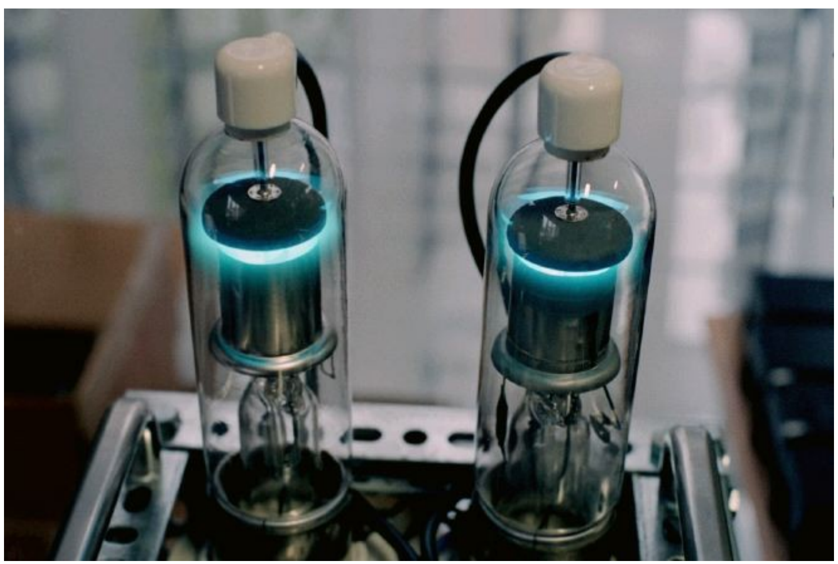
The New England Radio Discussion Society's "Electronics for Amateur Radio operators" course

"Getting down to nuts and volts"

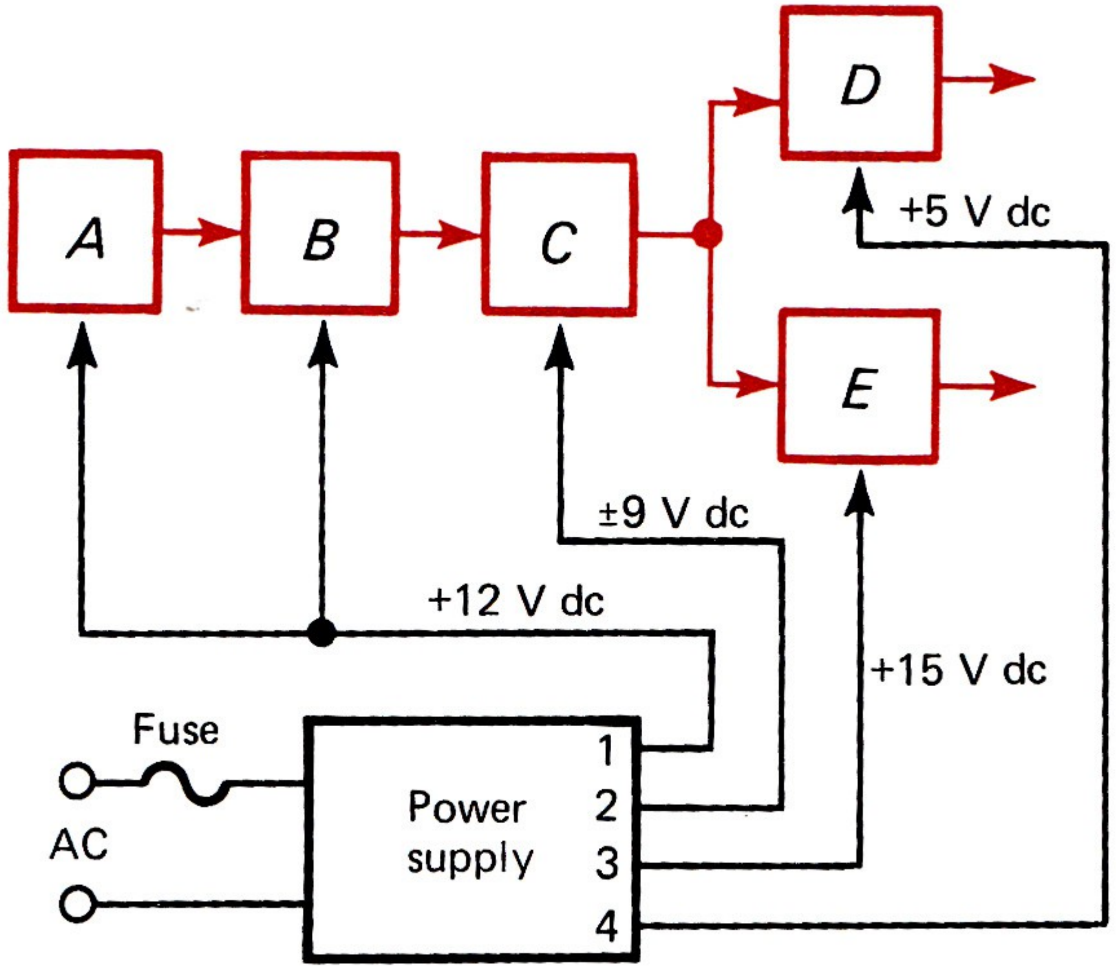
Phase Three, PPT1
November 2016

AI2Q, Nov. 2016

Diodes, rectifiers, and power supplies



A typical multi-output power supply block diagram



What is a *diode*?

