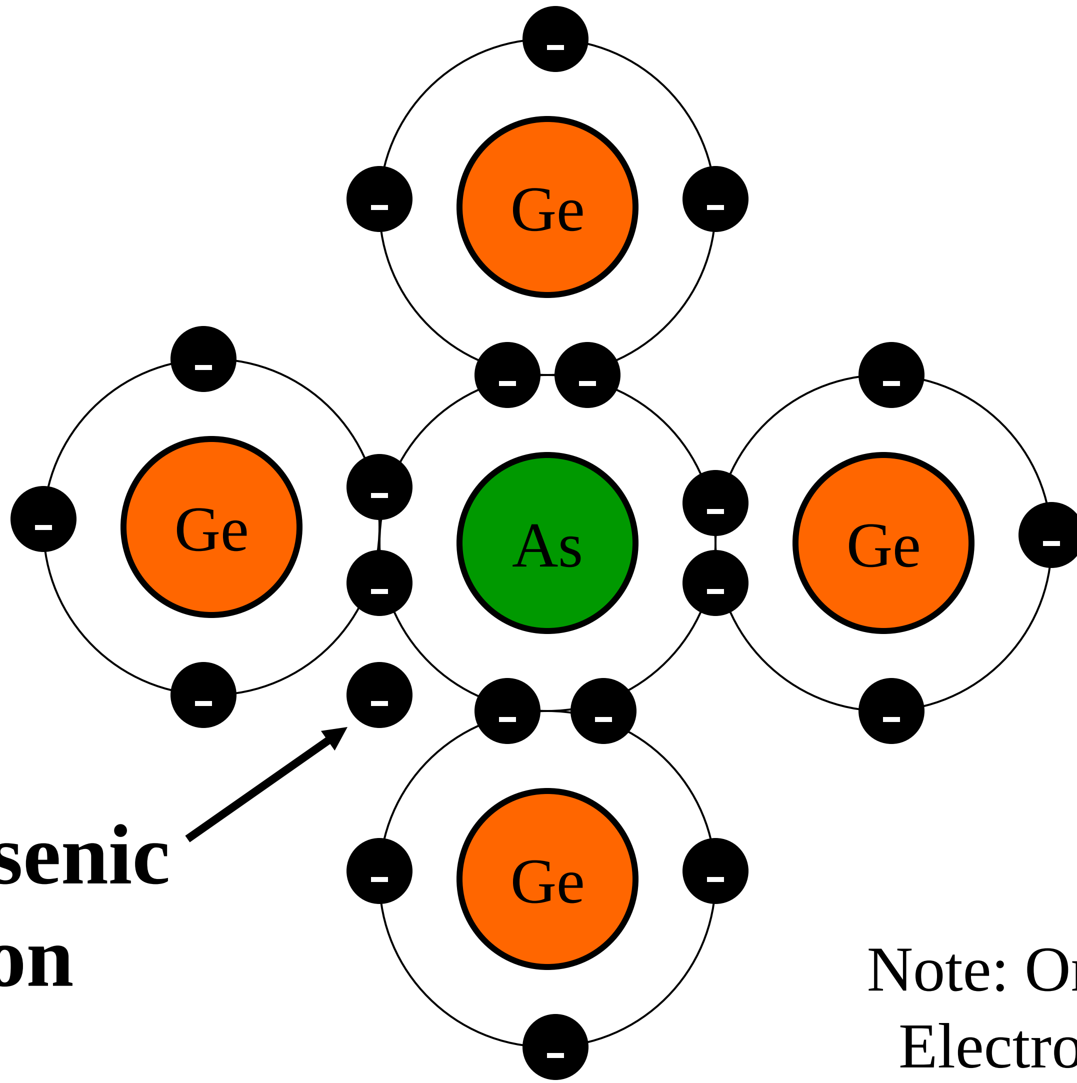
Germanium with Arsenic Doping



Extra Arsenic Electron

Note: Only Valence Electrons shown.

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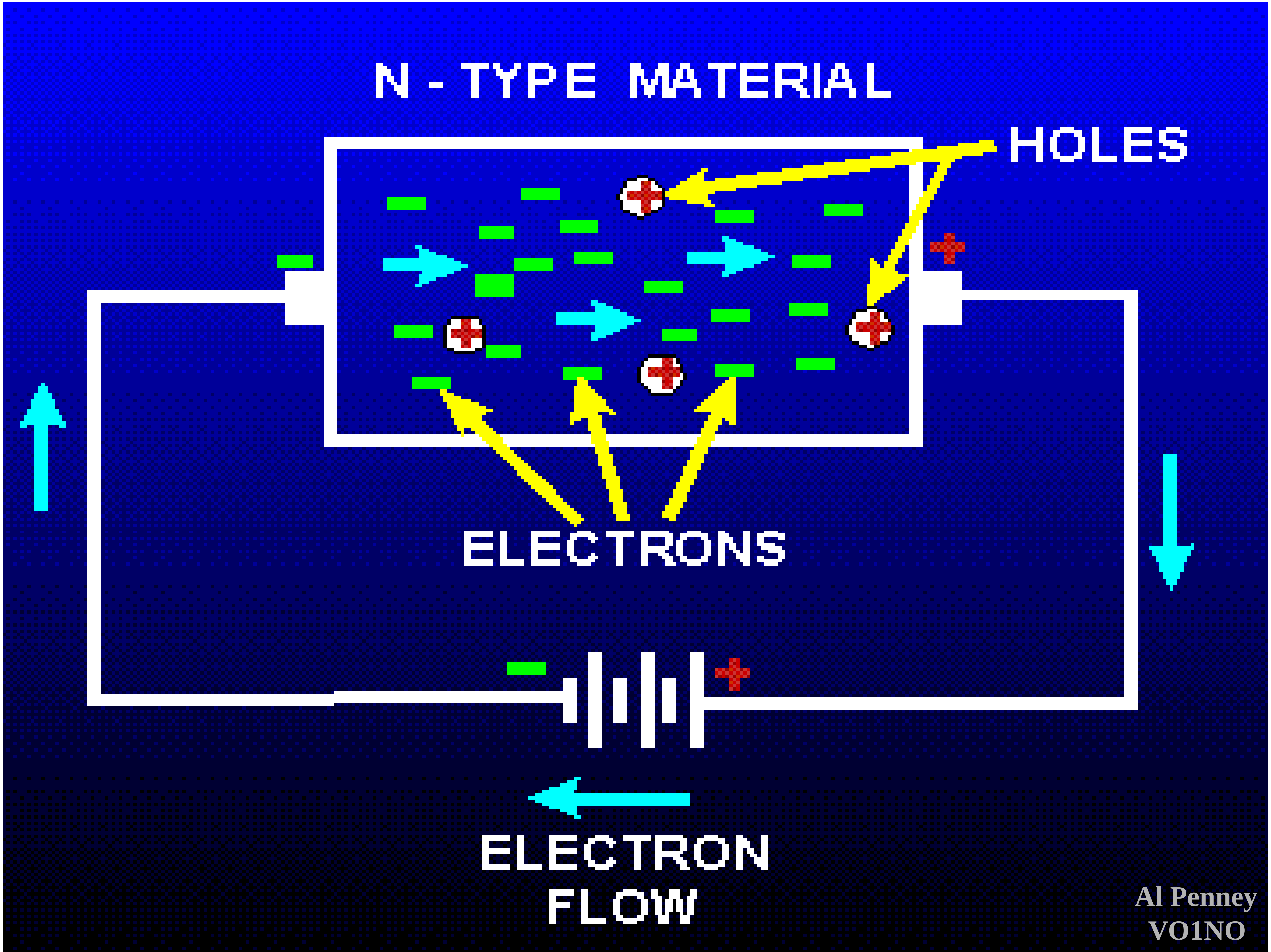
N-Type Material

- Because there are **“extra” electrons** that are not part of the covalent bonds, conduction of electricity is primarily through the **movement of these electrons (Majority Carriers).**
- Because **electrons** have a **negative charge,** these substances are called **N-Type**.
- There are still some holes available in N-Type material **(Minority Carriers).**


N - TYPE MATERIAL
HOLES
ELECTRONS
ELECTRON
FLOW
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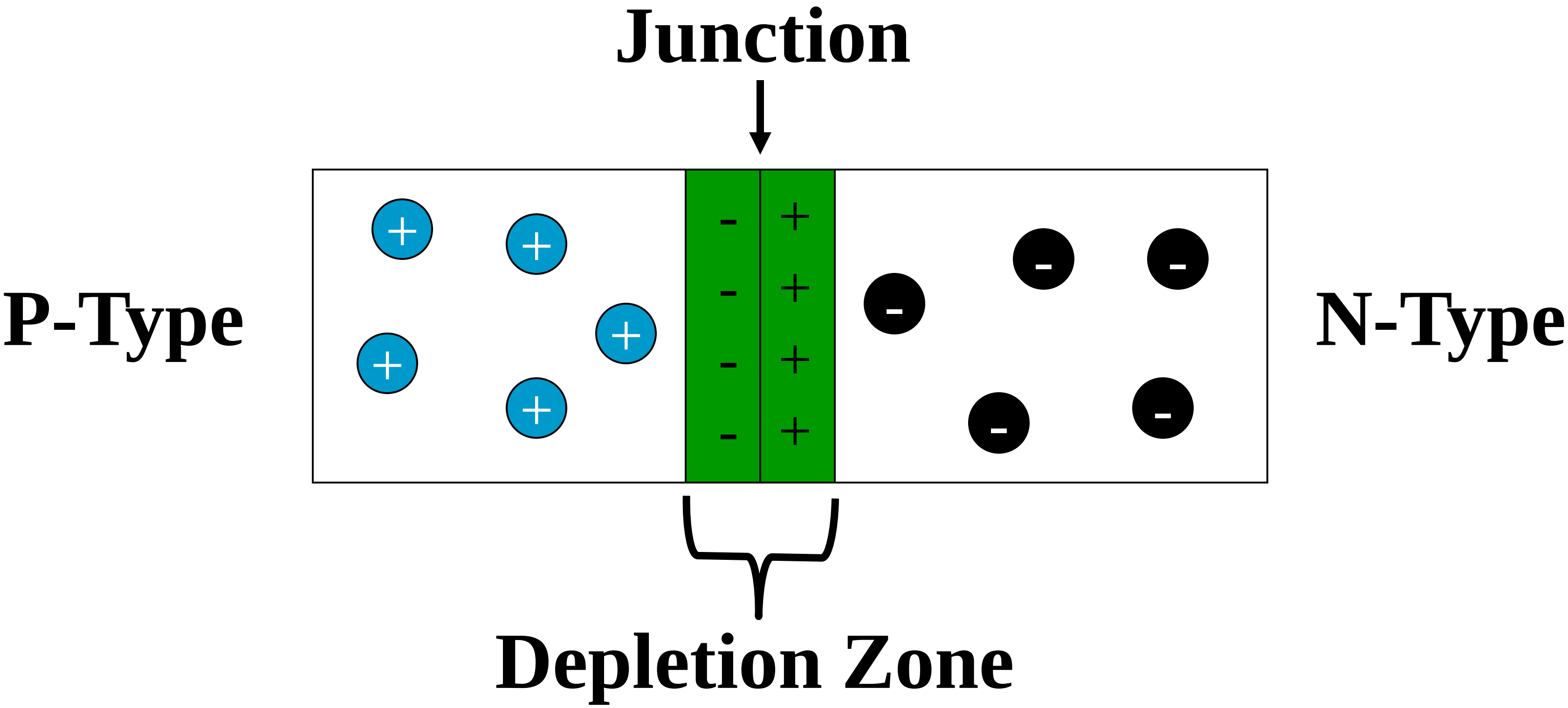
P-N Junction

- When P-type and N-type material are placed together, **electrons** and **holes** near the boundary **recombine.**
- This creates a region with **negatively charged atoms in the P-type** material, and **positively charged atoms in the N-type material.**
- This is called the **Depletion Zone,** because there is a lack of holes and electrons.
- It is very thin – approximately 0.01 mm thick.

Junction Barrier



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Junction Barrier

- It is **not possible** for **electrons** to **migrate** from the N-type material into the P-type material because they are **repelled** by the **negatively charged atoms** (called **Ions**) in the **Depletion Zone.**
- For this reason, the electric field created by the ions is called the **Junction Barrier.**

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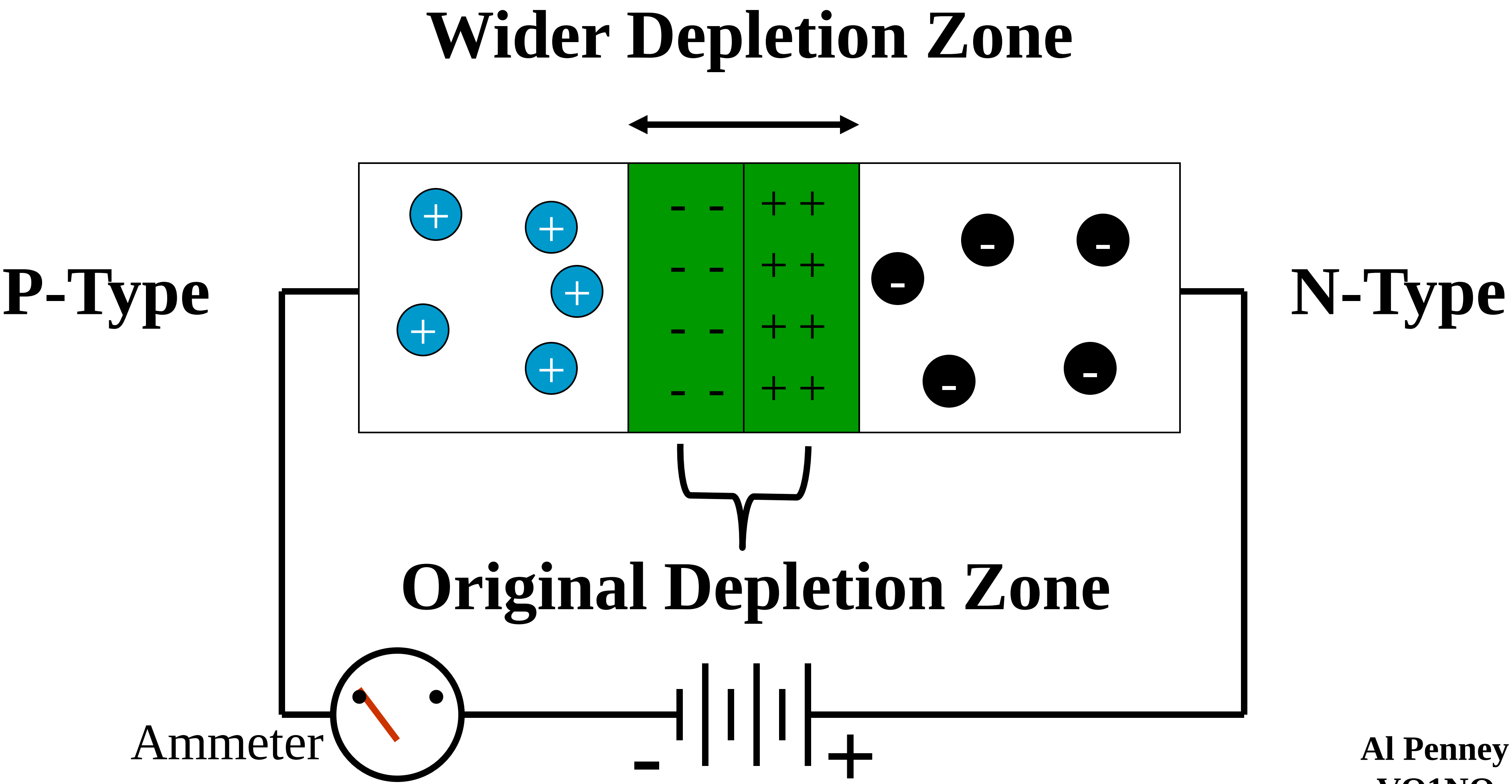
Junction Barrier Potential

- This electric field is small:
  - ~ 0.3 volts for germanium
  - ~ 0.7 volts for silicon
- Once established, **no further current flows** across the junction.
- For a current to flow, we must **overcome the barrier potential.**

Reverse-Biased Junction Barrier



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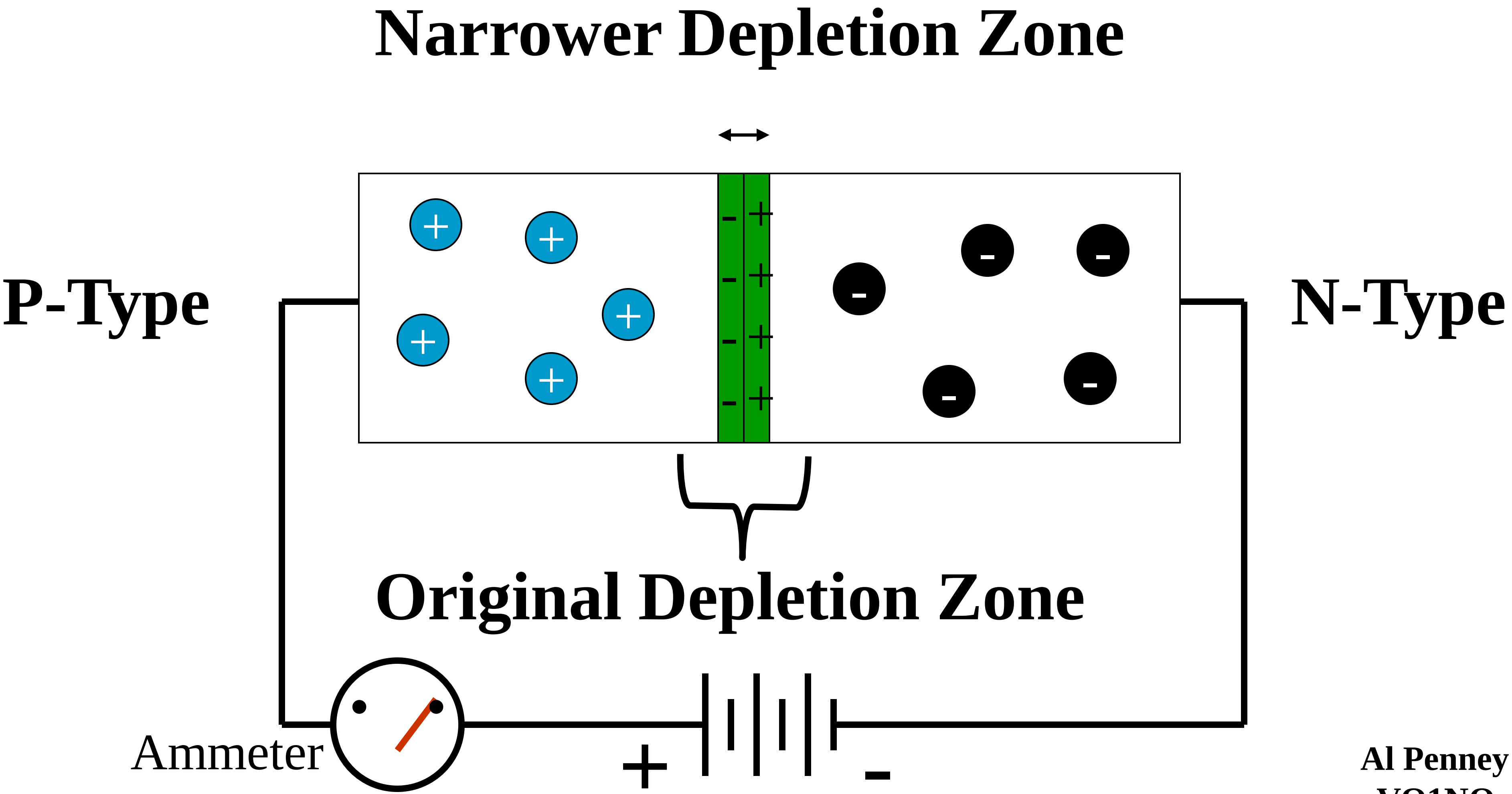
Forward-Biased Junction Barrier



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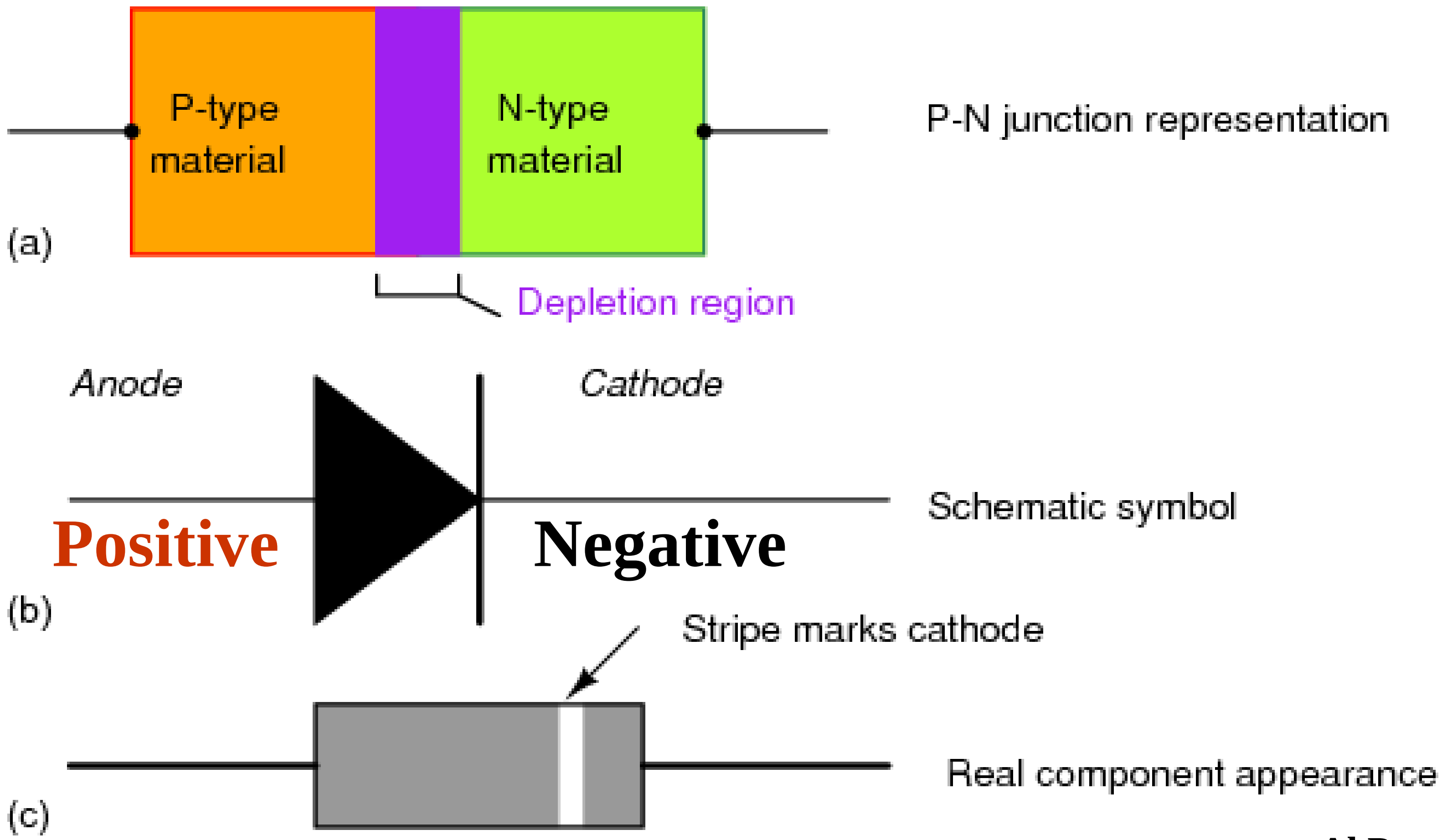
Diodes

- A PN junction allows current to flow in one direction only.
- This forms a diode.
- Used to rectify AC and demodulate AM transmissions among other things.

Diode Symbol



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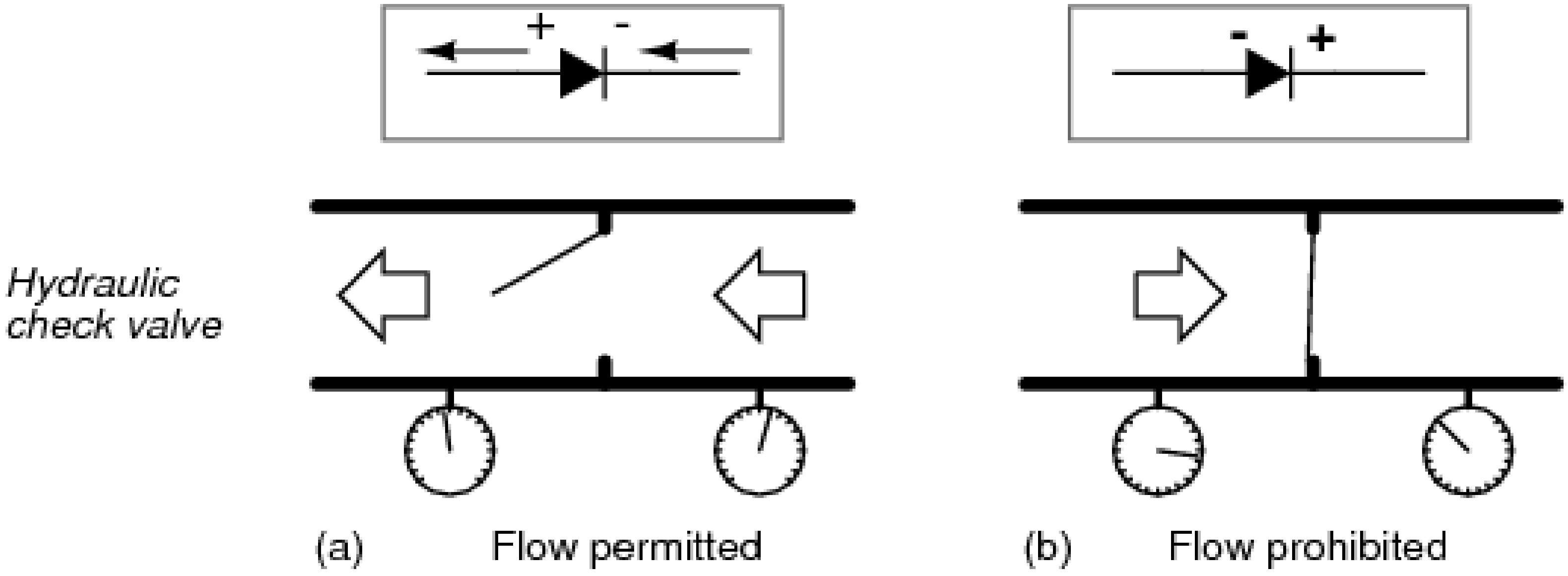
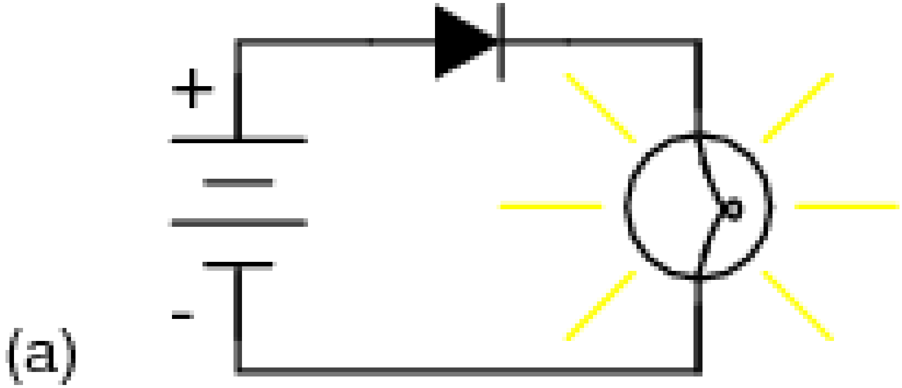
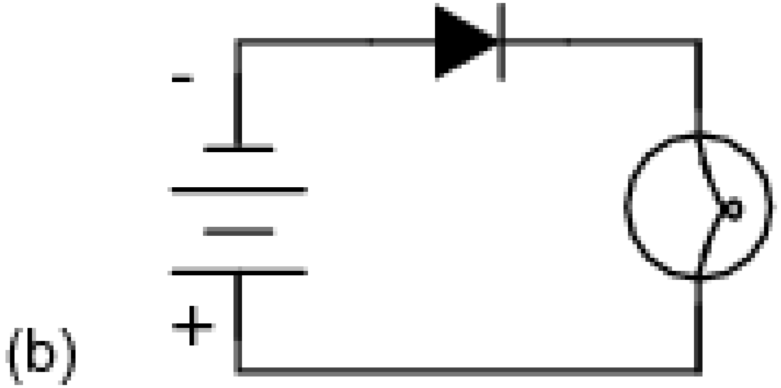
Valve Equivalent of Diodes



Biasing





Forward Biased **Reverse Biased**

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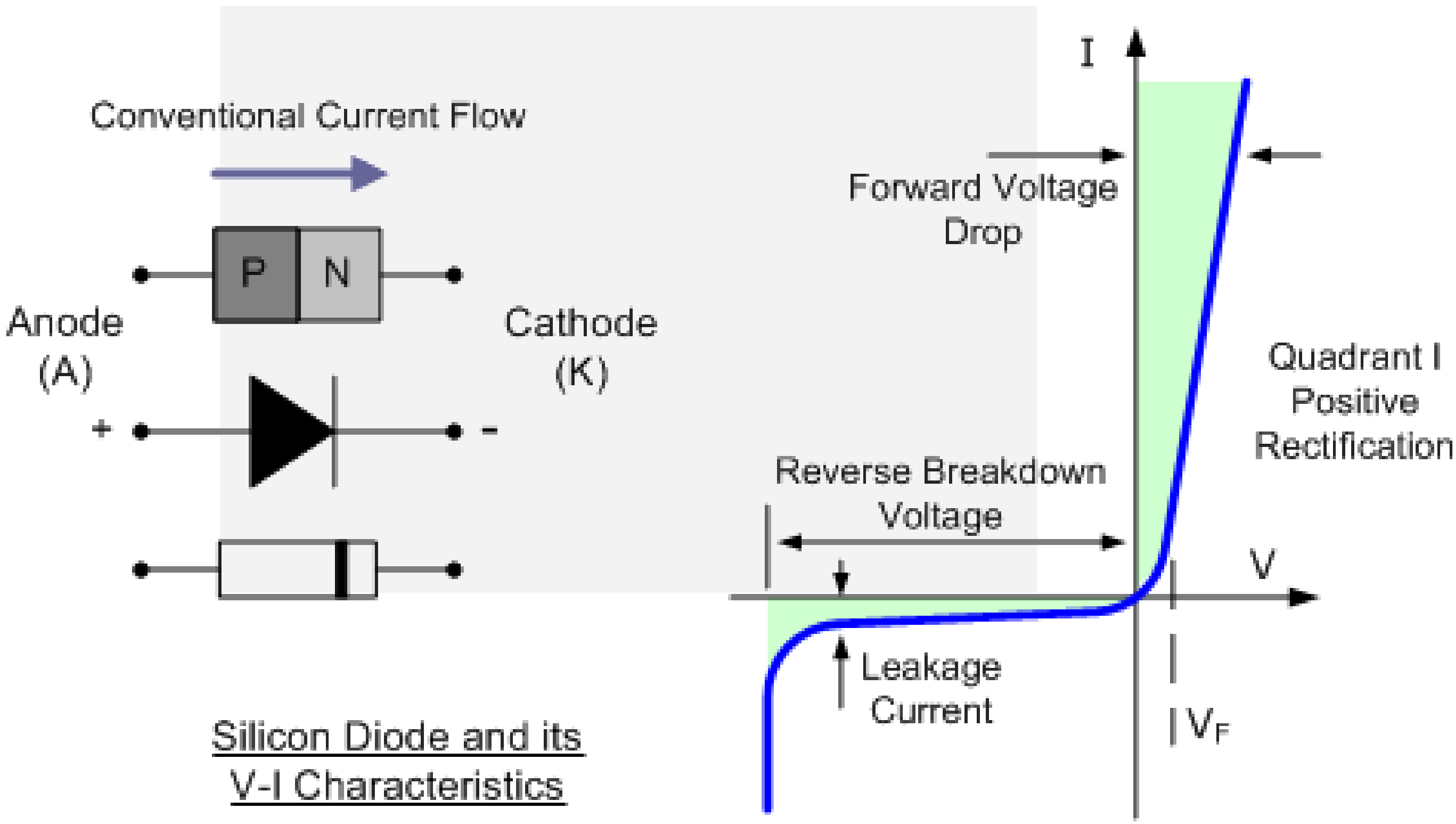
Diode Voltages



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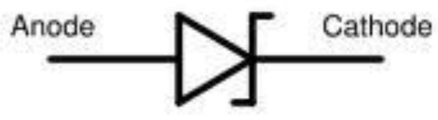
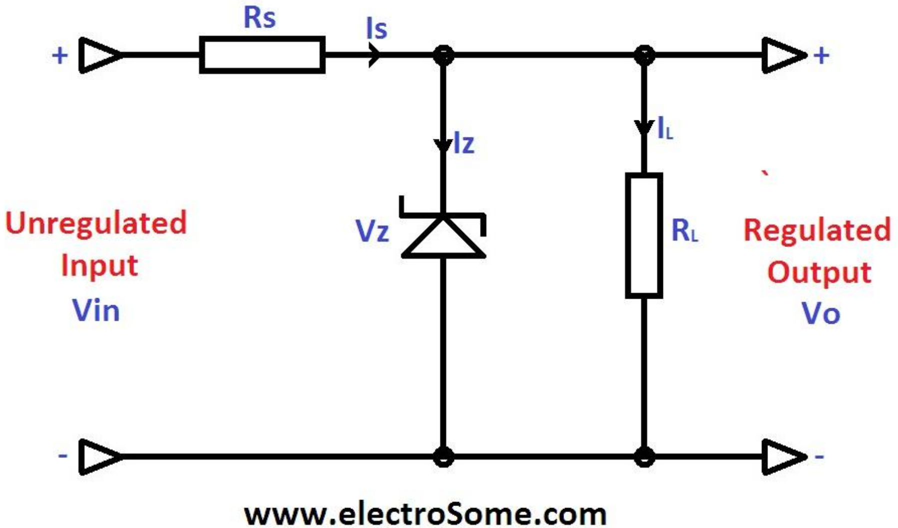
Zener Diode

- Acts as a voltage regulator in power supplies.
- Provides a reference voltage for regulator circuits, but can do it by itself if current requirements are low.





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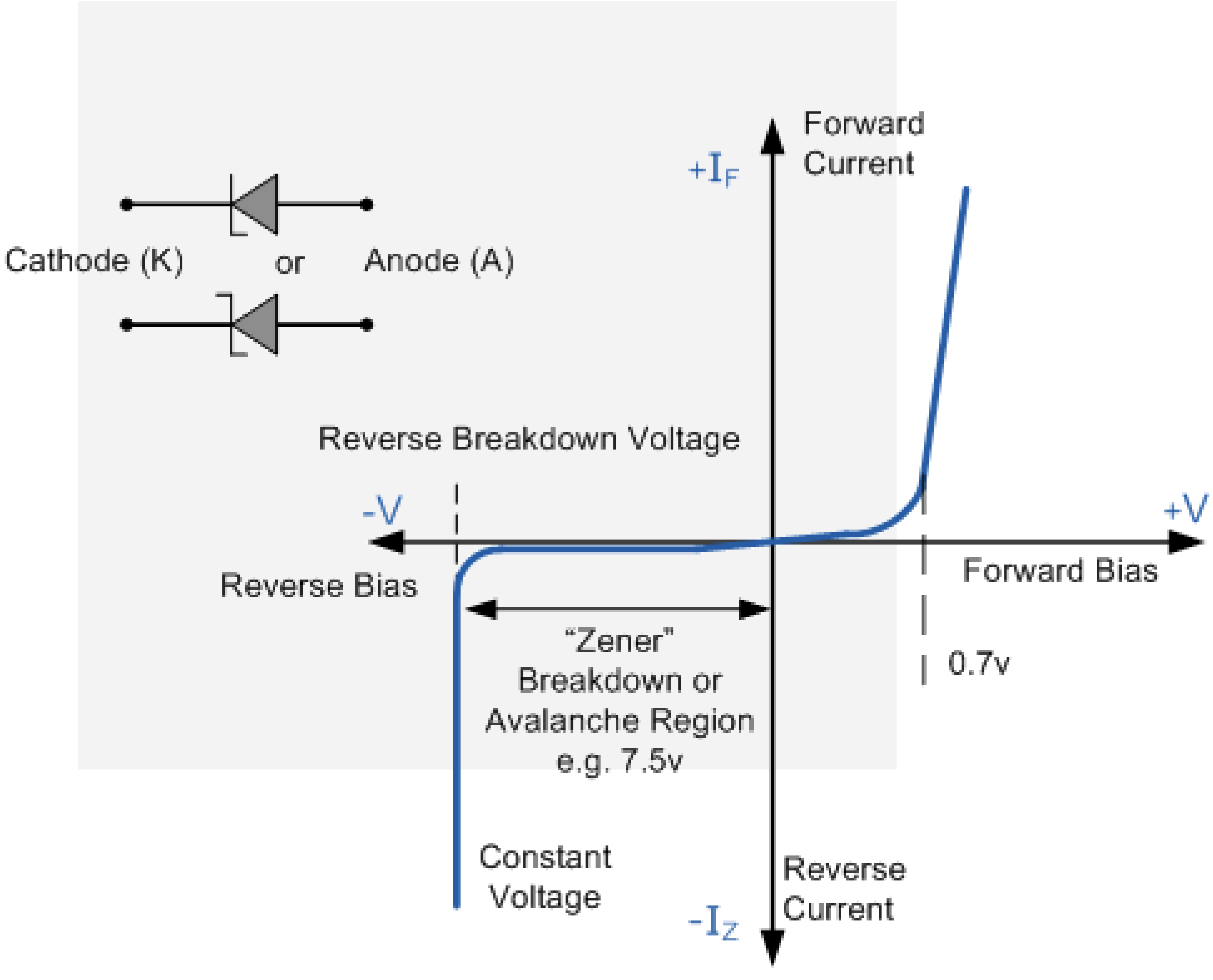
Zener Diodes



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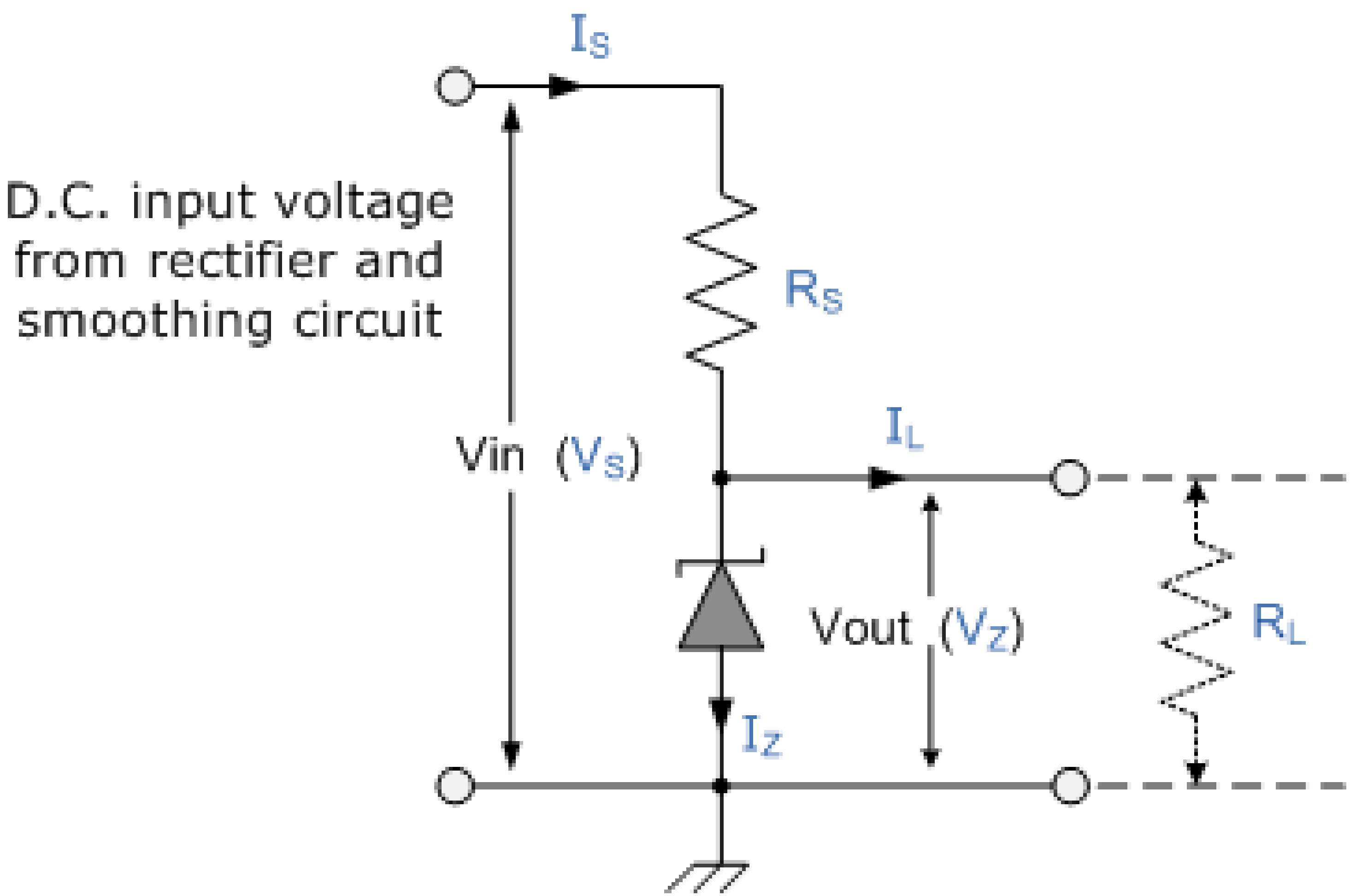
Zener Diode Voltage Regulation



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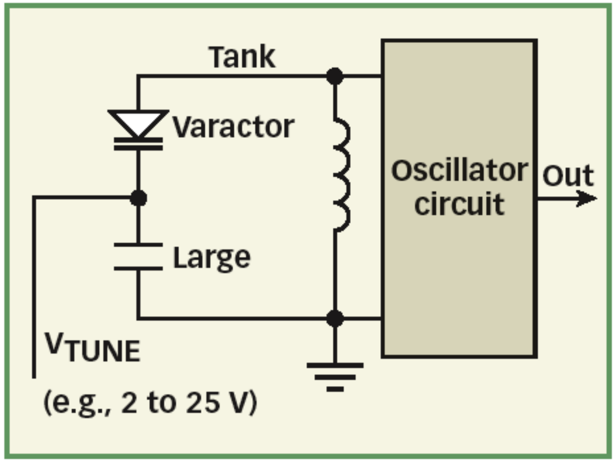
Varactor Diode

- Diode's **capacitance changes** as applied **voltage changes**.
- Used as a smaller/cheaper replacement for variable capacitors in radio circuits.
- Also called **varicap** or **tuning diode**.



2. A traditional VCO employs reverse-voltage tuning of a varactor diode to change oscillator frequency.

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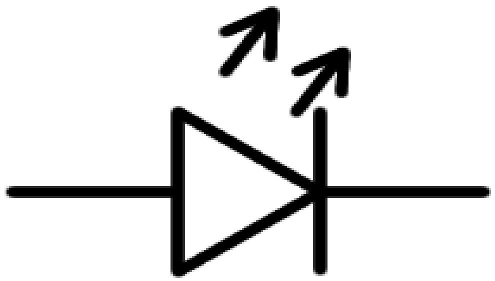
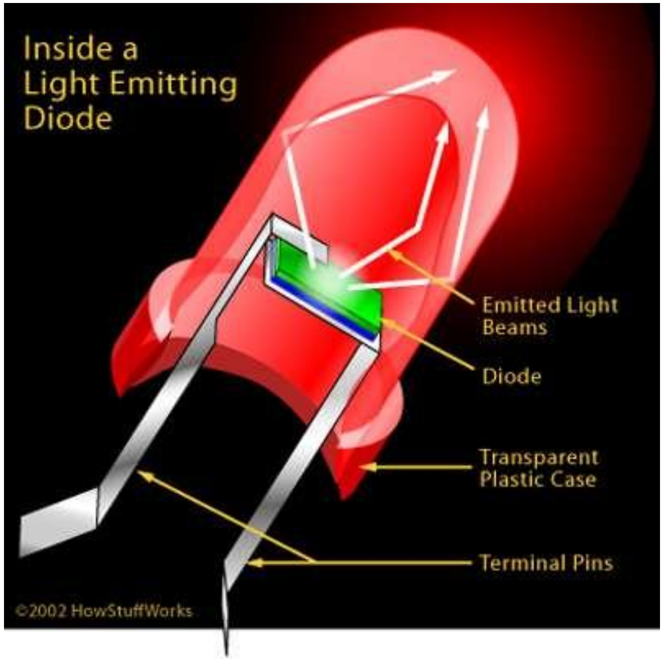
Light Emitting Diode (LED)

- When forward biased, LEDs emit red, yellow or green light depending on composition of the diode.