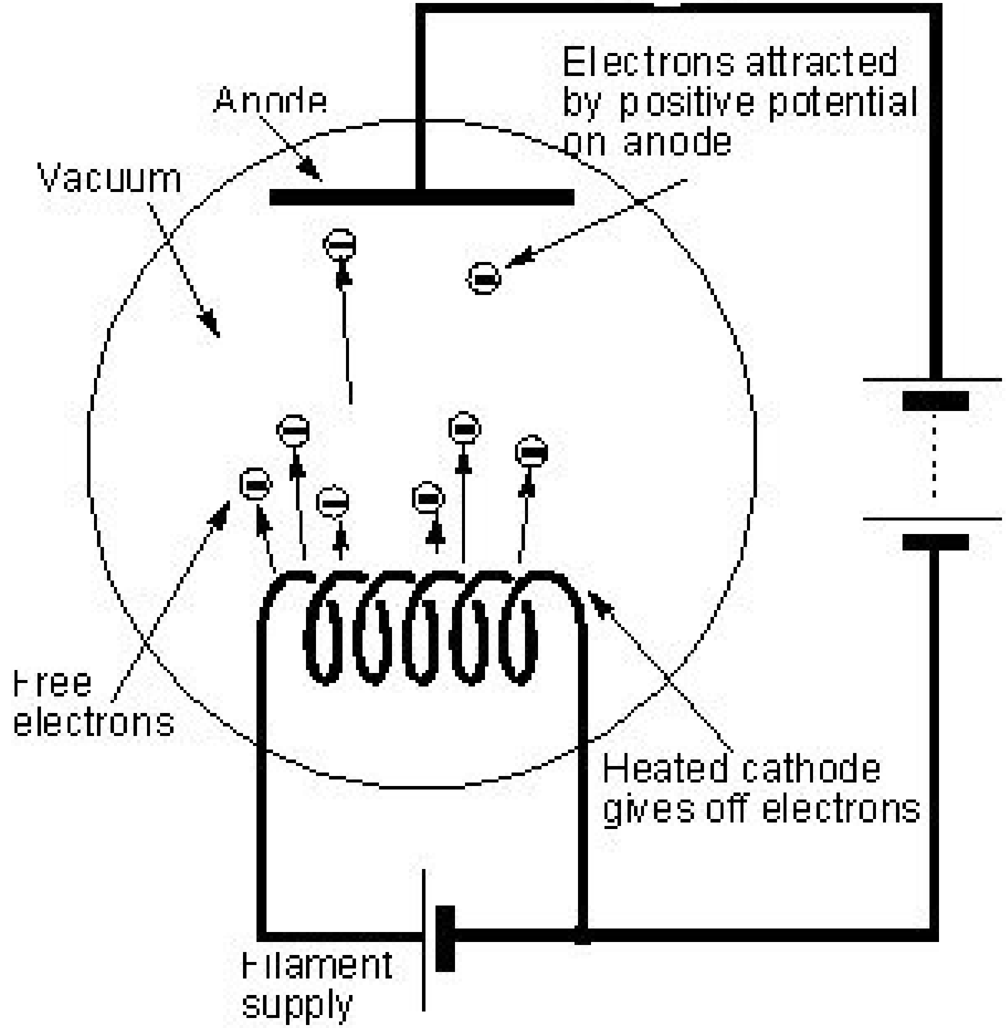
A *diode* is an electronic device that conducts current in only one direction.

A diode has a *cathode* and an *anode*.

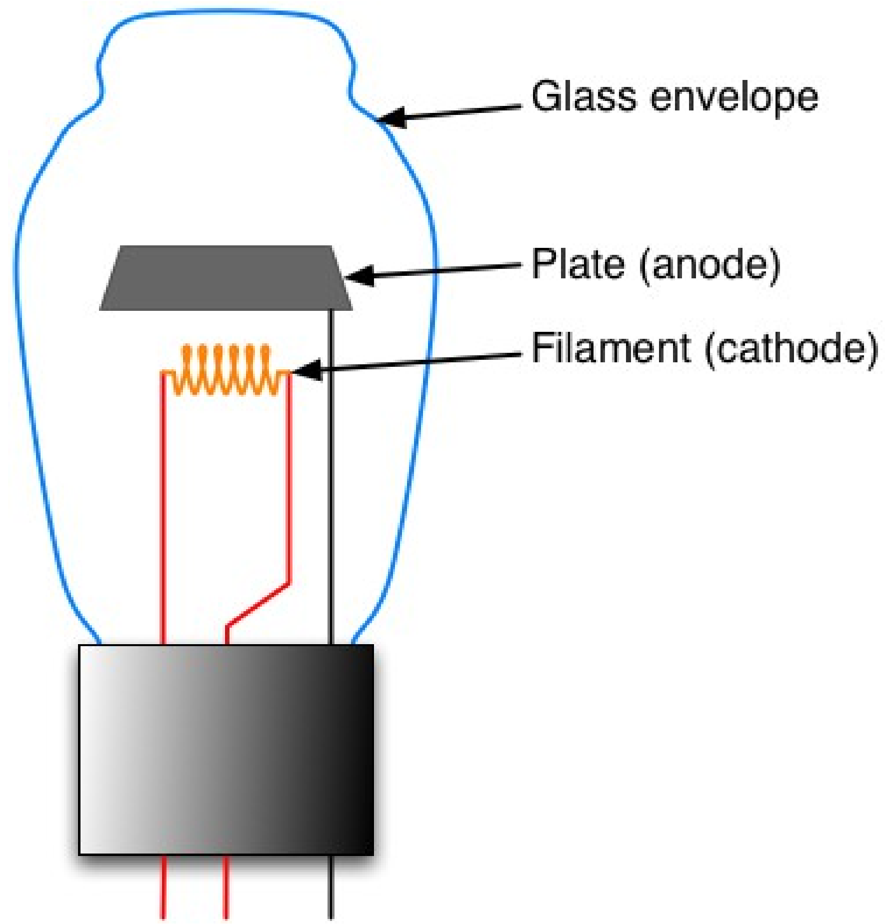
Vacuum tube electron flow

The cathode is often called the "heater."

This example uses the filament as the cathode.

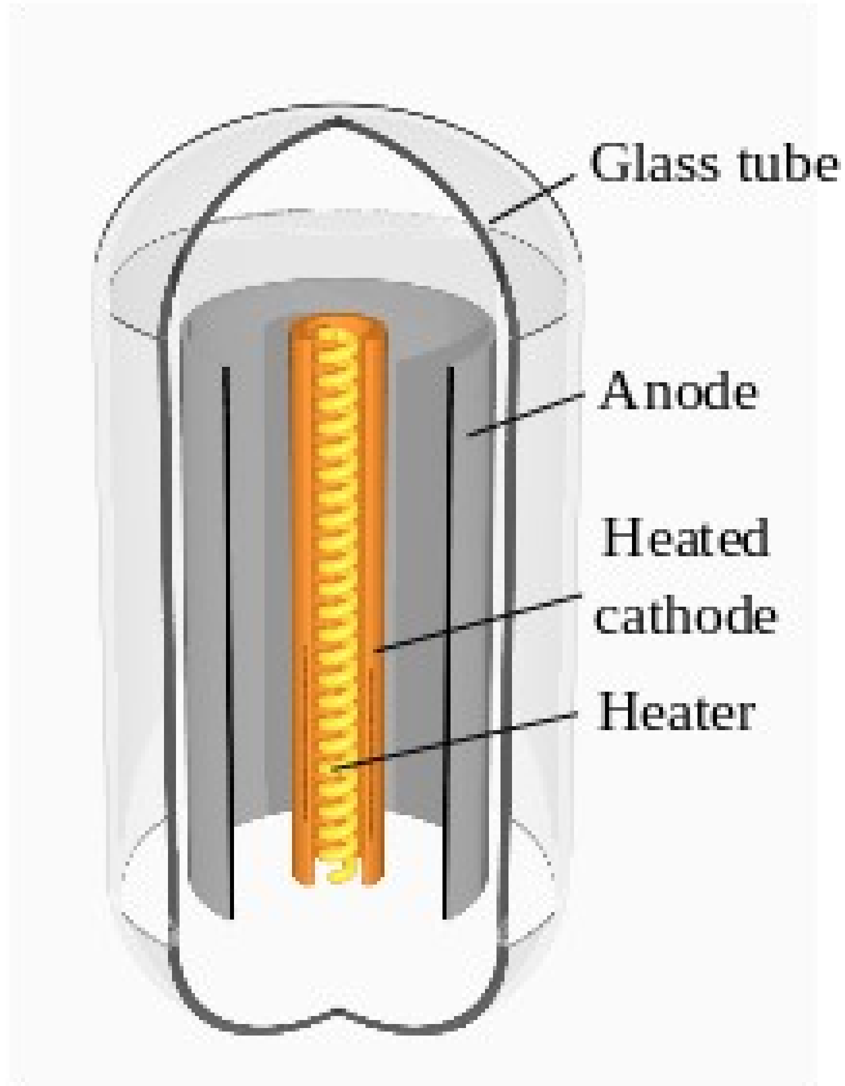


The vacuum tube diode

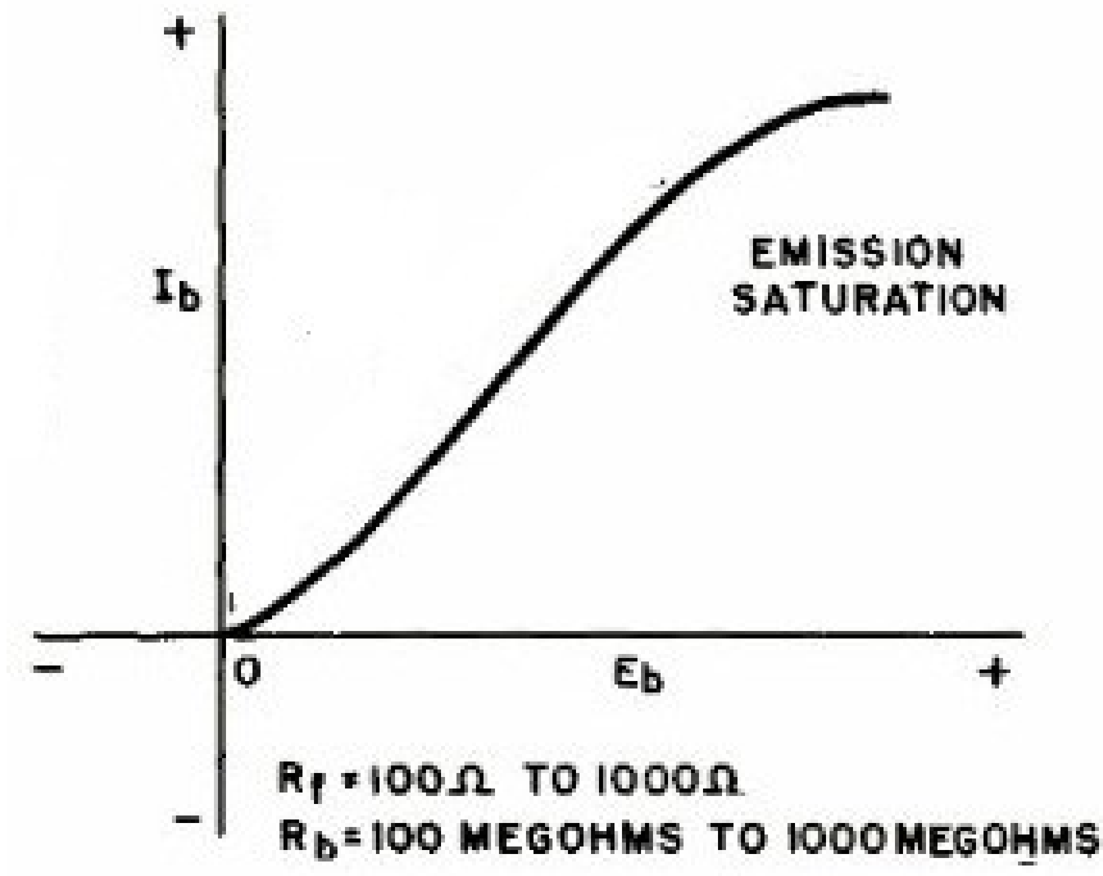