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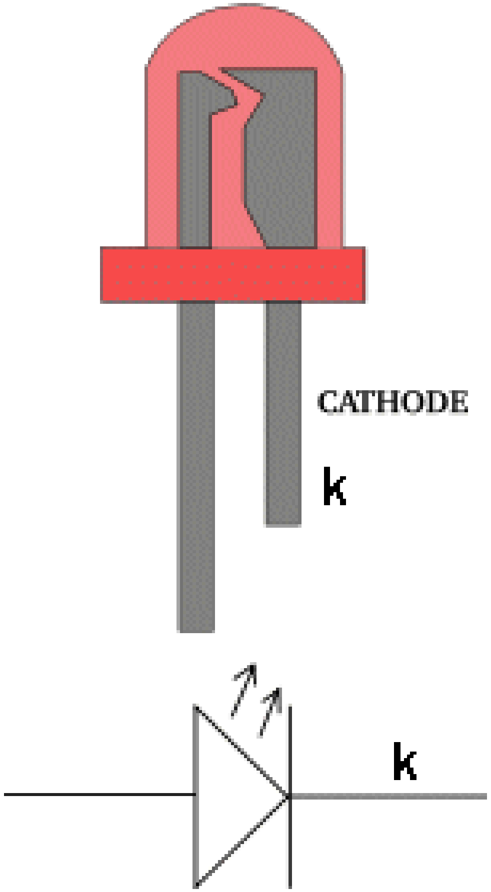
Light Emitting Diode (LED)



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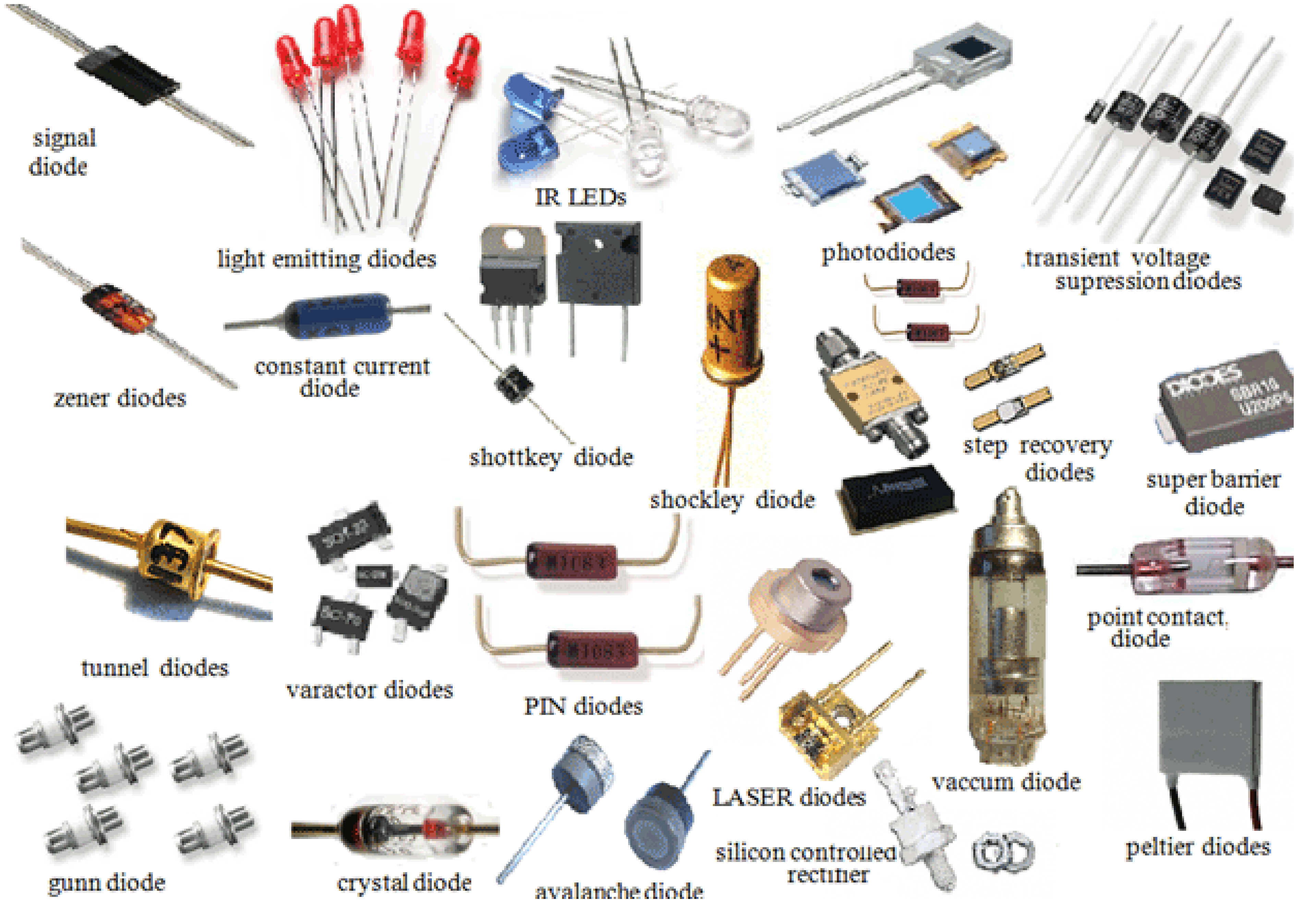

Types of Diode

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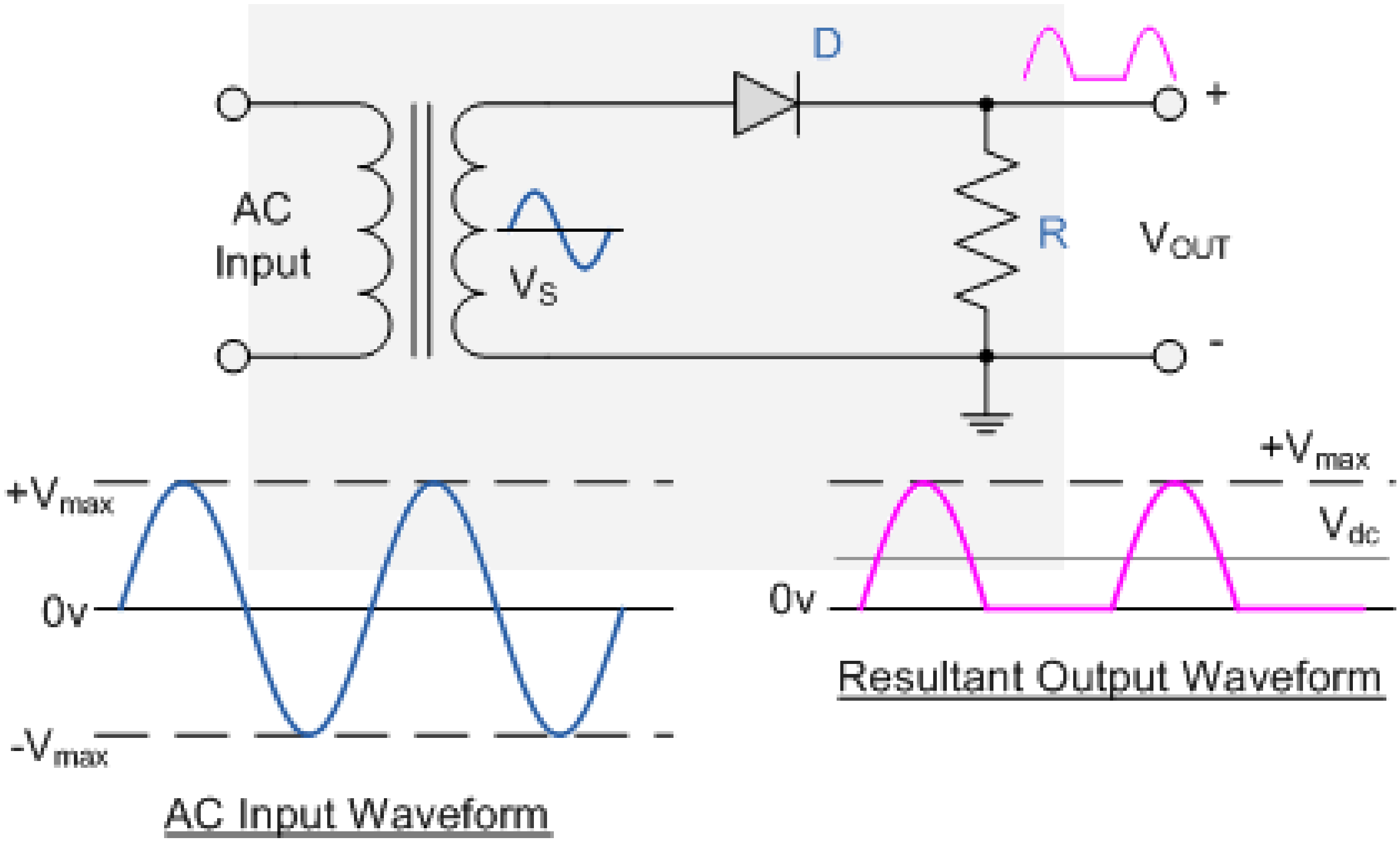
Diodes in Half Wave Rectifiers



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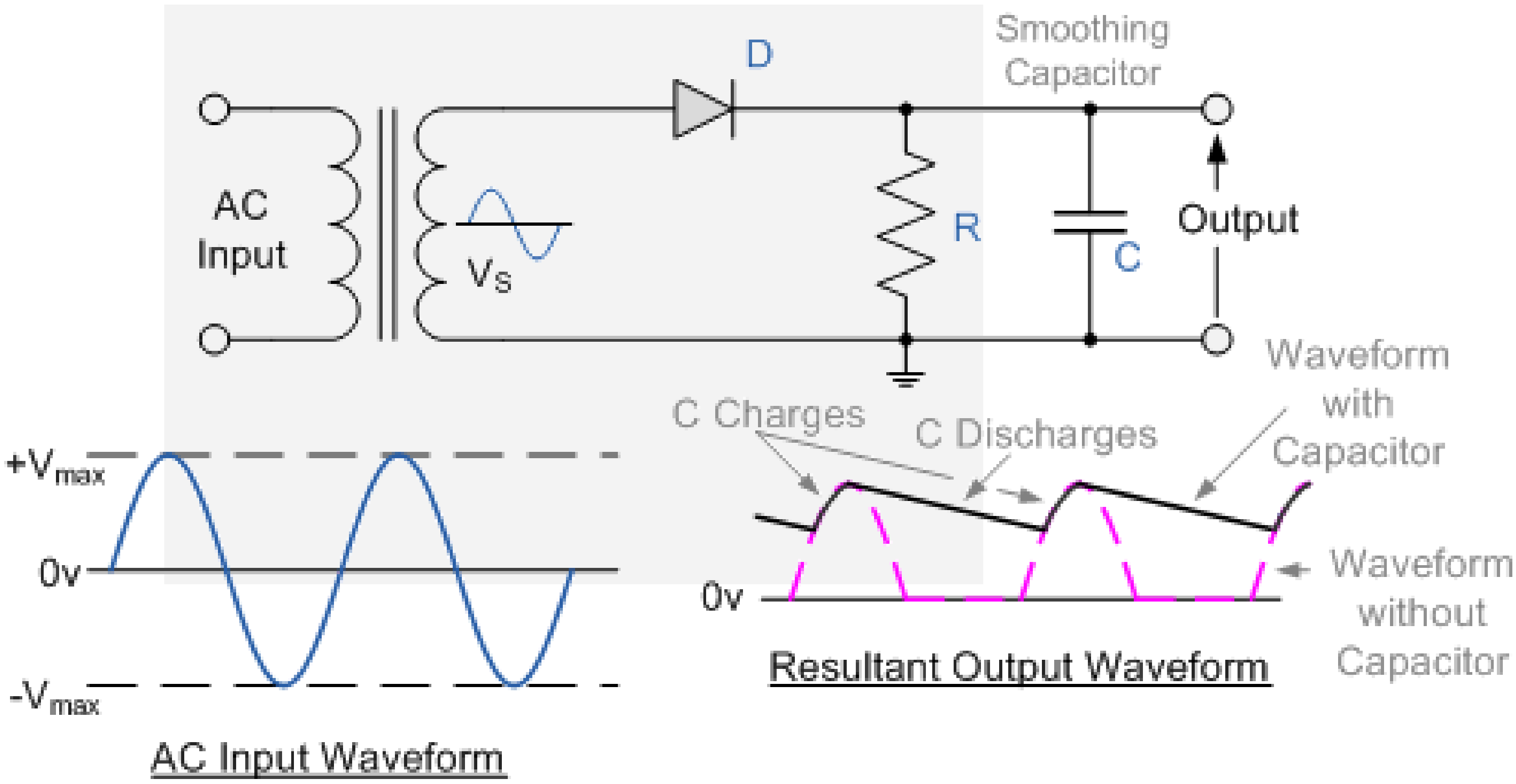
Half Wave Rectifier with a Capacitor



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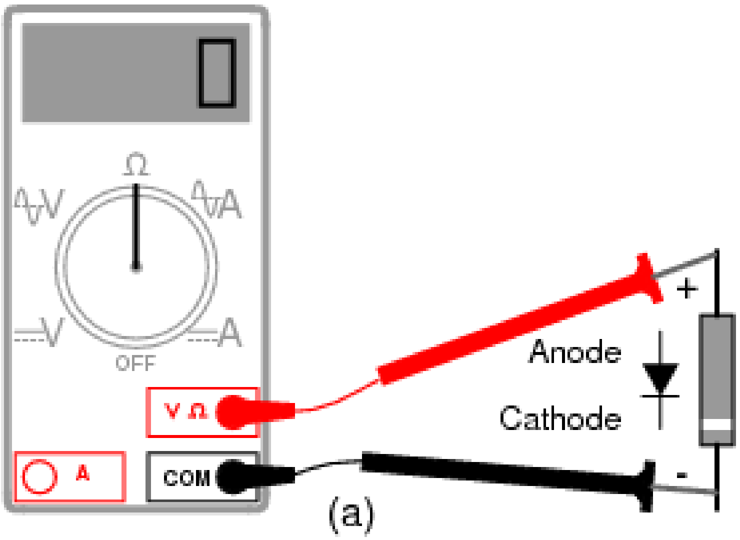
Checking Diodes



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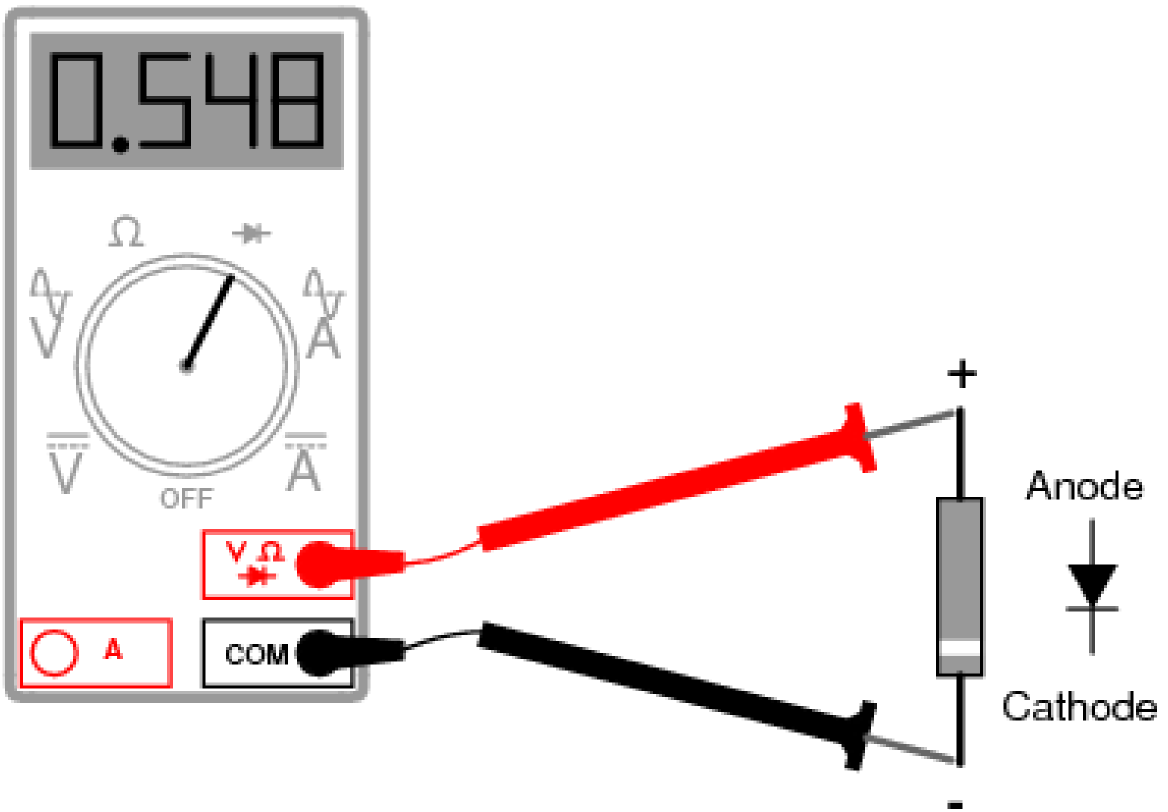
Diode Check Function



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Questions?

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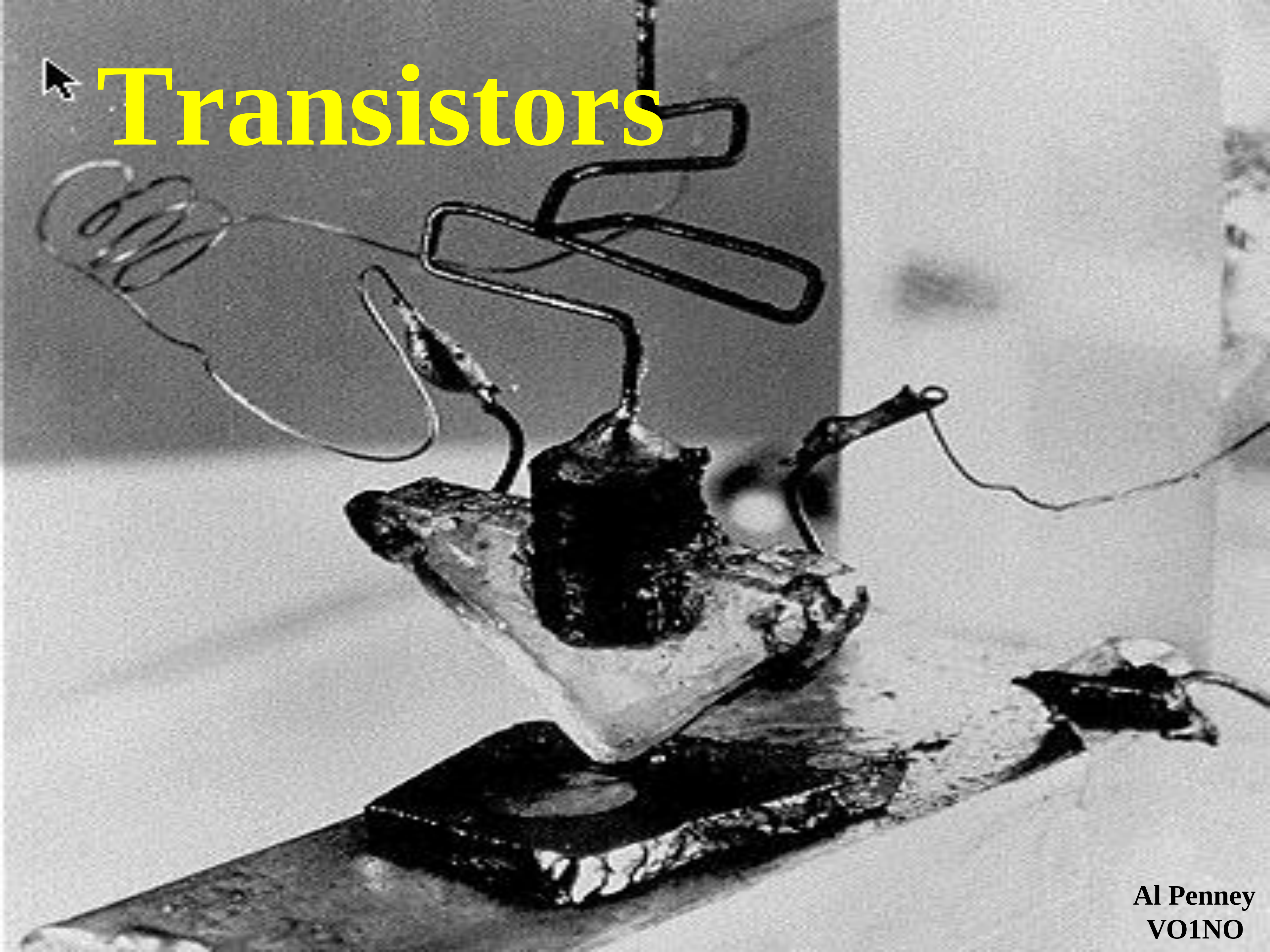
Transistors



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What do Transistors do?