This diode's filament serves as the cathode

Inside a vacuum tube diode's glass envelope

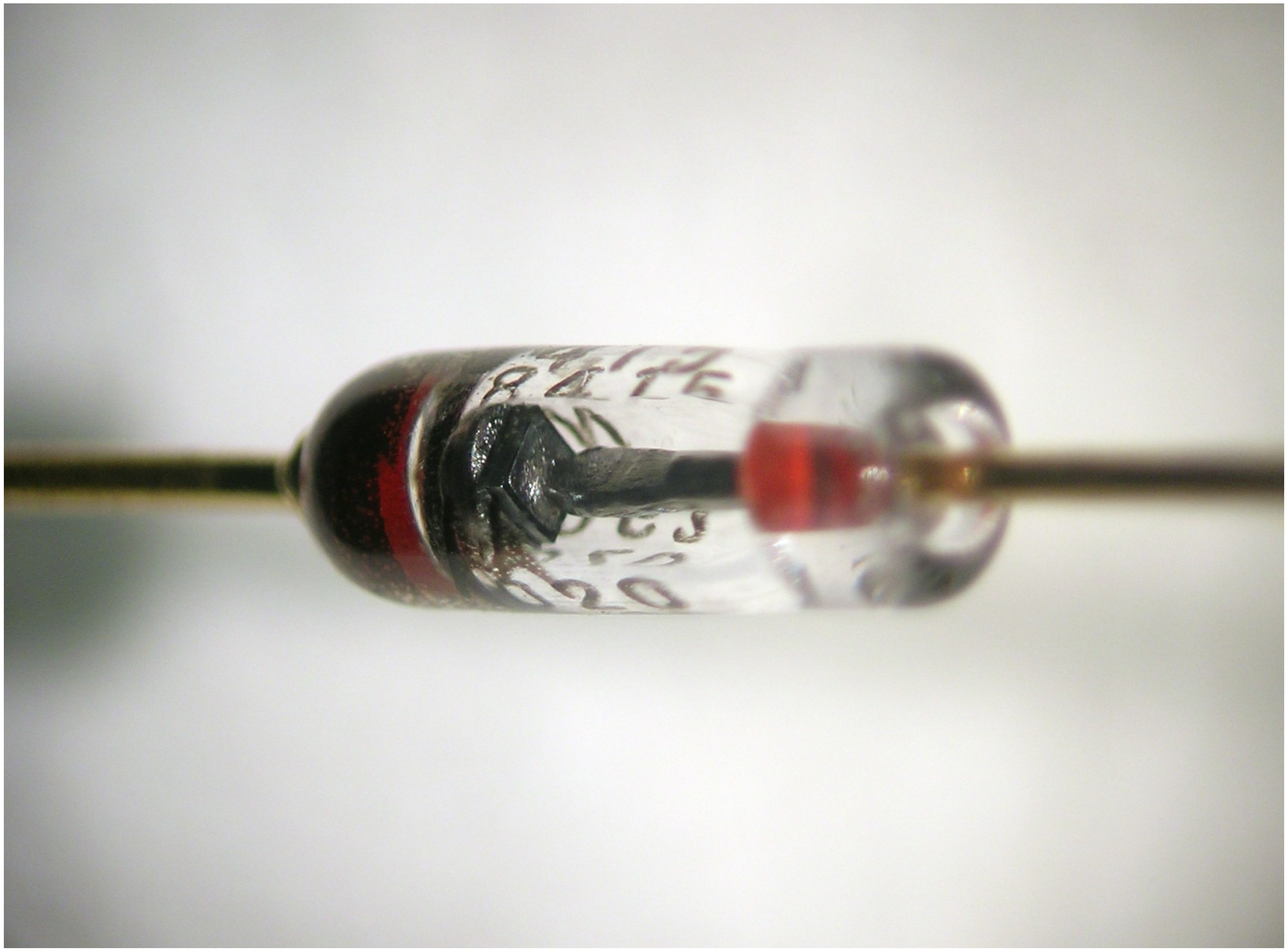


This example has an *indirectly heated* cathode

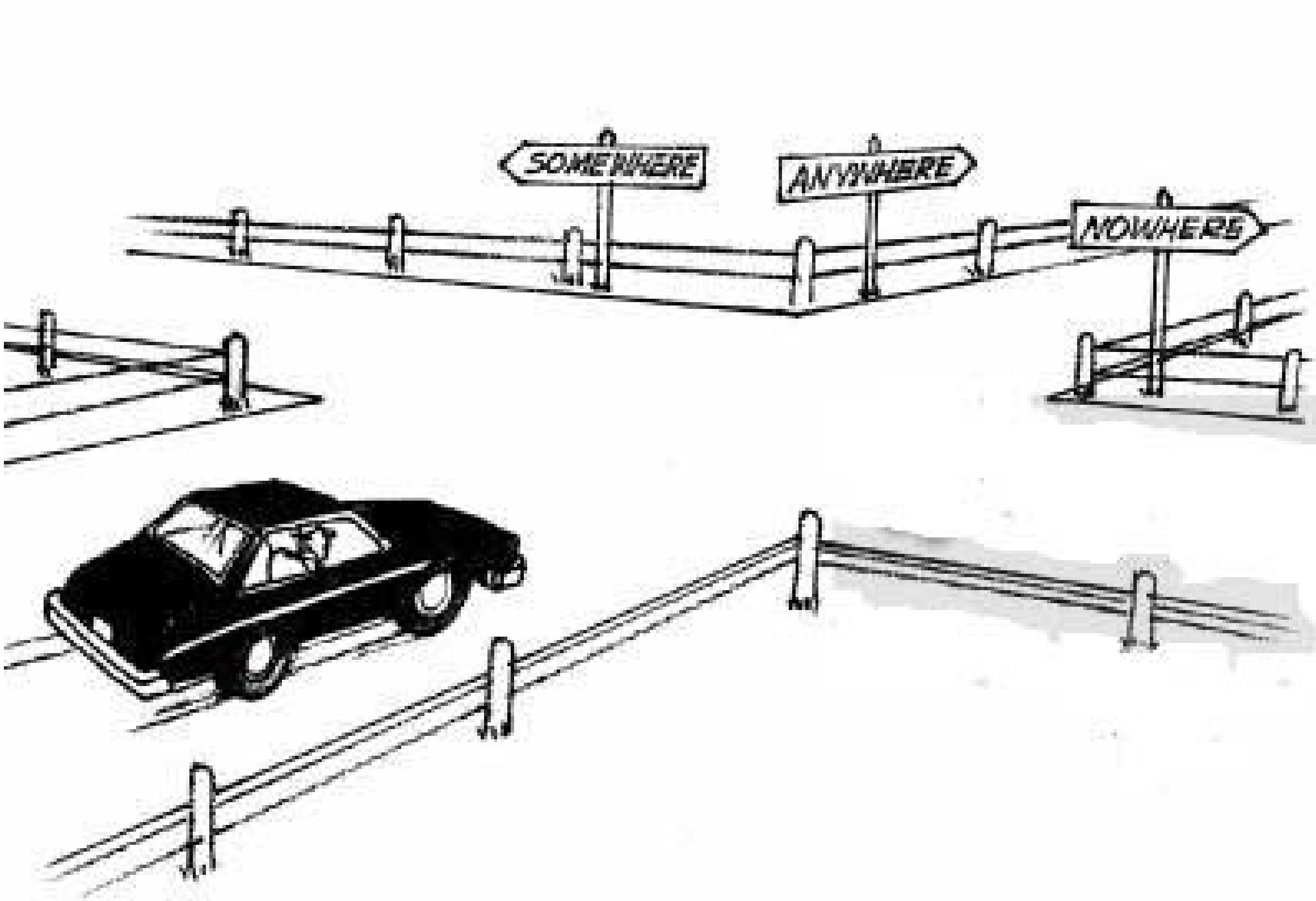


NOTE: A vacuum tube's transfer curve begins at zero on the X,Y axes. There is no reverse conduction.