- Switch current on and off
  - Computer and digital circuits
- Control current in a continuous manner
  - Amplifiers
  - Control circuits

Typical transistor packages

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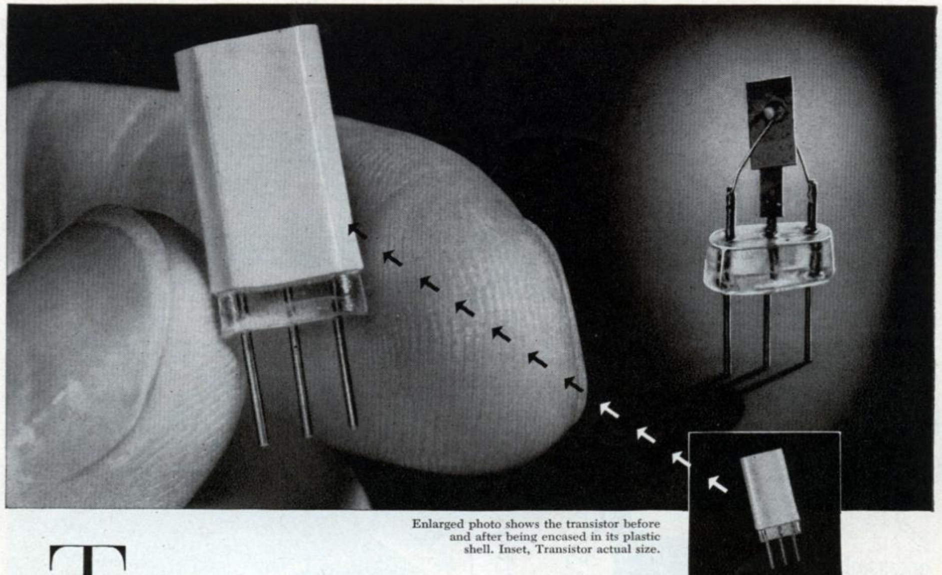

Enlarged photo shows the transistor before and after being encased in its plastic shell. Inset, Transistor actual size.

Transistor–
mighty mite of electronics

Increasingly you hear of a new electronic device — *the transistor.* Because of growing interest, RCA—a pioneer in transistor development for practical use in electronics—answers some basic questions:

Q: ***What is a transistor?***

A: The transistor consists of a particle of the metal germanium imbedded in a plastic shell about the size of a kernel of corn. It controls electrons in solids in much the same way that the electron tube handles electrons in a vacuum. But transistors are not interchangeable with tubes in the sense that a tube can be removed from a radio or television set and a transistor substituted. New circuits as well as new components are needed.

Q: ***What is germanium?***

A: Germanium is a metal midway between gold and platinum in cost, but a penny or two will buy the amount needed for one transistor. Germanium is one of the basic elements found in coal and certain ores. When painstakingly prepared, it has unusual electrical characteristics which enable a transistor to detect, amplify and oscillate as does an electron tube.

Q: ***What are the advantages of transistors in electronic instruments?***

A: They have no heated filament, require no warm-up, and use little power. They are rugged, shock-resistant and unaffected by dampness. They have long life. These qualities offer great opportunities for the miniaturization, simplification, and refinement of many types of electronic equipment.

Q: ***What is the present status of transistors?***

A: There are a number of types, most still in development. RCA has demonstrated to 200 electronics firms—plus Armed Forces representatives—how transistors could be used in many different applications.

Q: ***How widely will the transistor be used in the future?***

A: To indicate the range of future applications, RCA scientists have demonstrated *experimental* transistorized amplifiers, phonographs, radio receivers (AM, FM, and automobile), tiny transmitters, electronic computers and a number of television circuits. Because of its physical characteristics, the transistors qualify for use in lightweight, portable instruments.

* * *

RCA scientists, research men and engineers, aided by increased laboratory facilities, have intensified their work in the field of transistors. The multiplicity of new applications in both military and commercial fields is being studied. Already the transistor gives evidence that it will greatly extend the base of the electronics art into many new fields of science, commerce and industry. Such pioneering assures finer performance from any product or service trademarked RCA and RCA Victor.

RCA

RADIO CORPORATION OF AMERICA

World leader in radio—first in television

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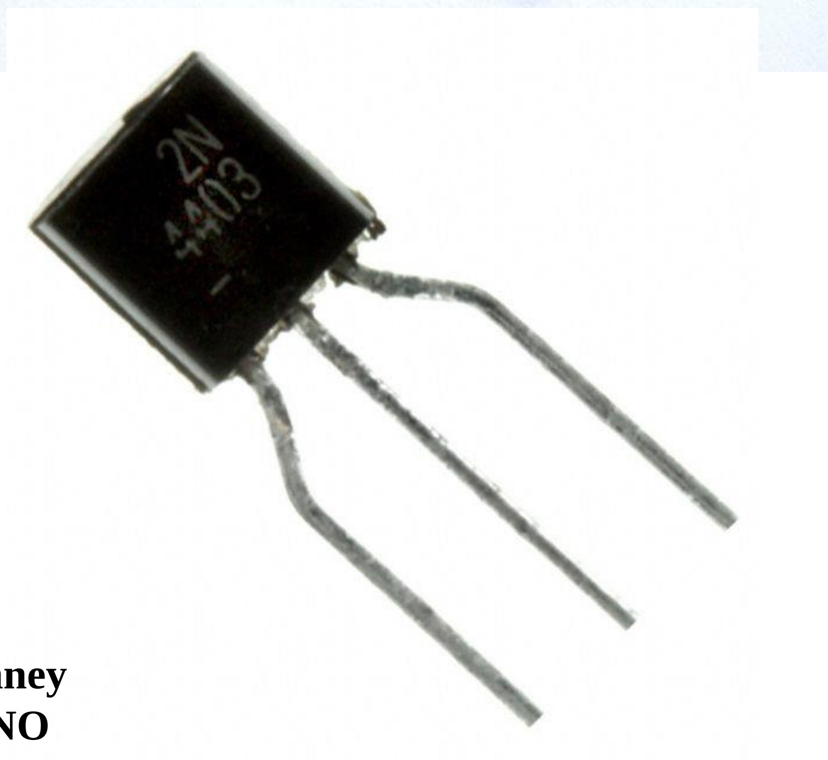

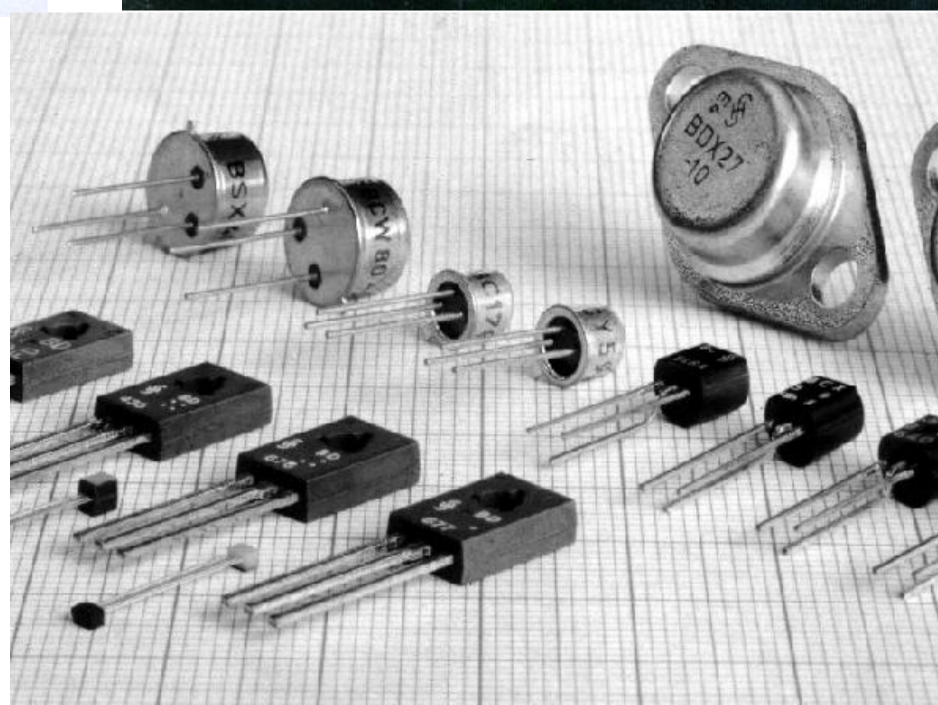

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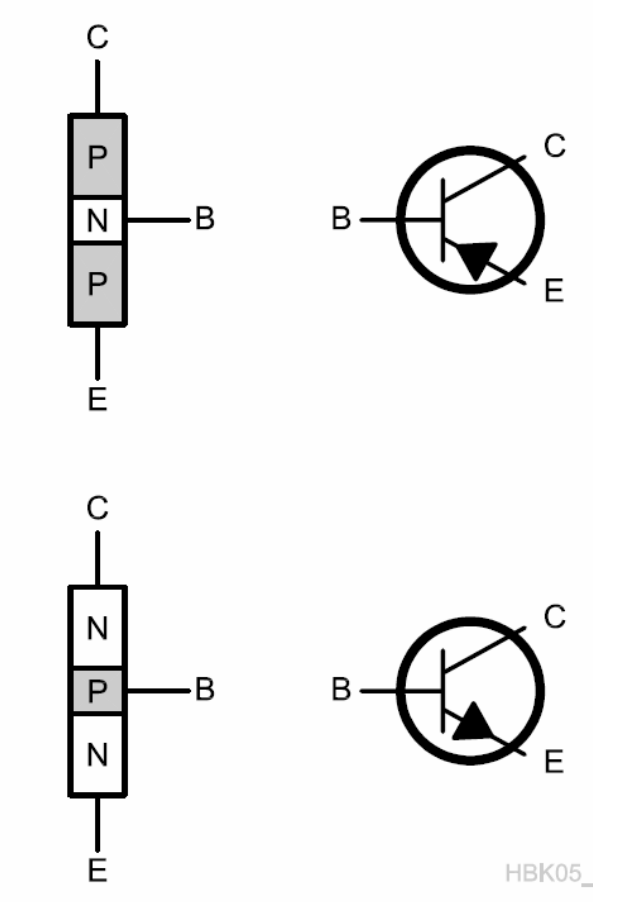
Transistor Construction

- Stack 3 slices of doped material together.
- **PNP** Transistor
  - “P in P” for arrow
- **NPN** Transistor
  - Arrow points out



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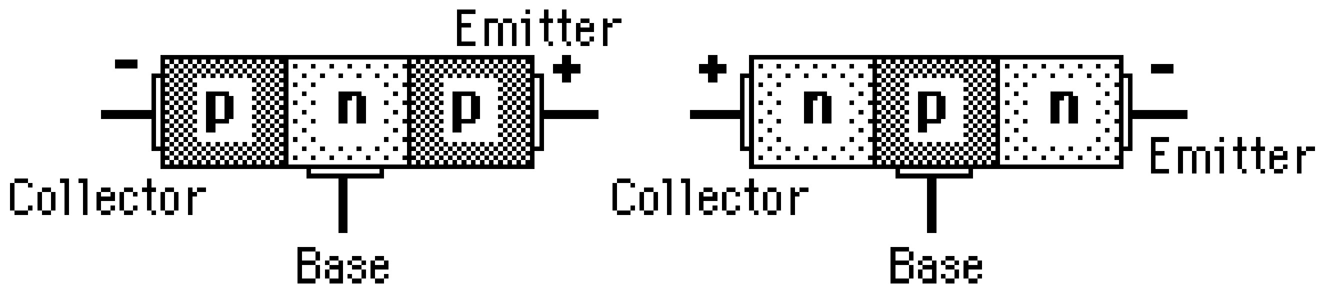
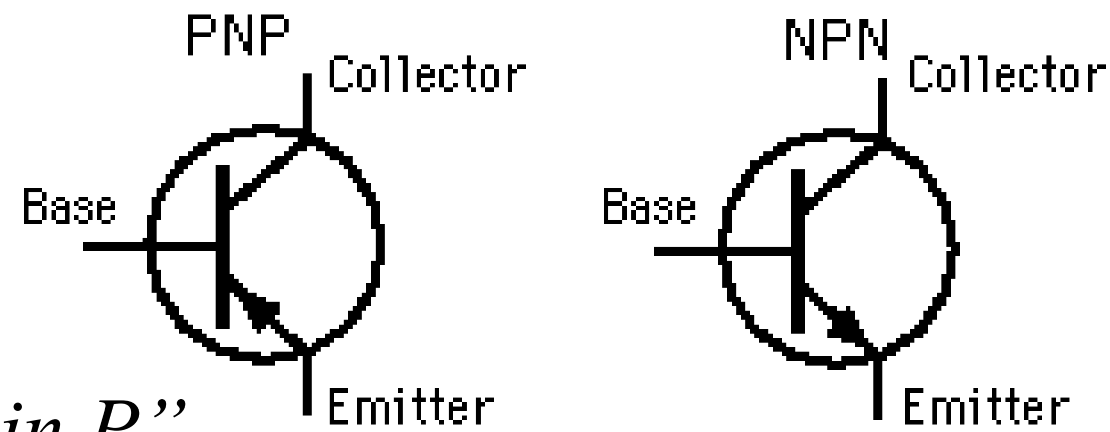
Bipolar Transistors





“ P in P”

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Current Flow

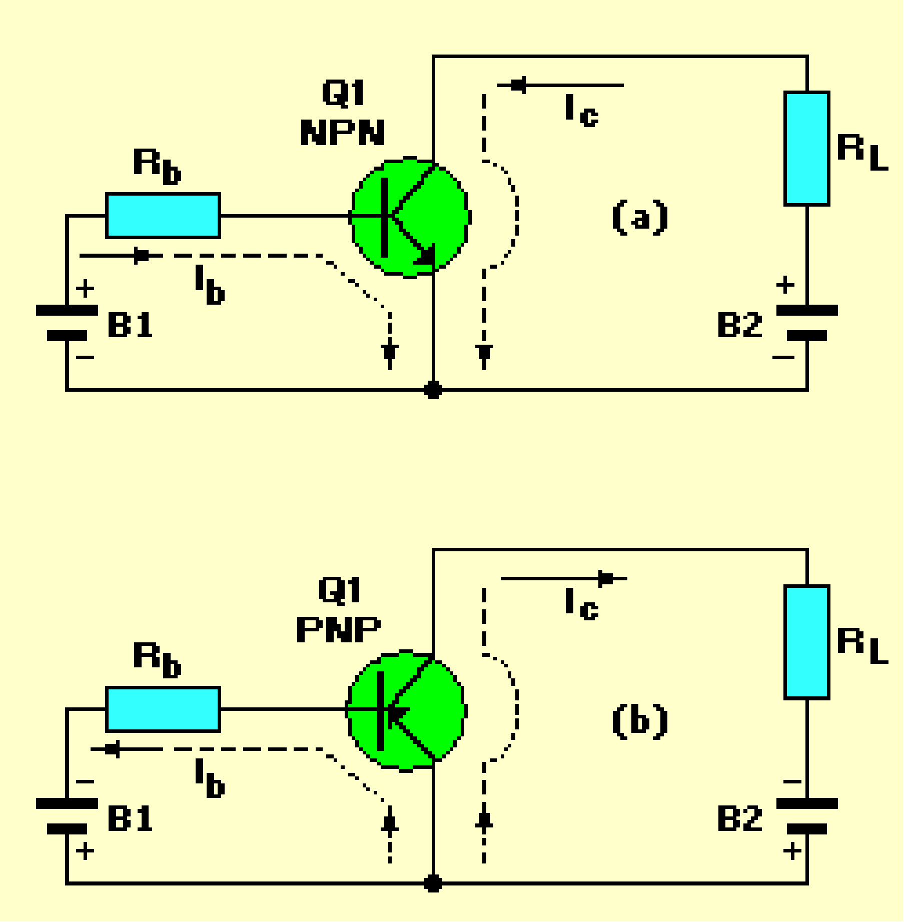

Fig. 3--CURRENT FLOW in transistors:
NPN (a), and PNP (b).

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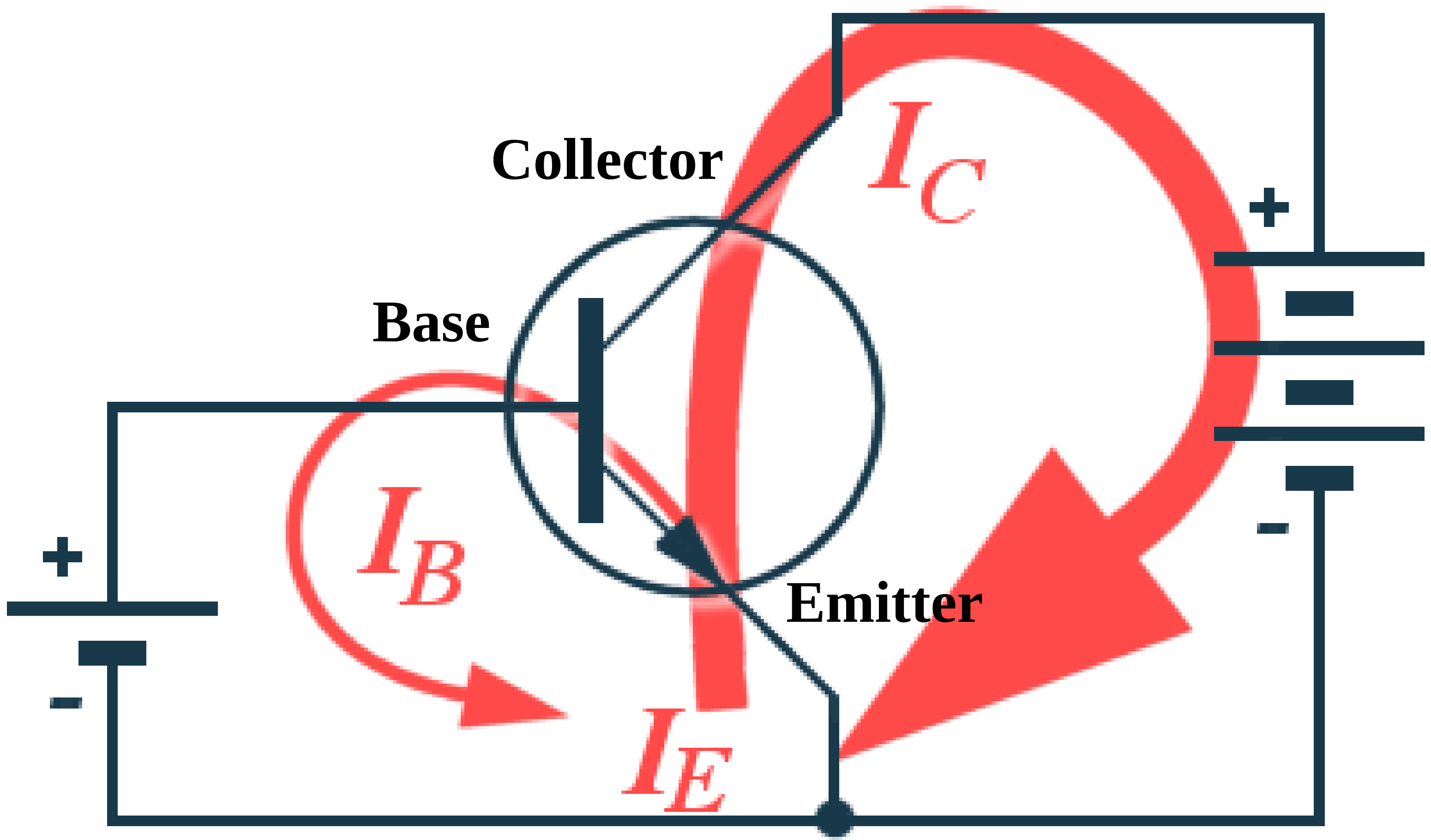

A small current between the base and the Emitter controls a LARGE current between the Emitter and Collector