The solid-state diode

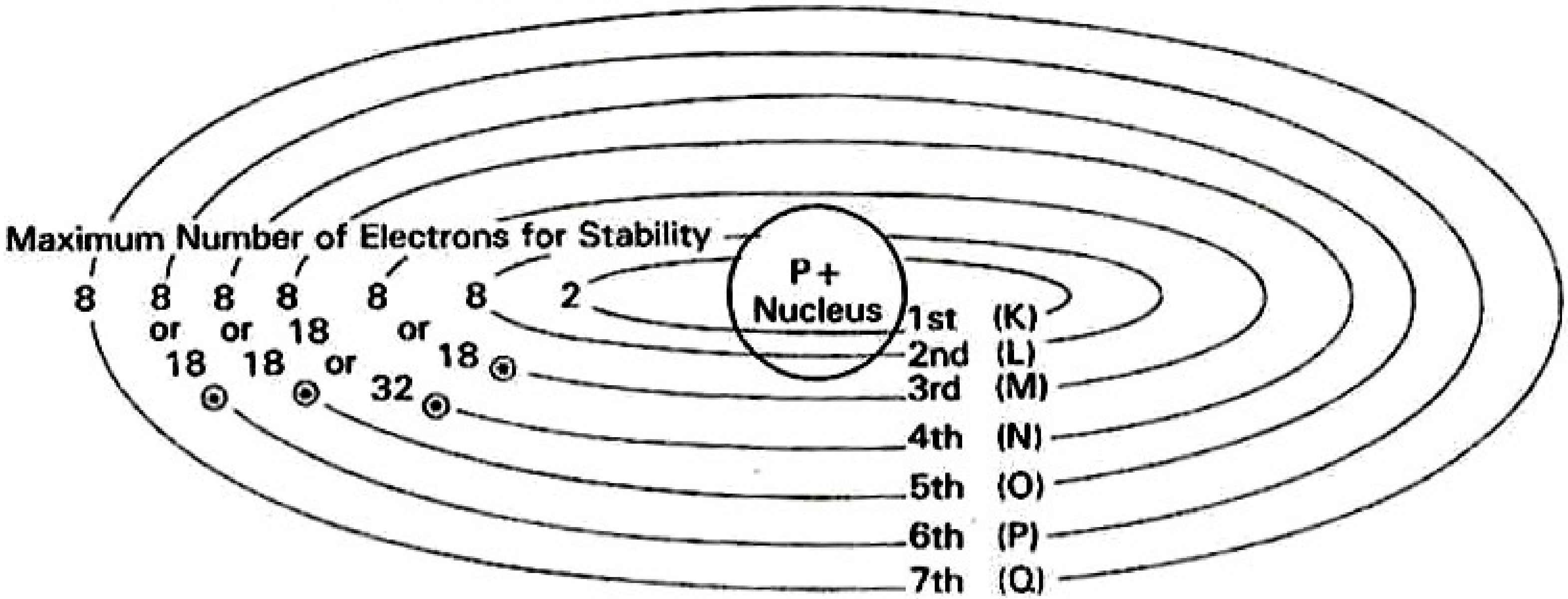


Solid-state junctions

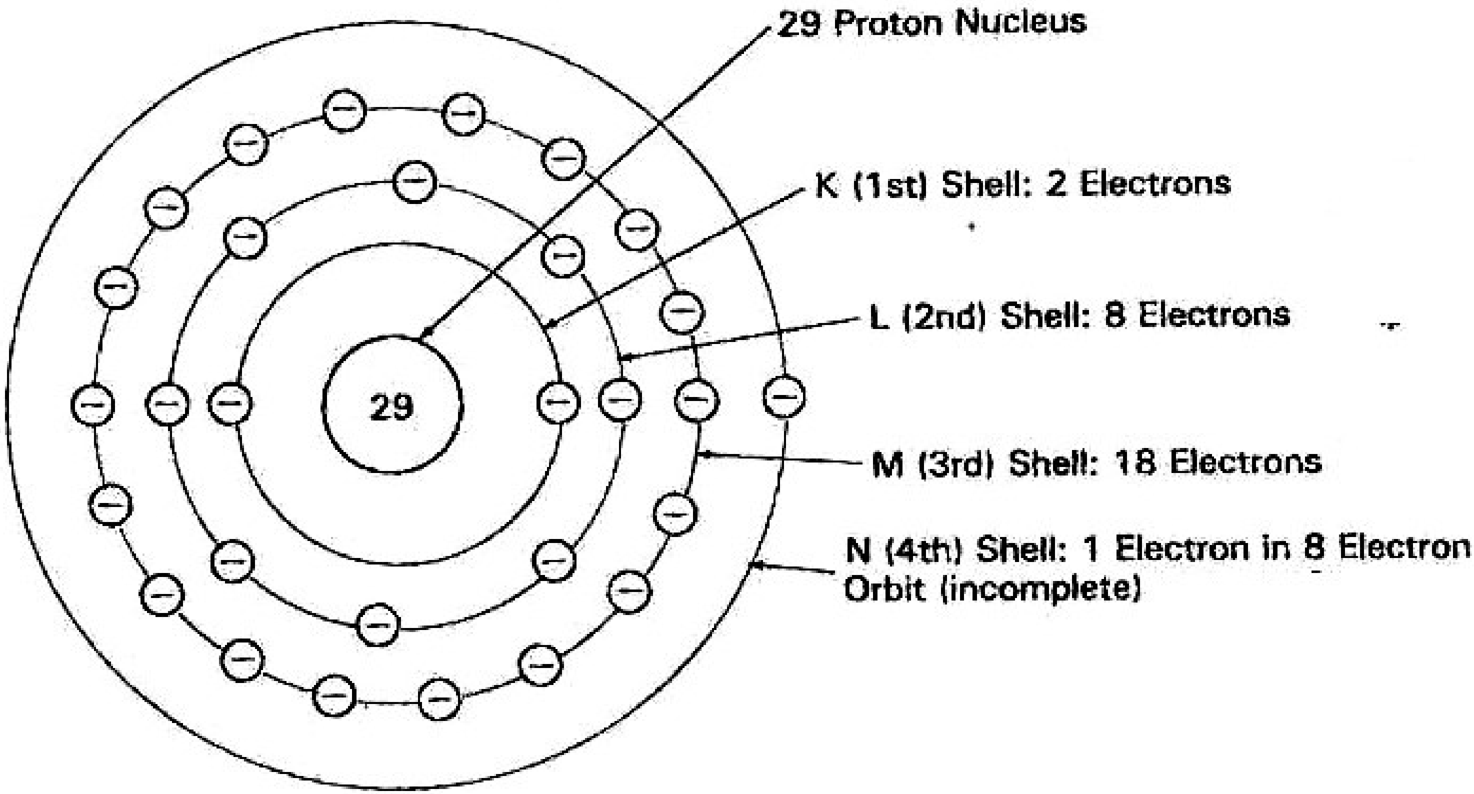


Electrons are said to orbit an atom's nucleus, in rings

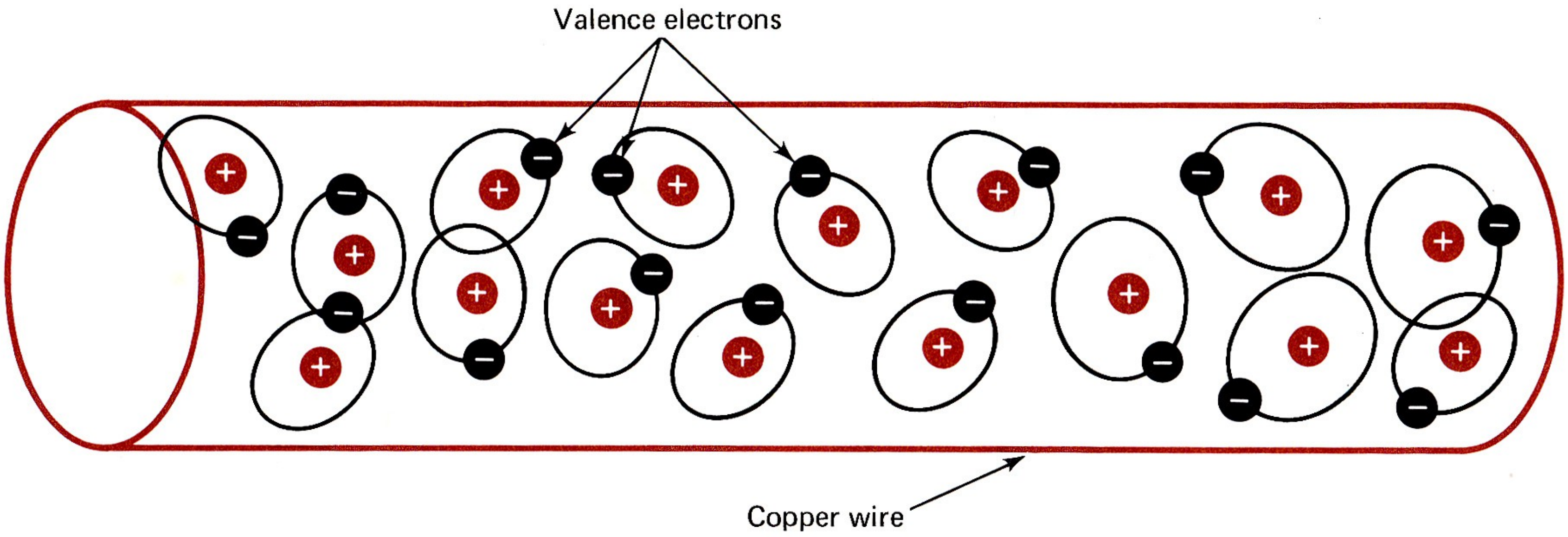
Electrons and Shells