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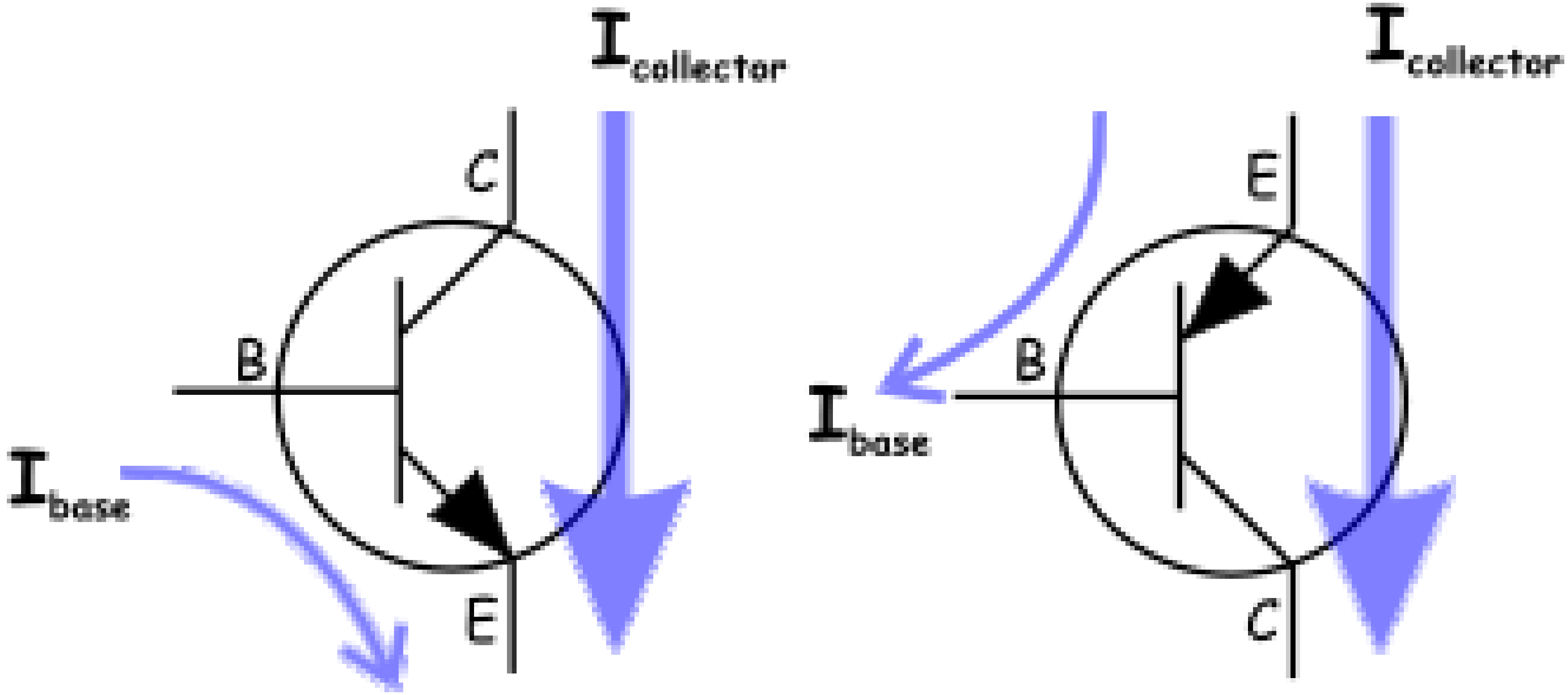

$$I_{collector} = H_{fe} * I_{base}$$

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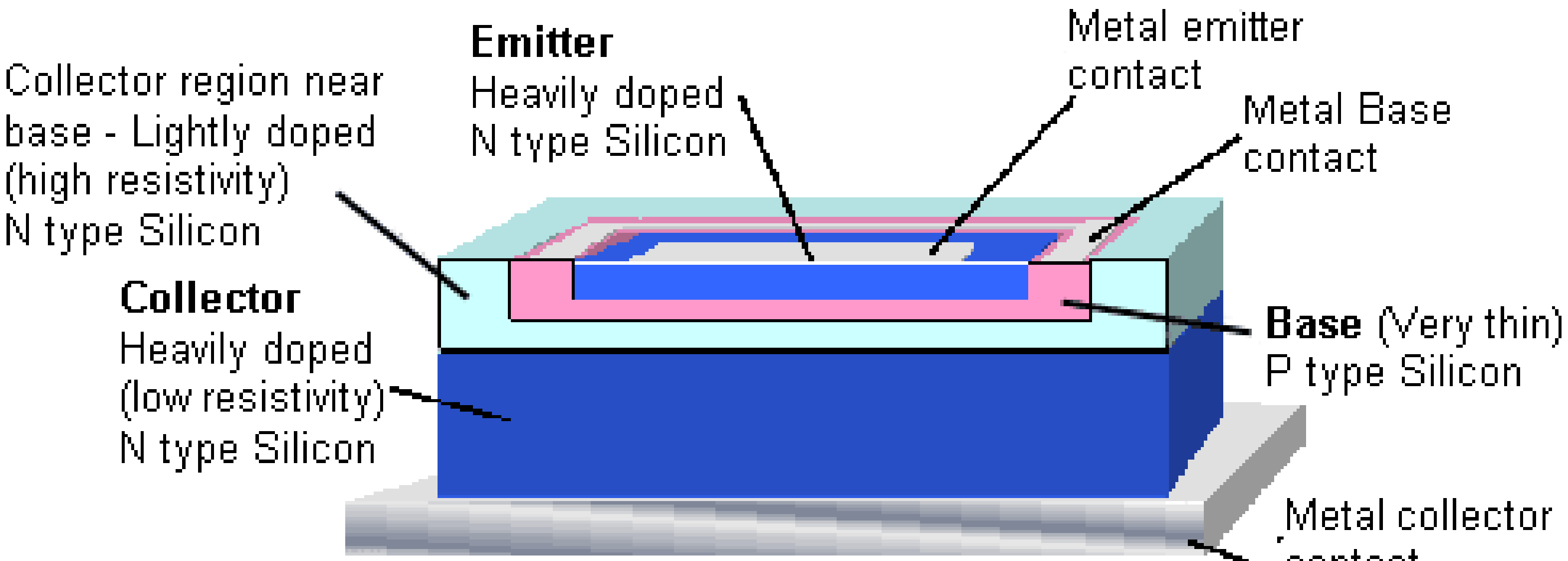
Modern Bipolar Transistor



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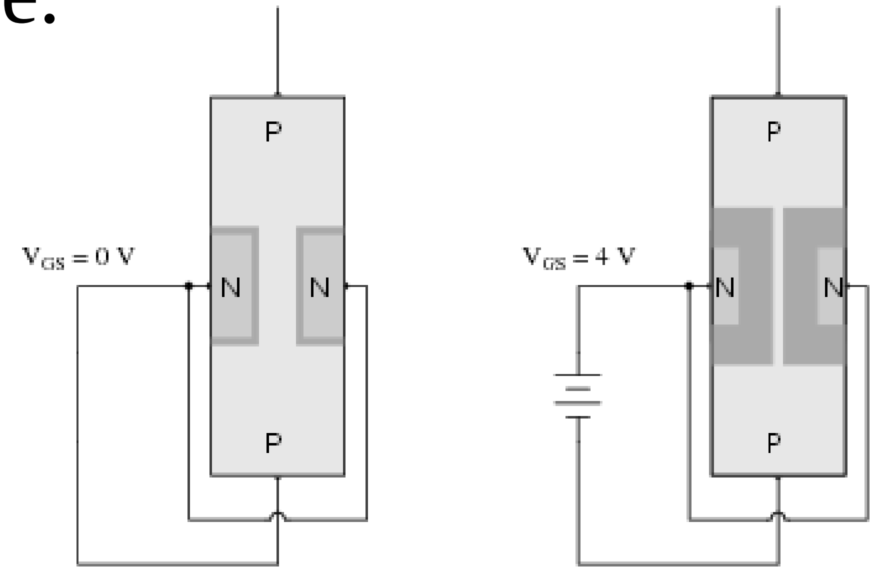
Field Effect Transistors

- Uses voltage to control the flow of current.
- Very little current flows through the Gate, so it does not affect the preceding circuit.
- Very high impedance.



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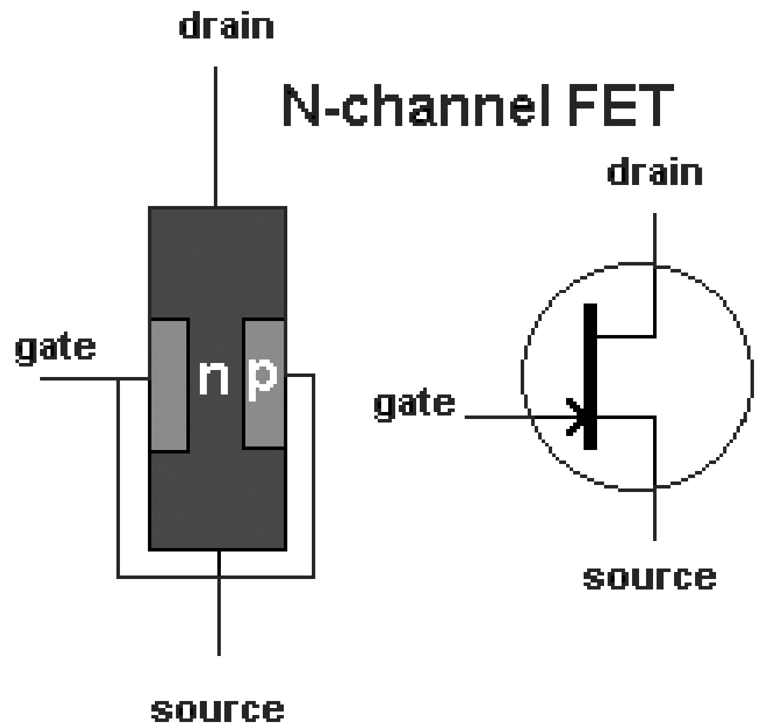
Field Effect Transistors

- **Source** – Terminal where the charge carriers enter the channel.
- **Drain** – Terminal where charge carriers exit the channel.
- **Gate** – Electrode that controls the conductance of the channel between the Source and Drain.



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Types of FETs

- The **JFET** (Junction Field Effect Transistor) uses a reverse biased P-N junction to separate the gate from the body.
- The **MOSFET** (Metal Oxide Semiconductor Field Effect Transistor) utilizes an insulator (typically SiO_2) between the gate and the body.

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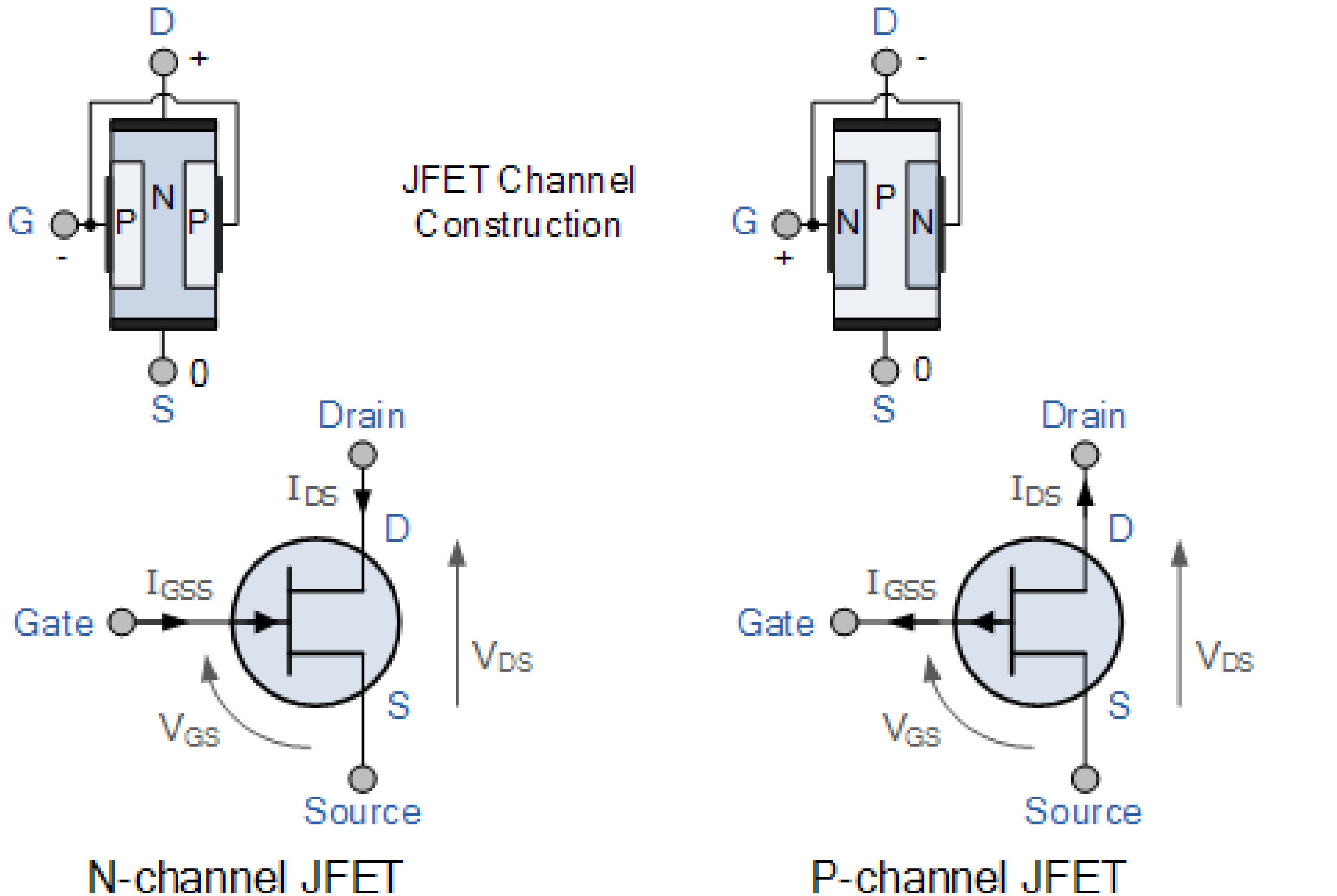
N and P Channel JFET



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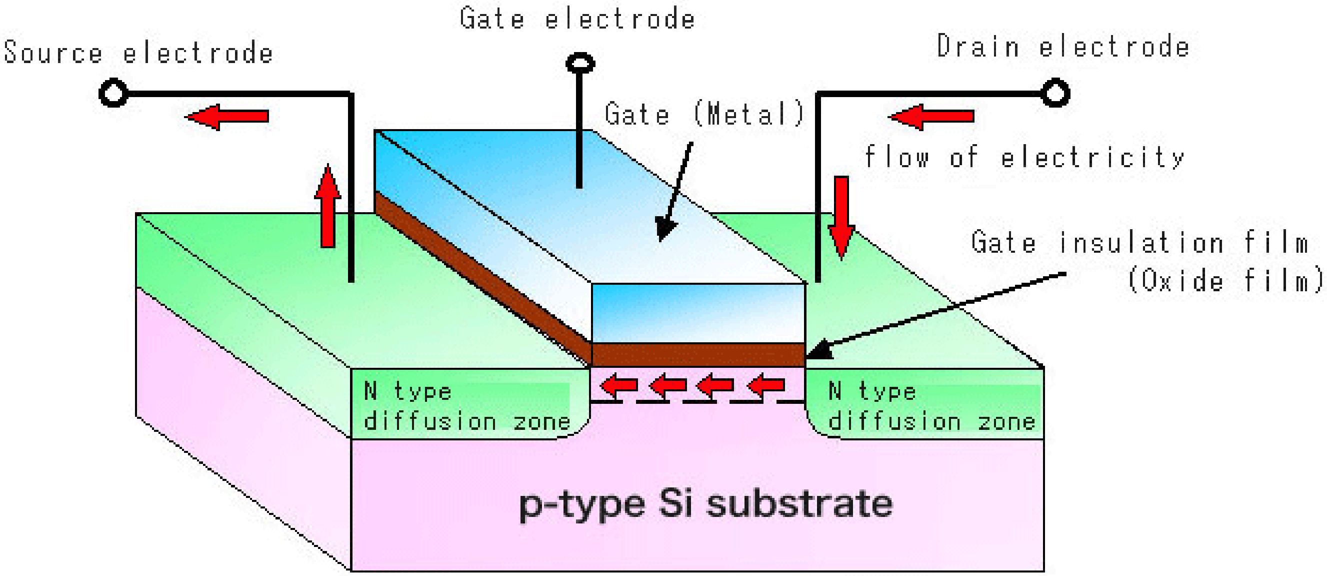
MOSFET



Construction of MOSFET

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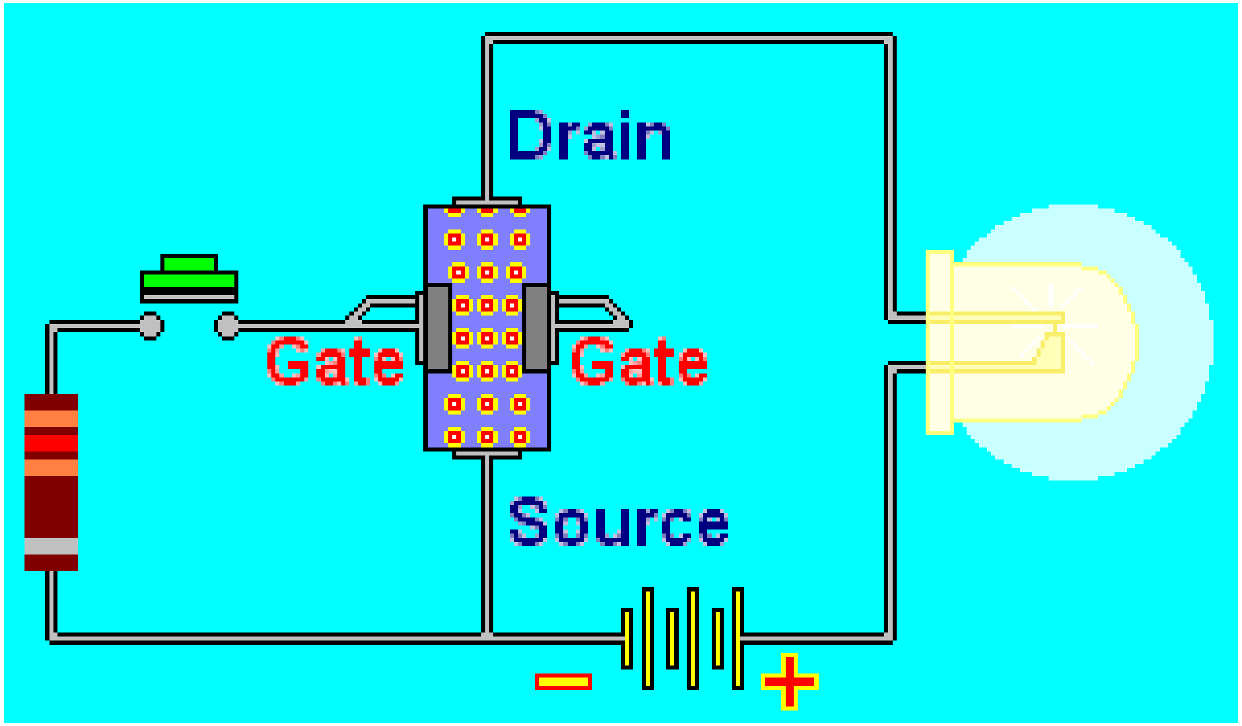
Pinch-Off Voltage

- The reverse bias voltage that cuts off conduction completely.



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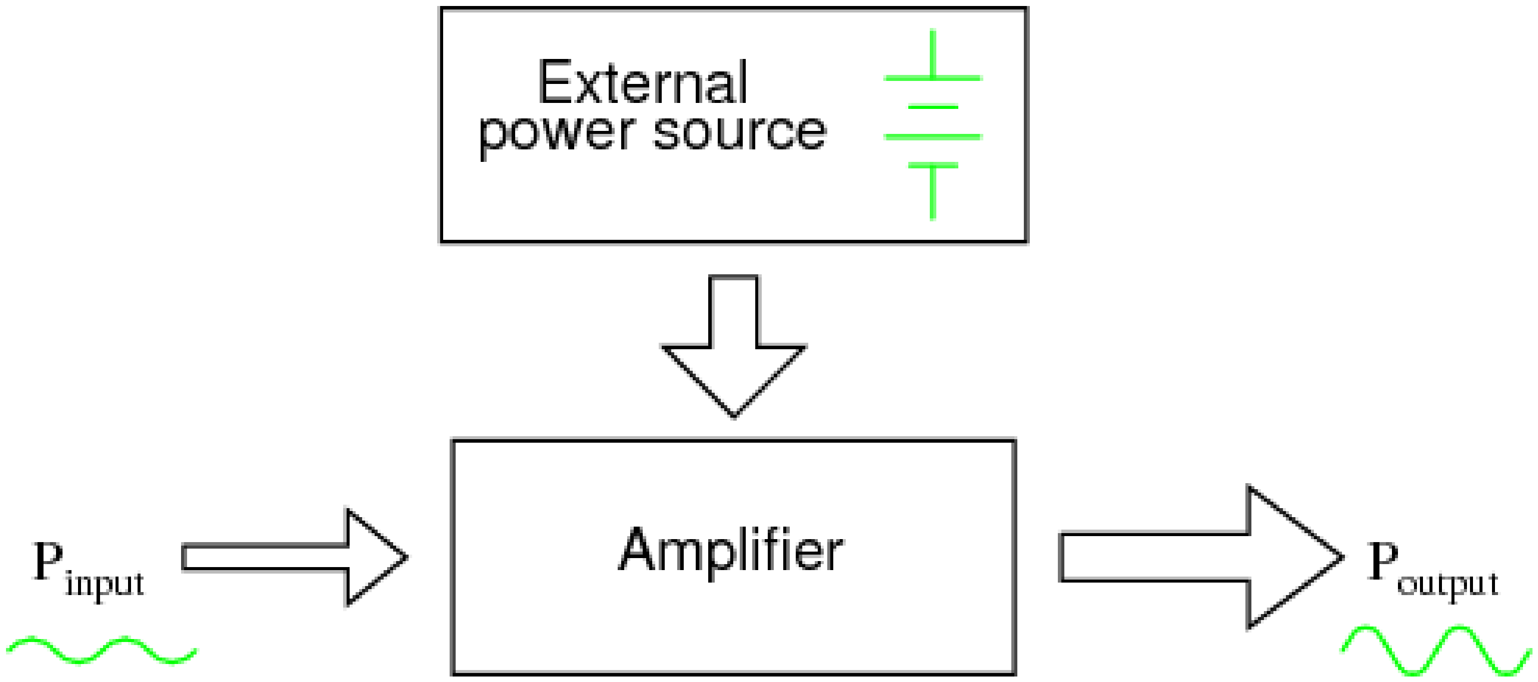
Gain

- Gain is an increase in the strength of a signal.
- An electronic circuit that accomplishes this is an Amplifier.
- The process is called Amplification.
- We can amplify voltage, current or power.

The Amplifier



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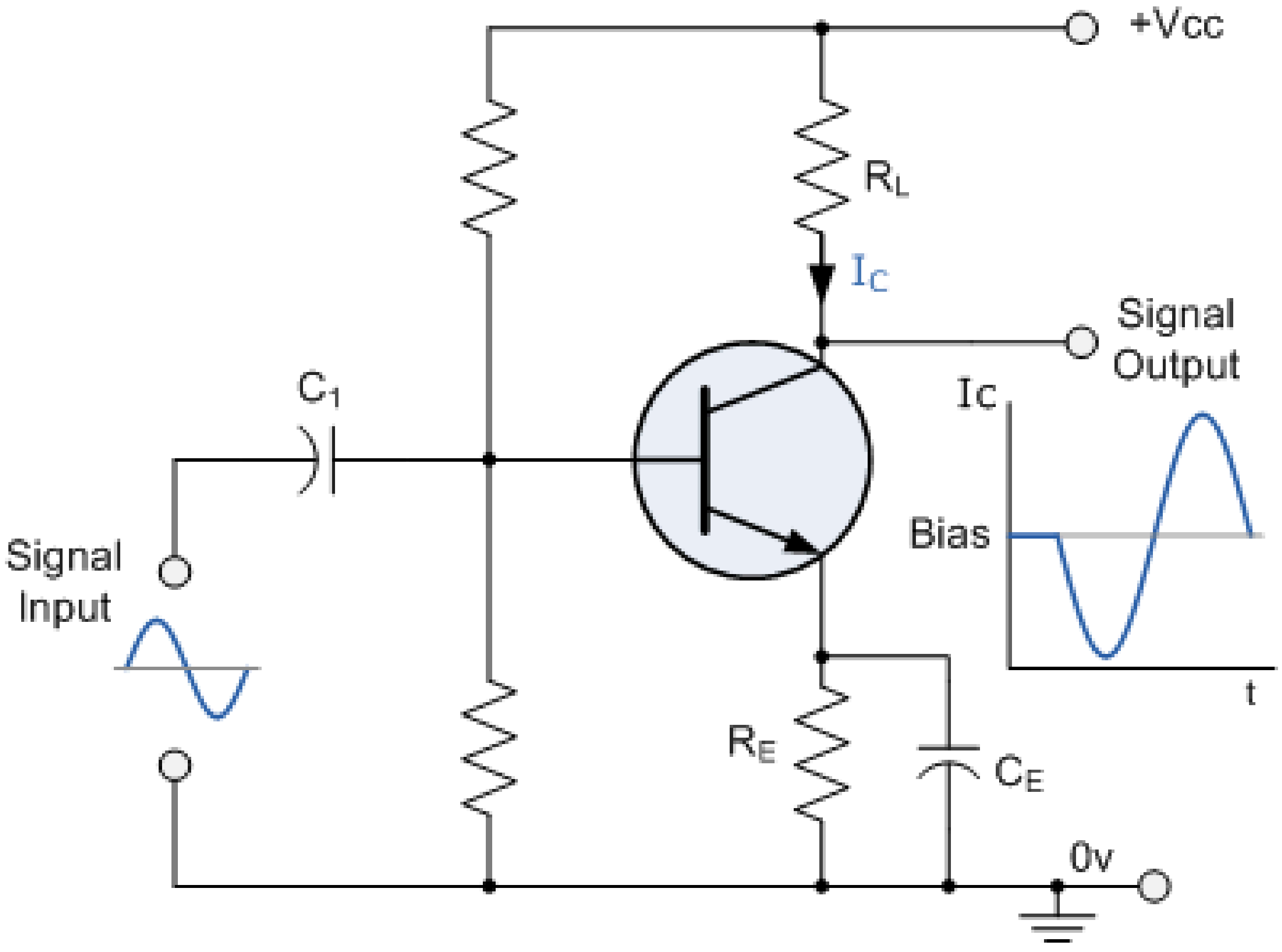
Basic Bipolar Transistor Amplifier



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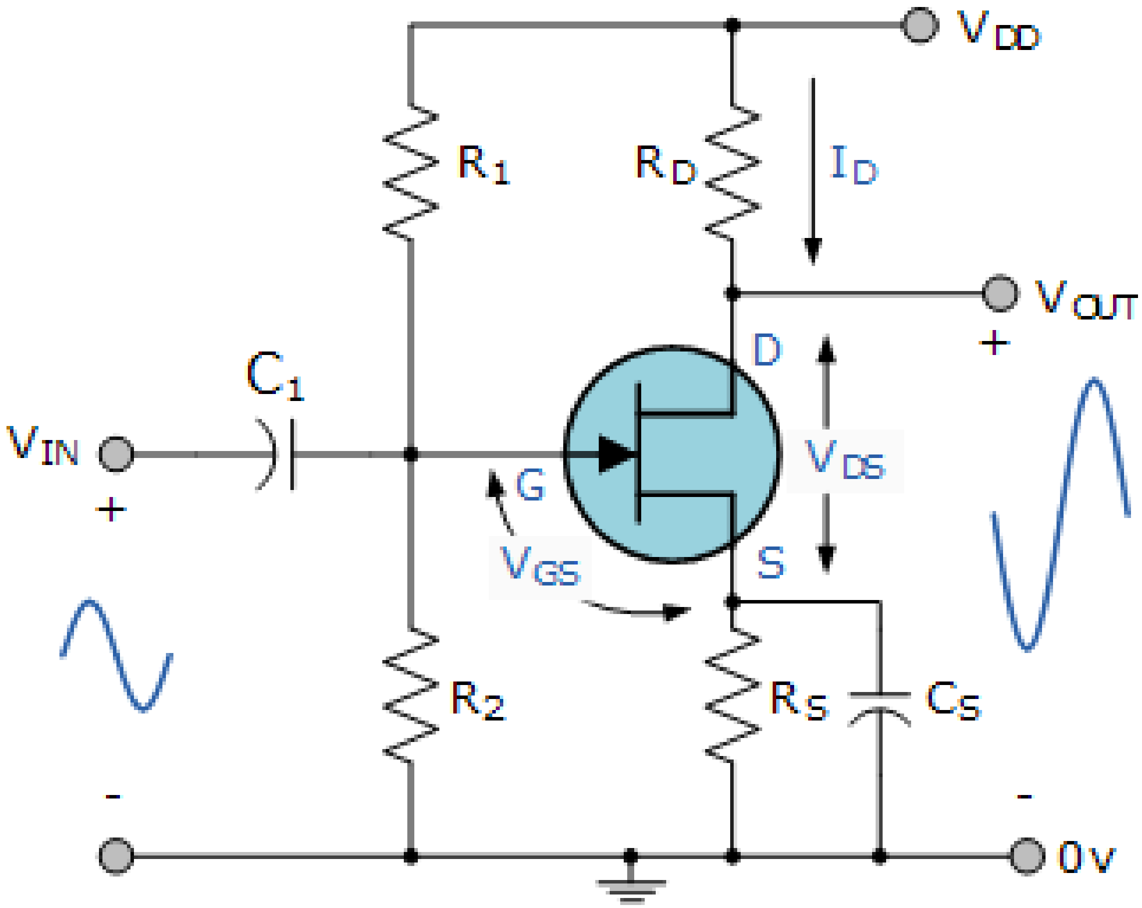
Basic FET Amplifier



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Audio and RF Amplifiers

- Audio Frequency (AF) Amplifiers work in the audio range.
  - 20 Hz to 20 KHz
- Radio Frequency (RF) Amplifiers work in on higher frequencies.
  - Greater than 20 KHz (in general)

Transistor Characteristics

- Breakdown Voltage – Max voltage that may be safely applied to the electrodes.
- Maximum Voltage – Max operating voltages that may safely be applied to the electrodes. Usually less than Breakdown Voltage, and never greater.

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Transistor Characteristics

- Maximum Current – Usually refers to the maximum Collector Current, I_c
- Maximum Power – Maximum amount of power the device can shed in terms of heat.
- Heat is the big enemy of most semiconductor devices!

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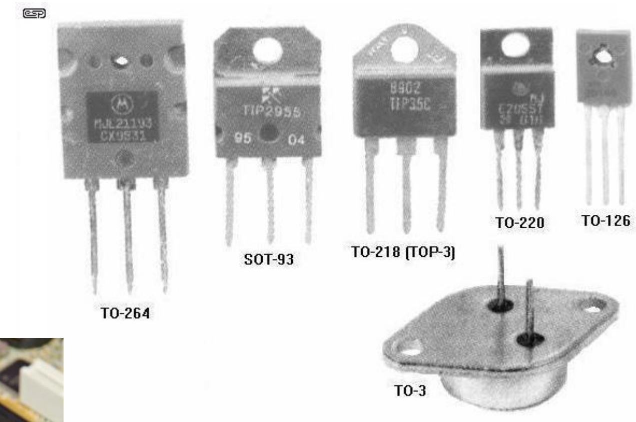

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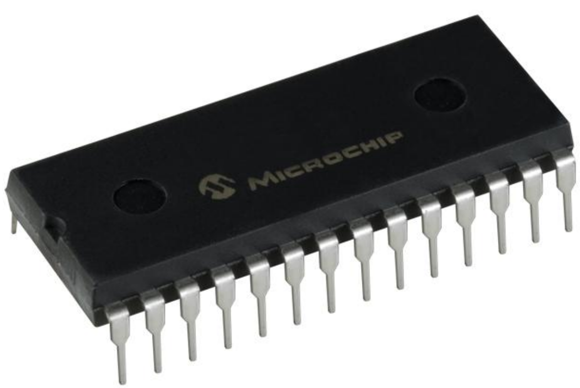
Integrated Circuits

- Electronic circuits built on a small plate, usually silicon.
- Contains transistors, resistors, capacitors, diodes, and sometimes inductors.
- Newest "chips" have billions of transistors!



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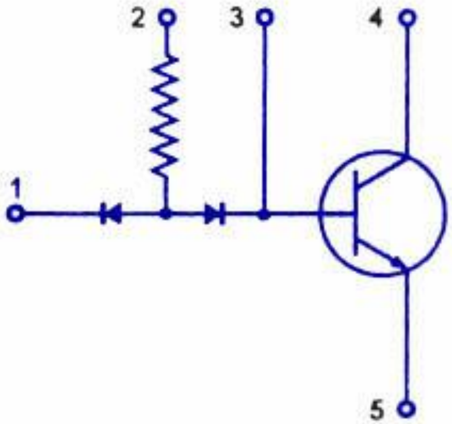
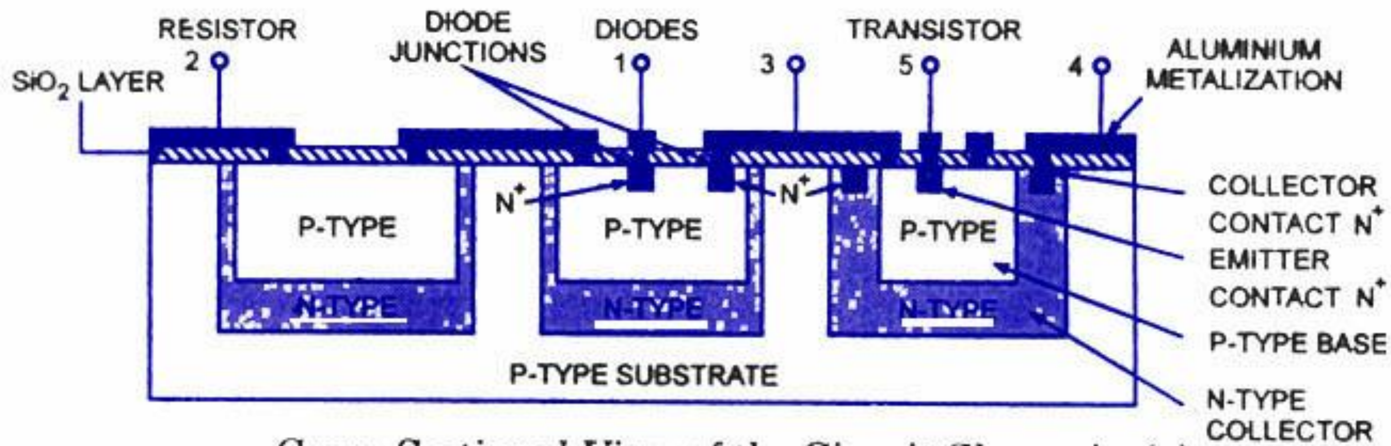
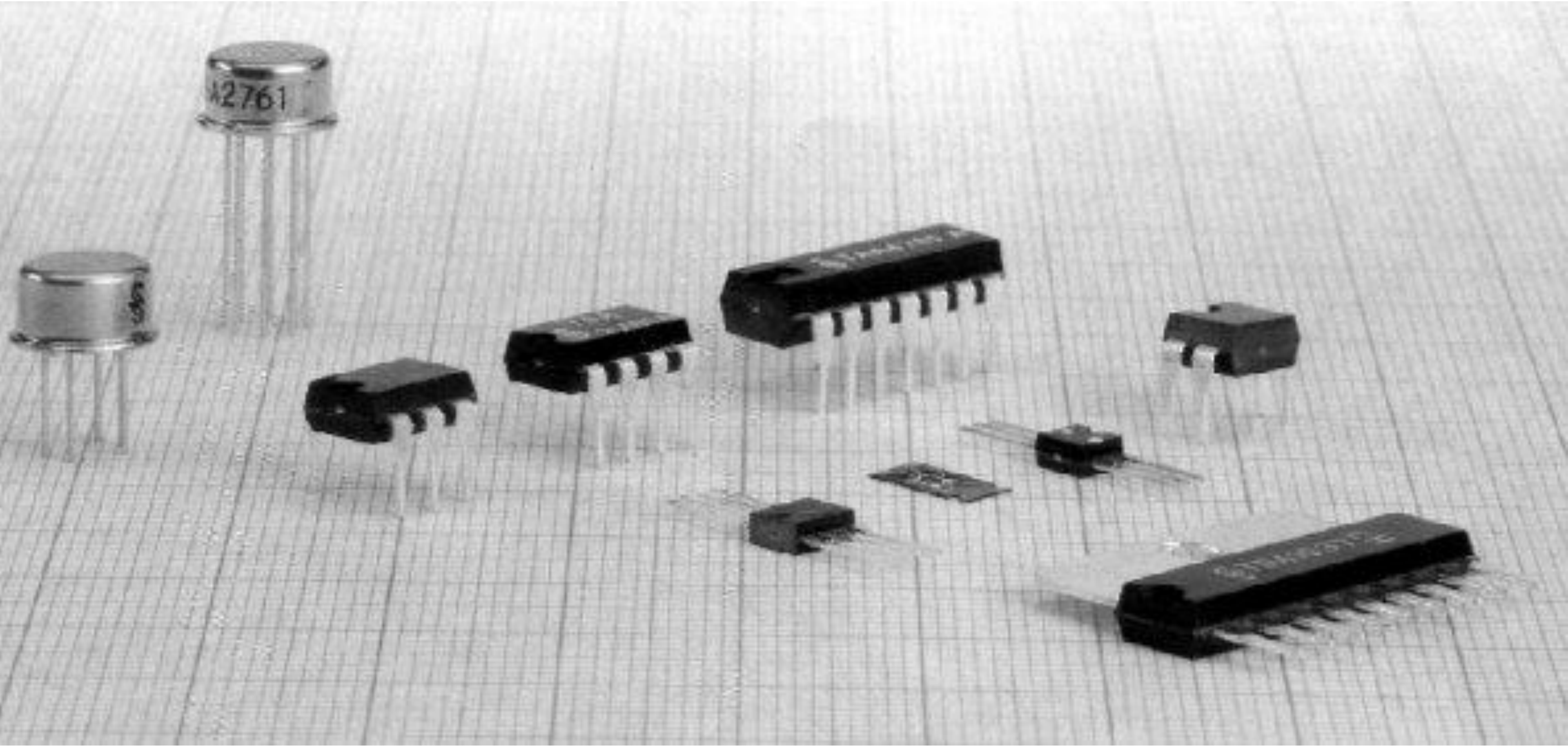


(a)



Cross-Sectional View of the Circuit Shown in (a) When Transformed into a Monolithic Form



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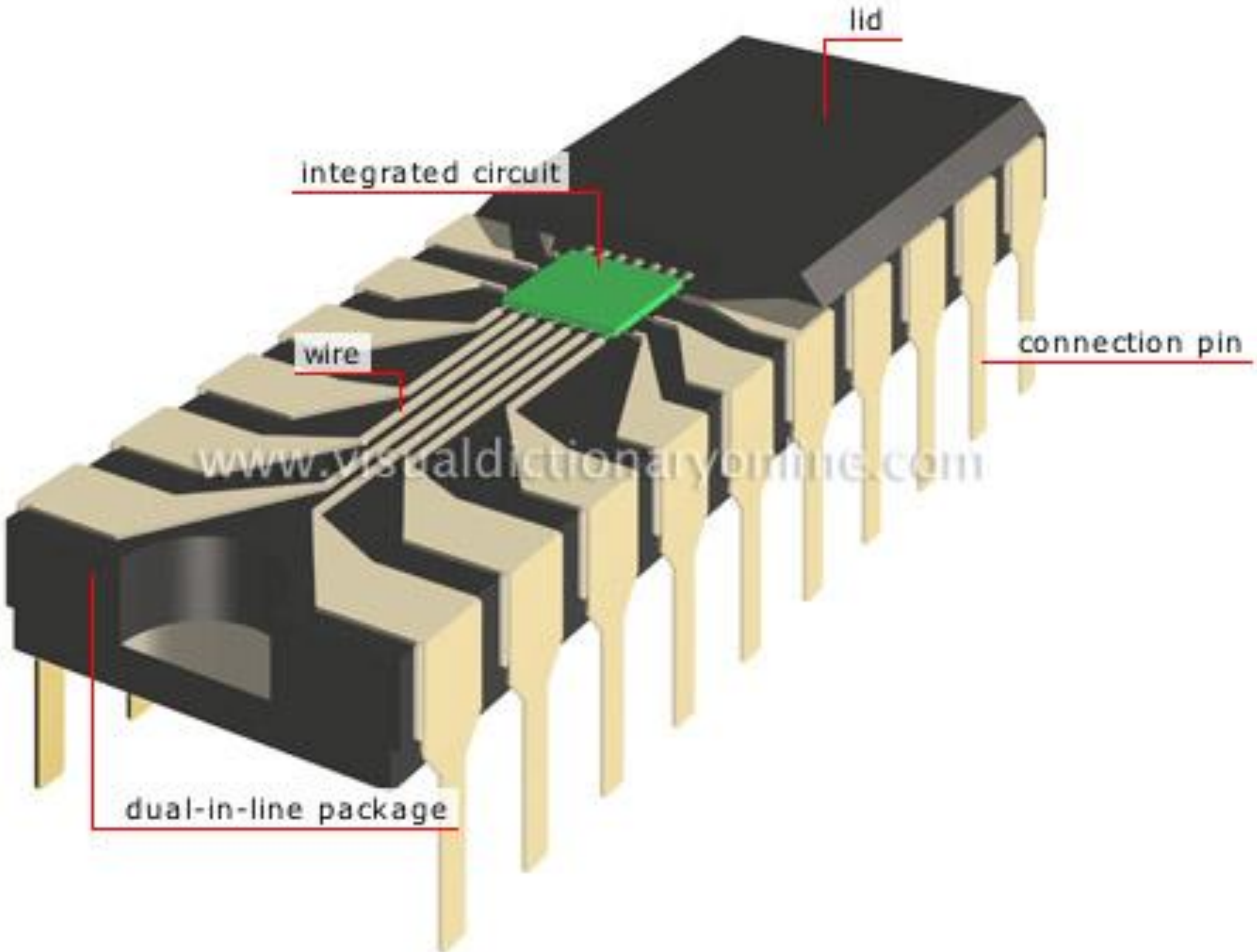

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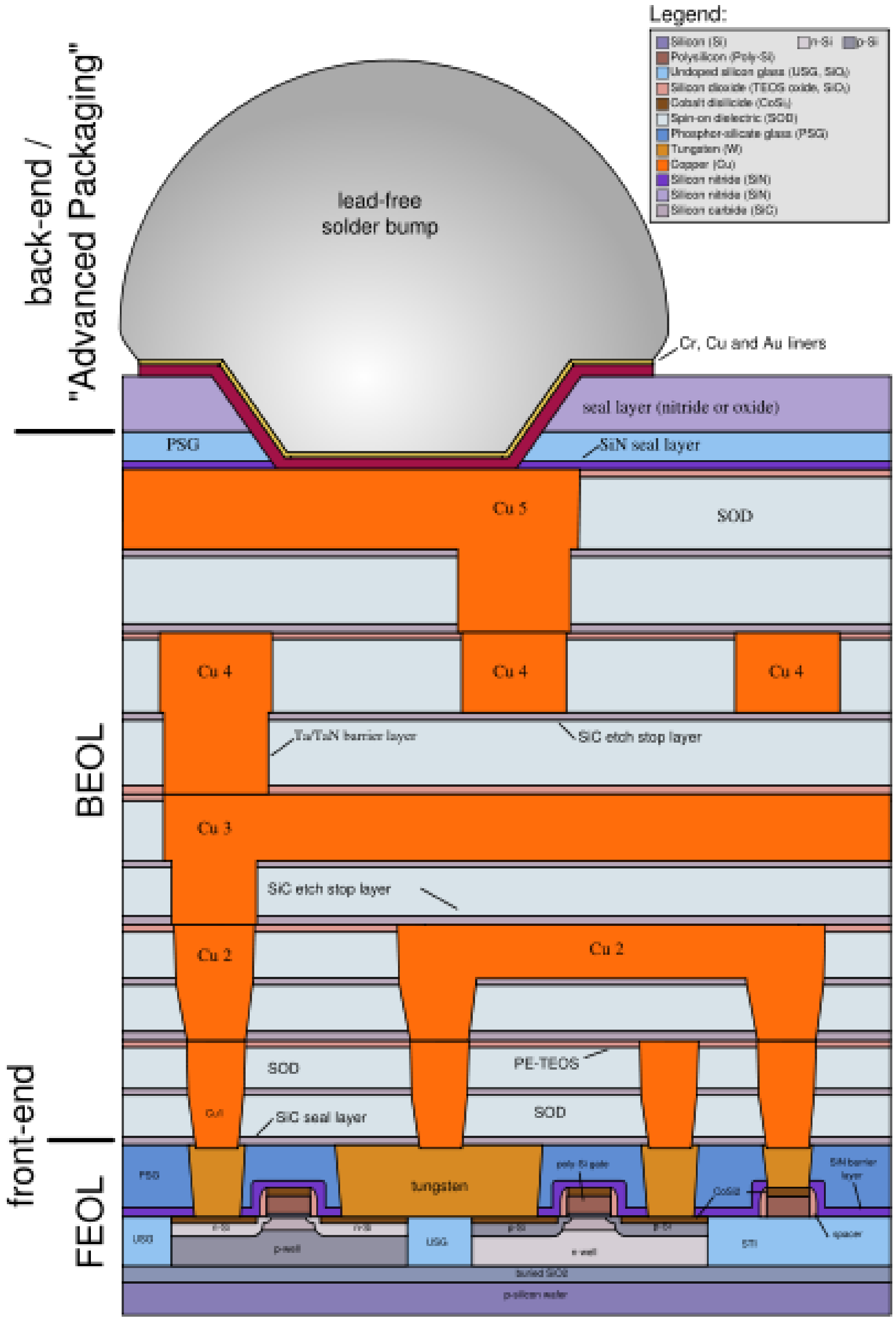

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Advantages of Integrated Circuits

- Scale – Millions, even billions of discrete components on a single chip.
- Cost – MUCH cheaper than individual components!
- Reliability – Manufacturing process is strictly controlled and chips thoroughly tested before leaving the factory.

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Vacuum Tubes

- An electronic device that controls electric current through a vacuum in a sealed container.
- Obsolete now, but still used for some specialized applications.
- Often found in power amplifiers (“Linears”).