A copper atom might look like this:

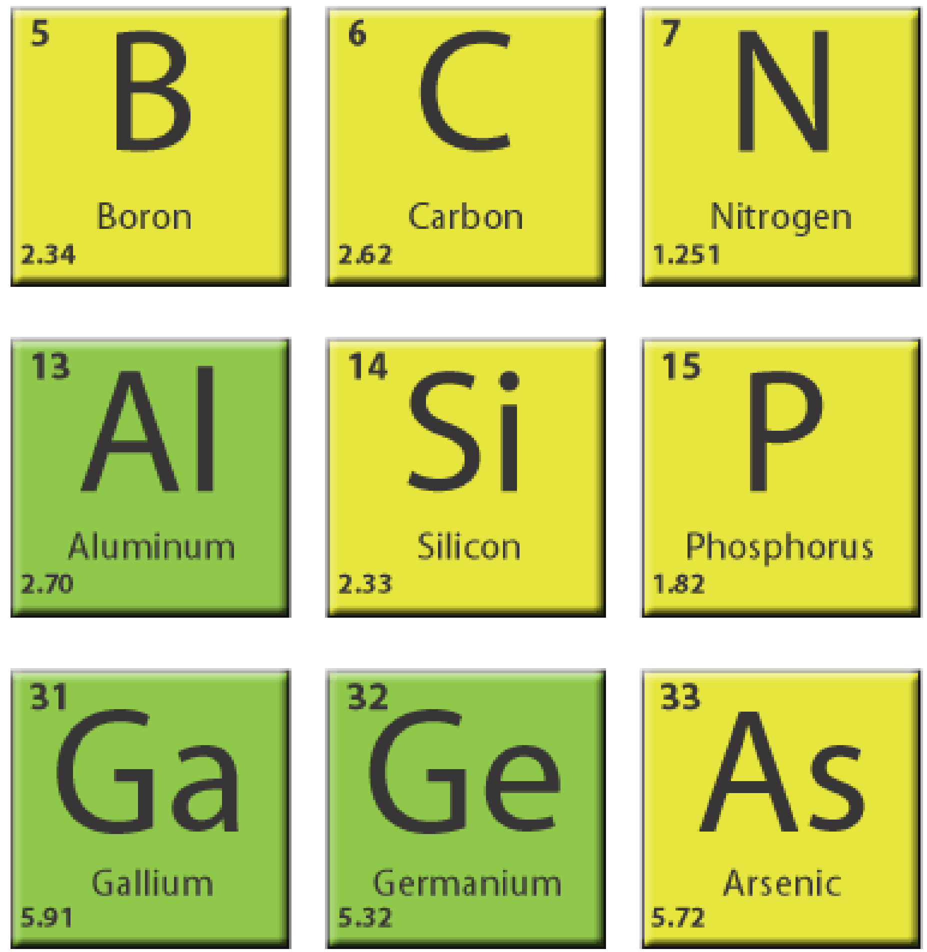


Valence electrons in copper



Silicon is a very common element

Silicon sits between aluminum and phosphorus in the *Periodic Table of the Elements*