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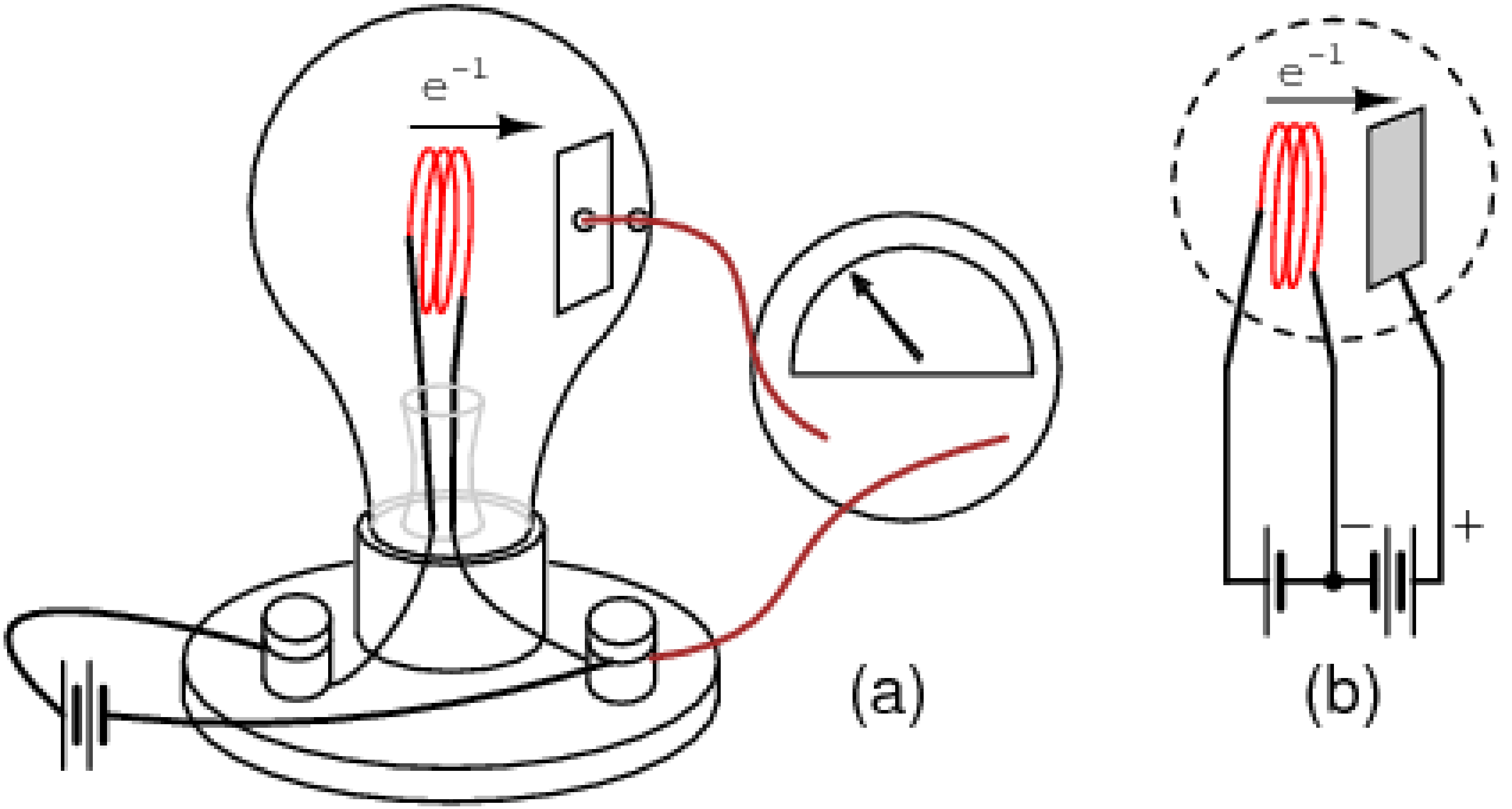
Edison Effect



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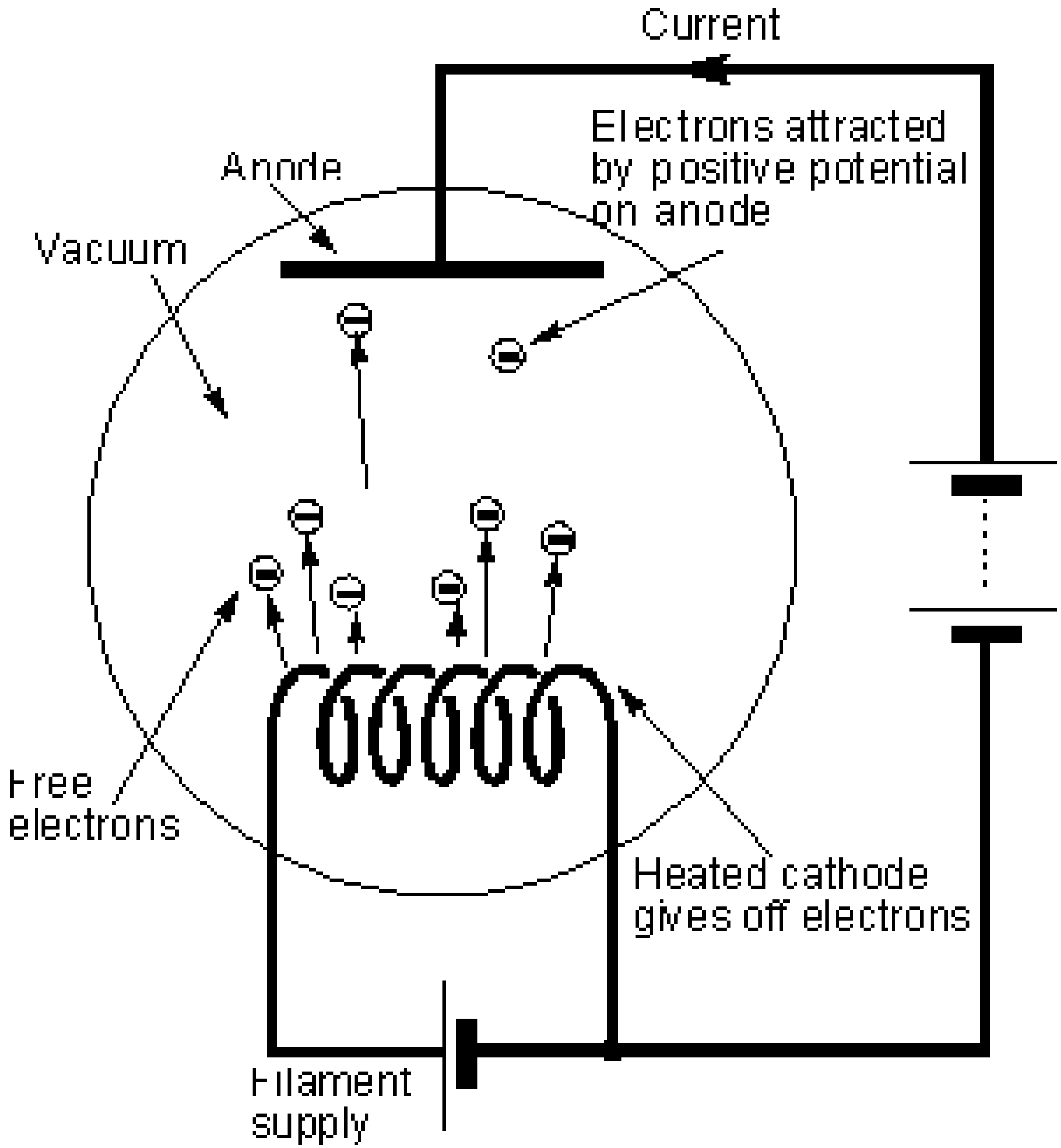

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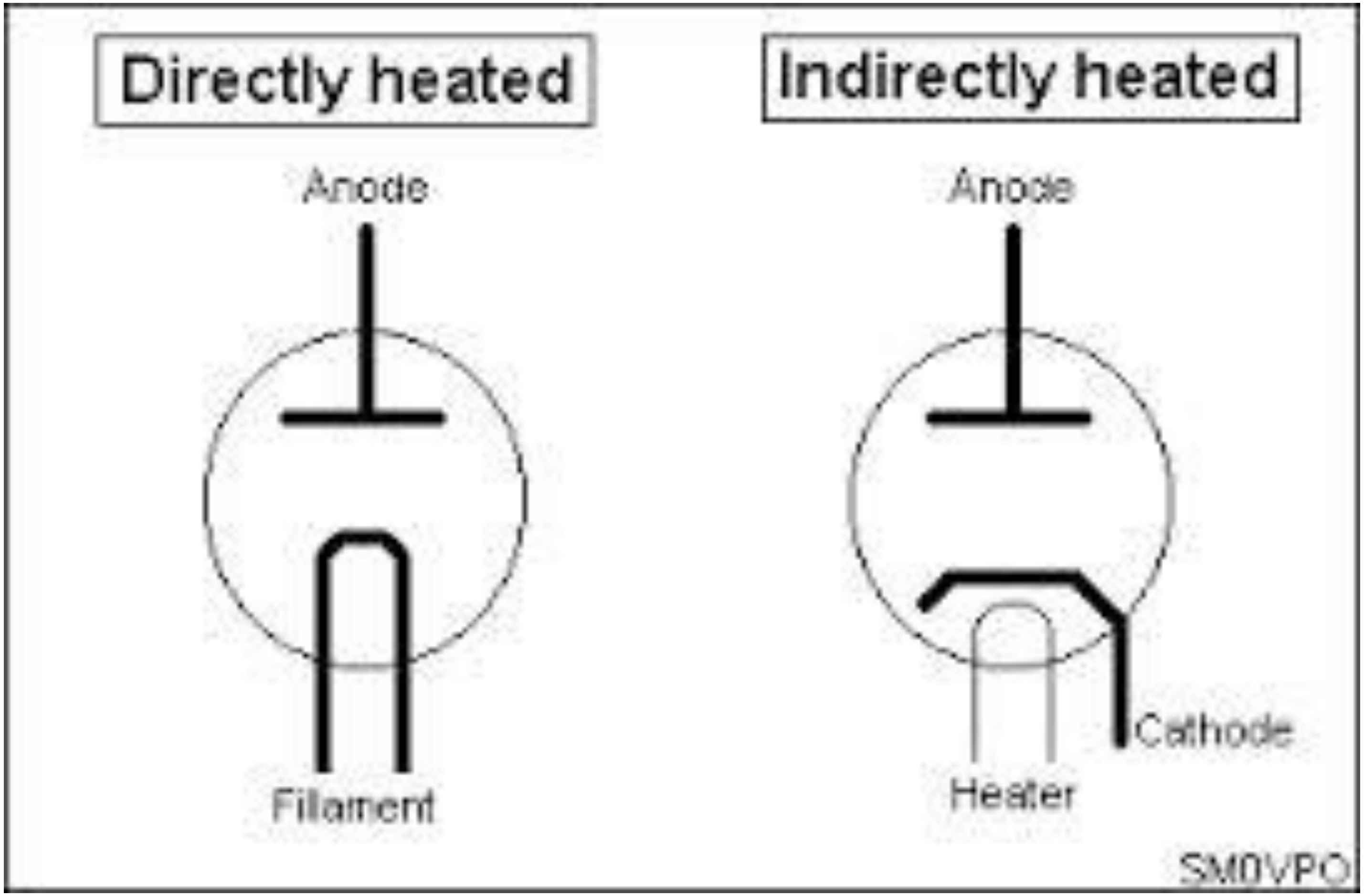
The Diode



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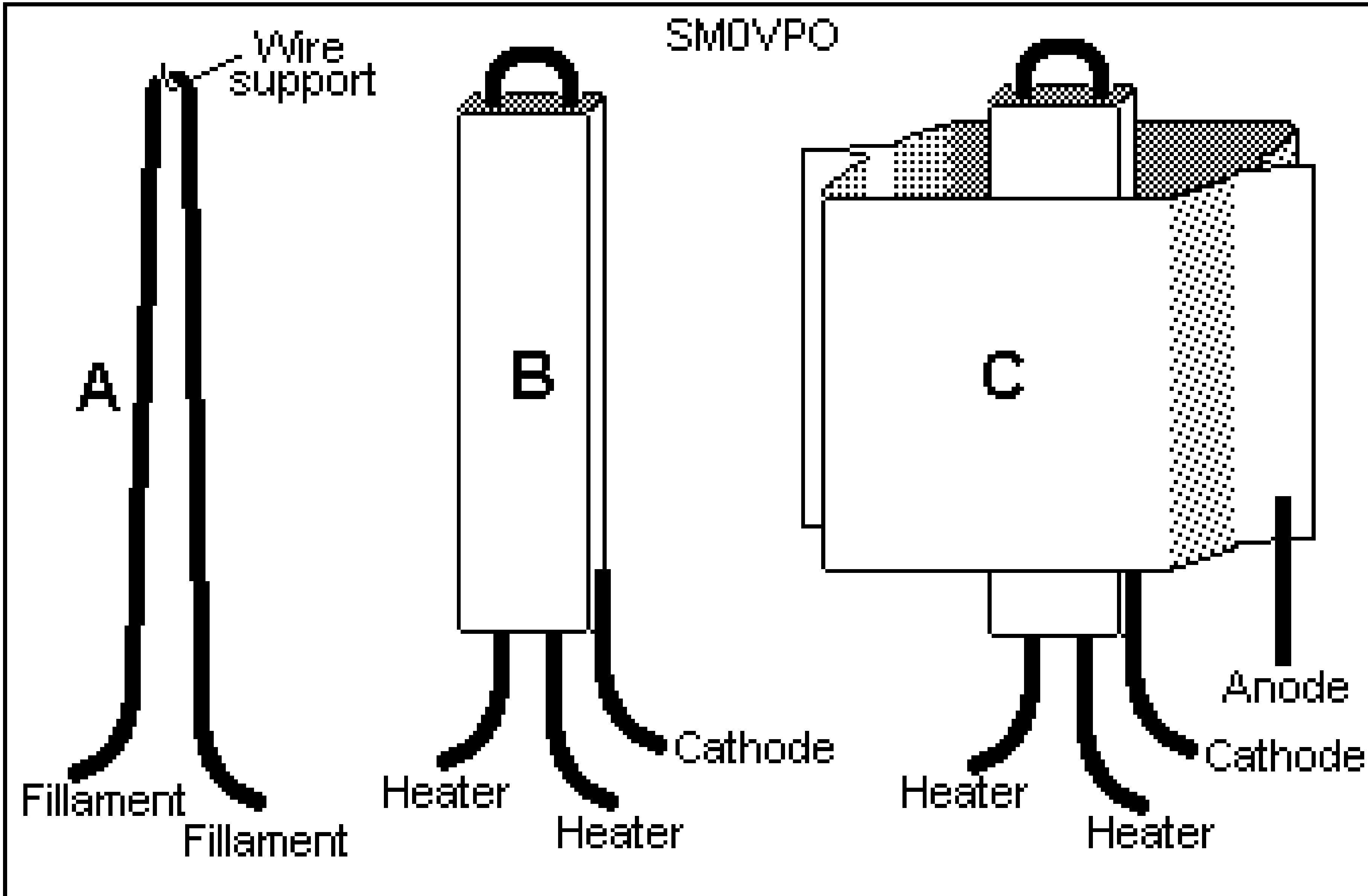

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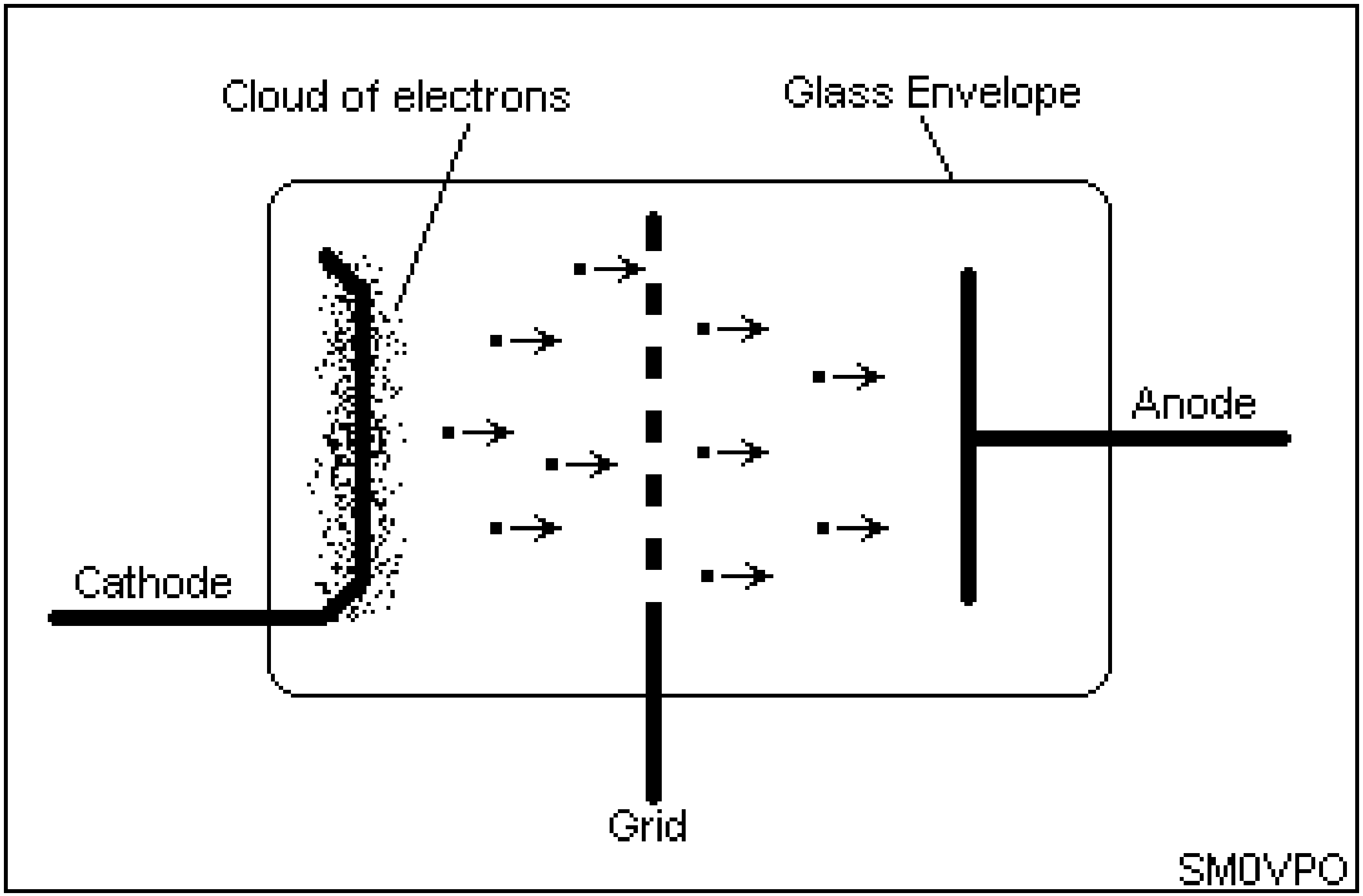
The Triode



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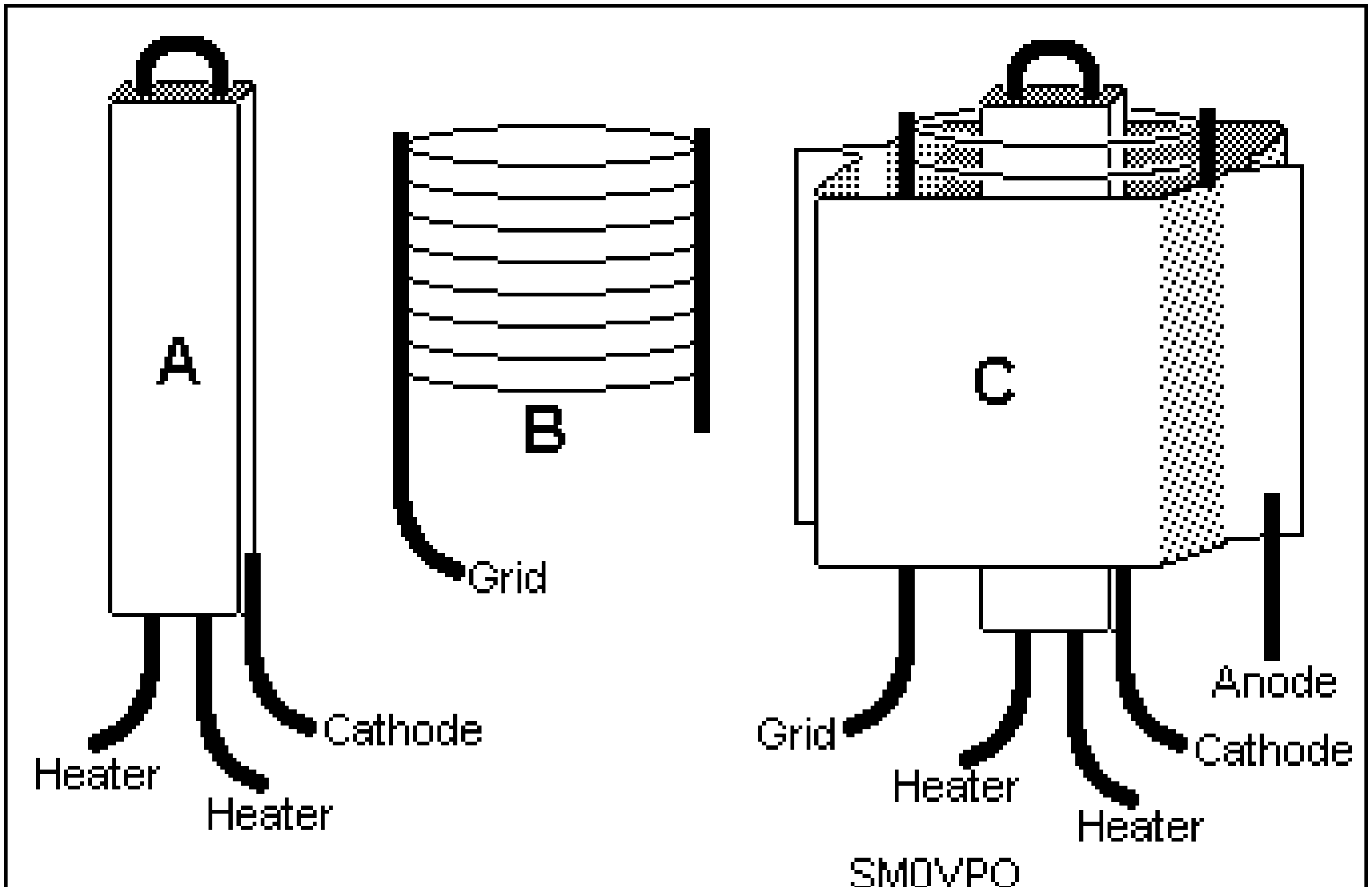
The Triode



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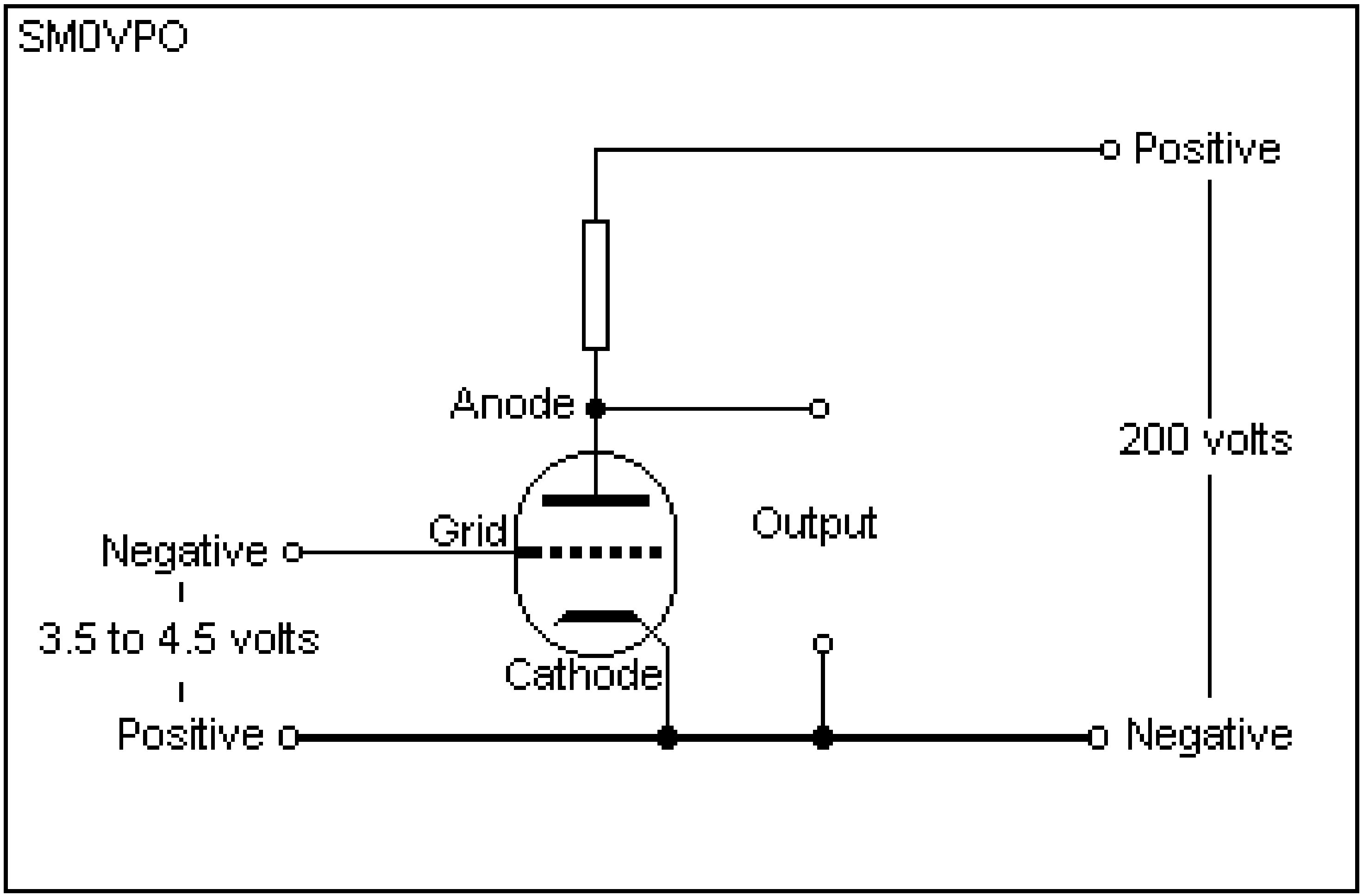
Using the Triode



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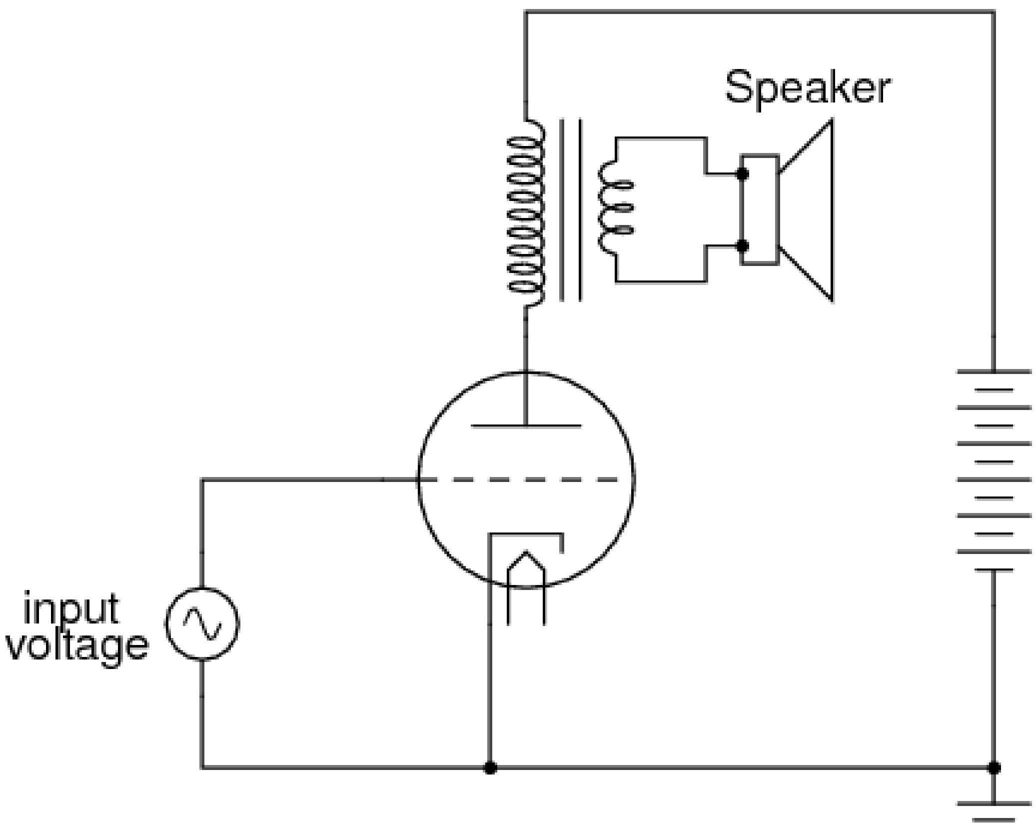
Triode Audio Amplifier



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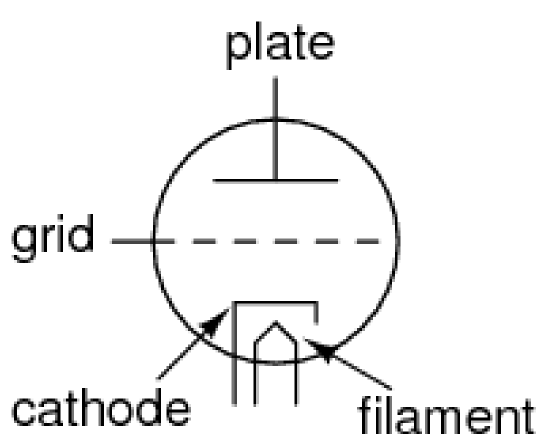
Grid Bias

- If we make the grid sufficiently negative, all electrons will be repelled, and none will get through to the Anode.
- This is called cut-off.
- That voltage value is called the cut-off bias.



Comparison – Transistors and Tubes

	Transistor	FET	Triode
Input	Emitter	Source	Cathode
Output	Collector	Drain	Plate/Anode
Control	Base	Gate	Control Grid

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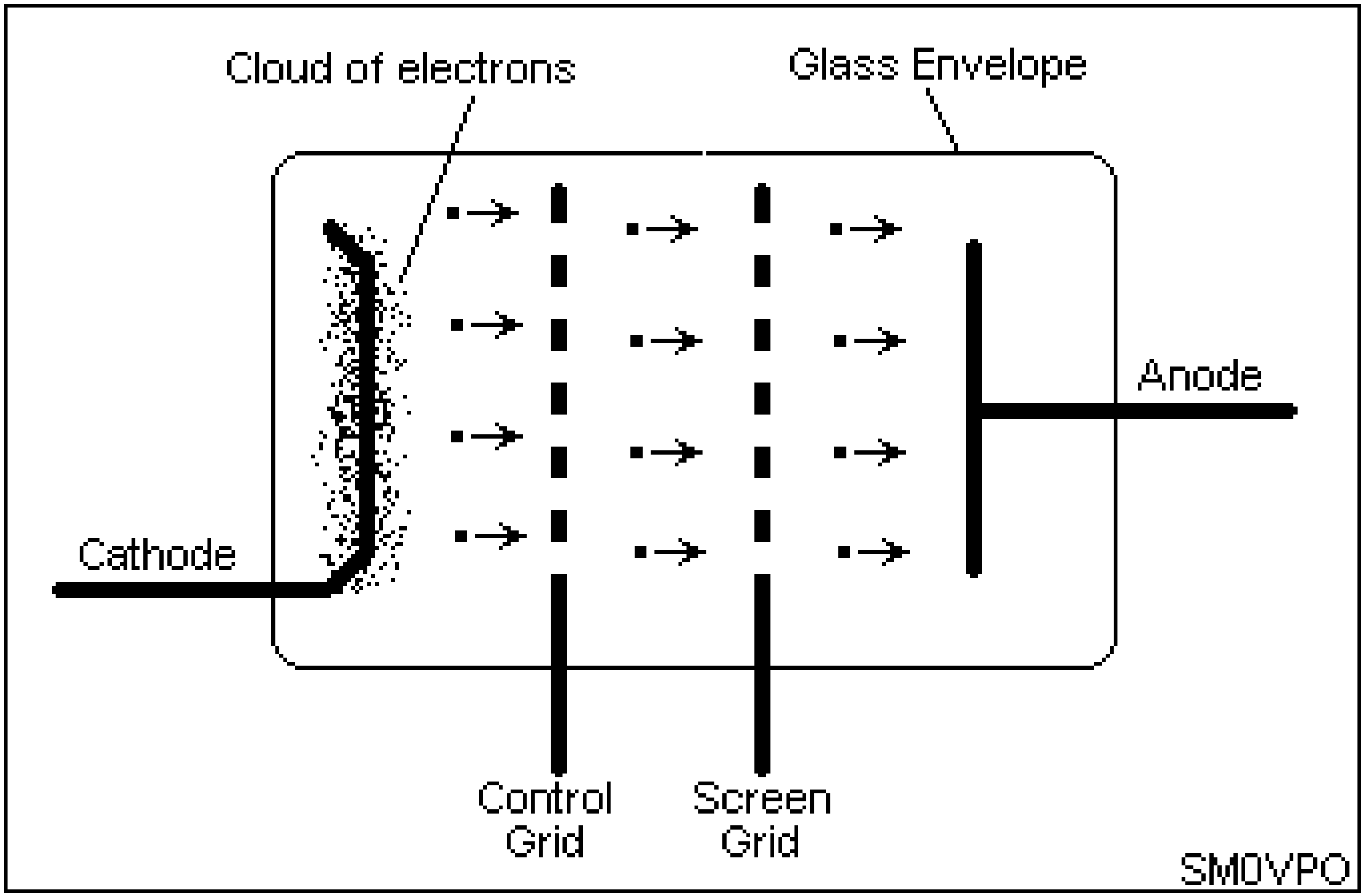
The Tetrode



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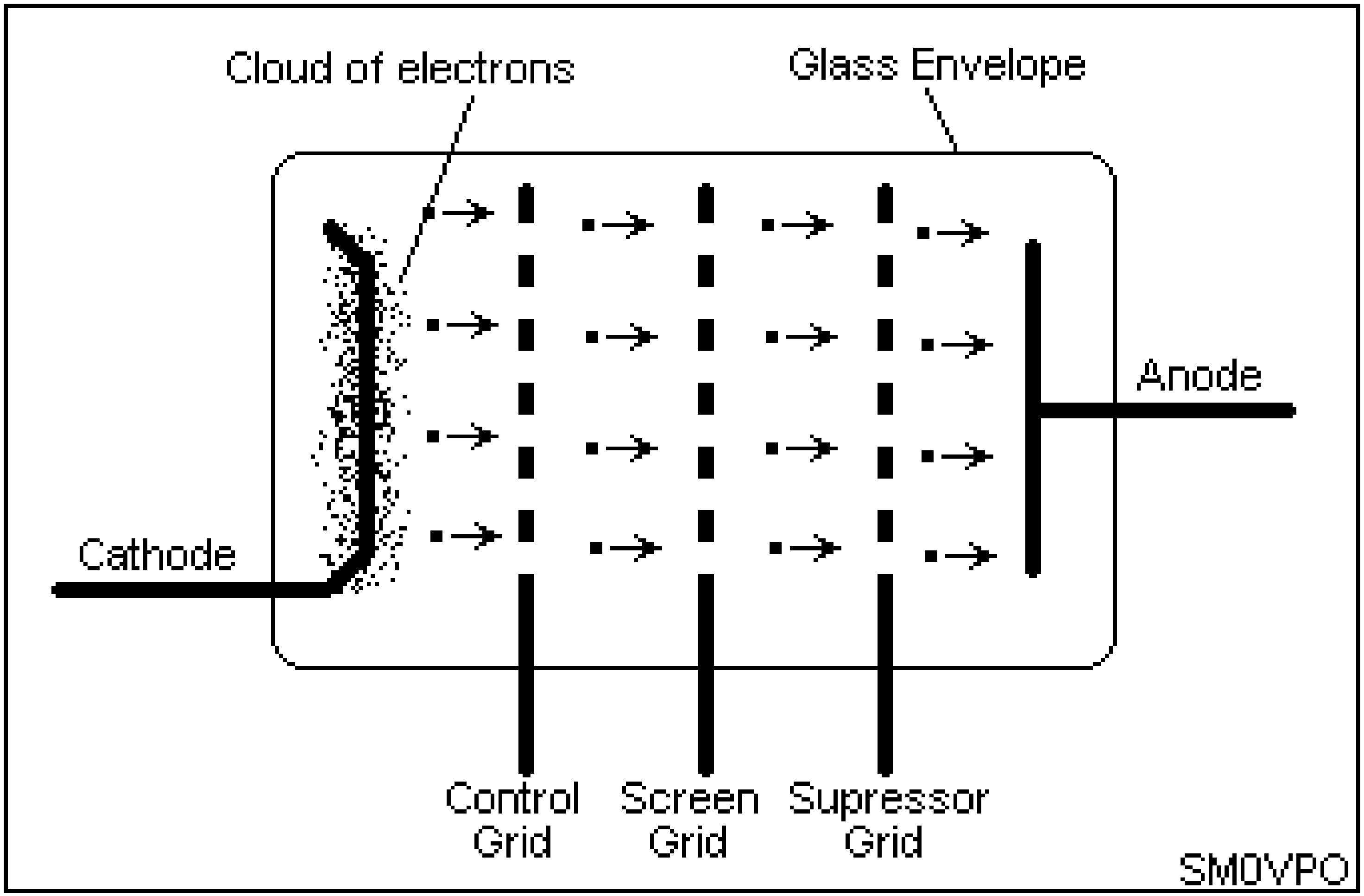
The Pentode



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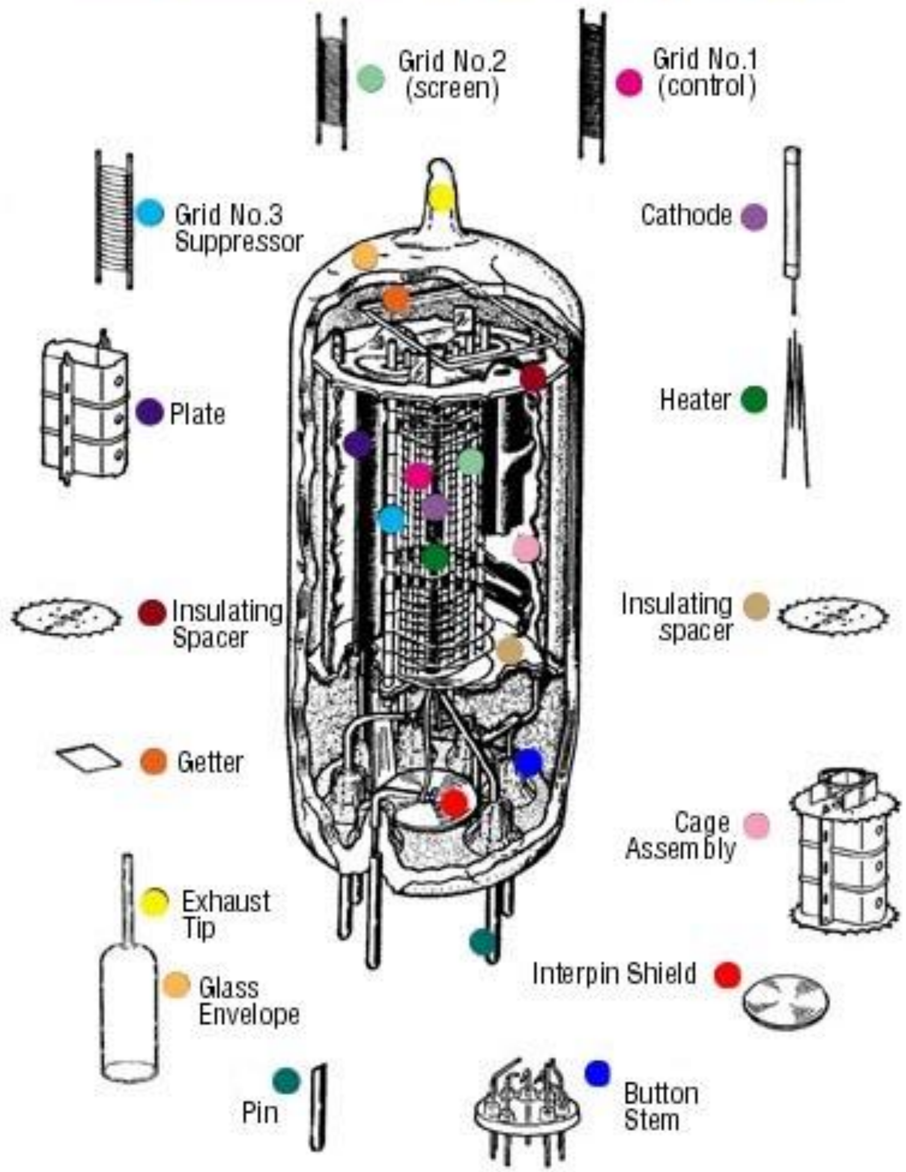
Inside a miniature tube (this is a pentode)



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Questions?

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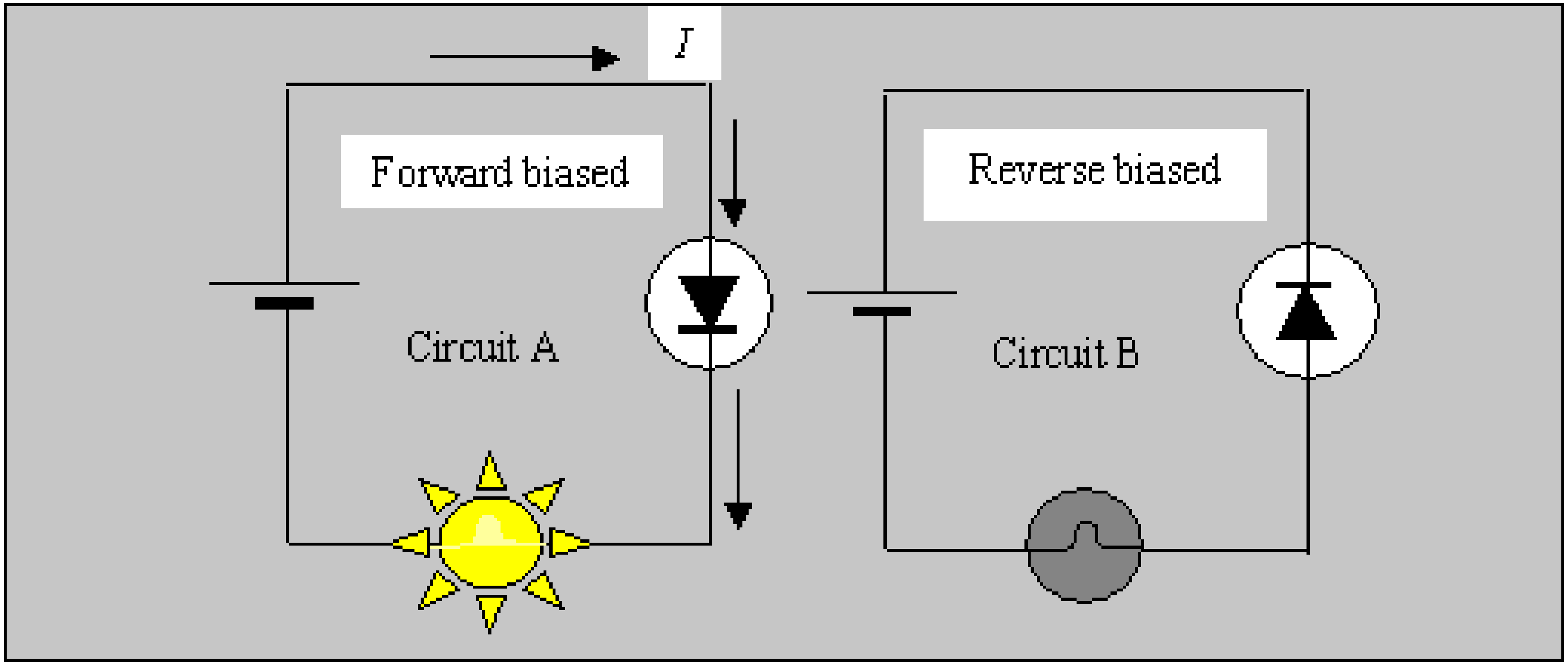

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