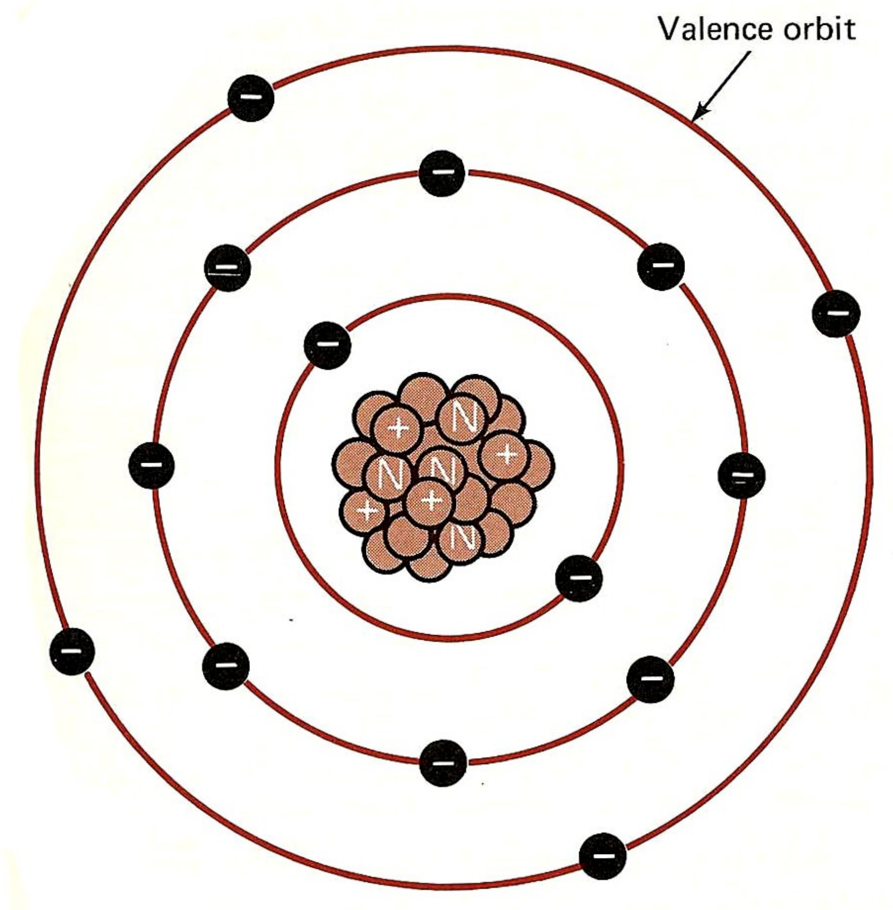


PERIODIC TABLE OF THE ELEMENTS

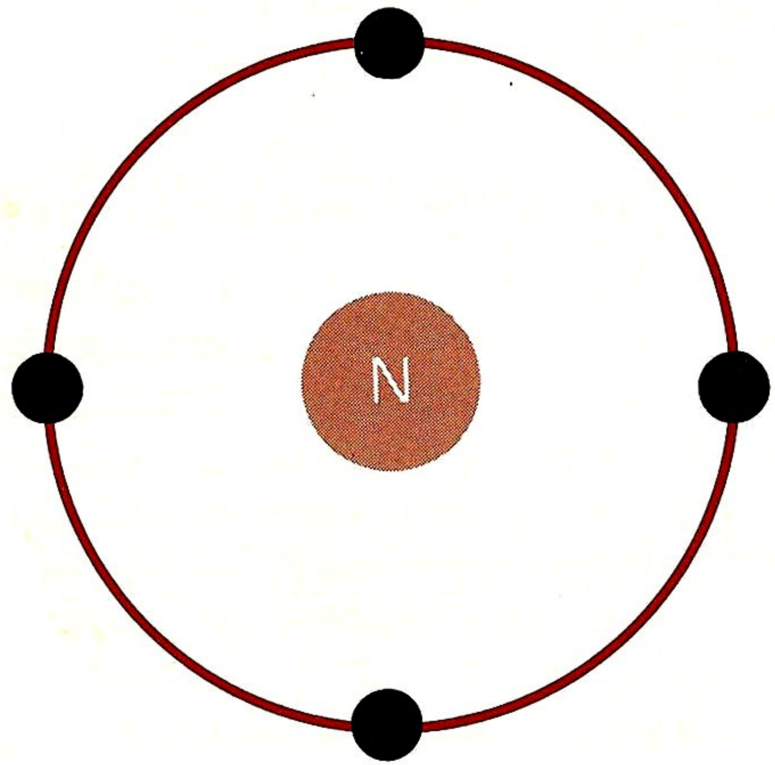
Atomic Number	Element Name	Symbol	Atomic Weight	Electrons/Shell K	L	M	N	O	P	Q	Discovered	Comments
1	Hydrogen	H	1.007	1							1766	Active gas
2	Helium	He	4.002	2							1895	Inert gas
3	Lithium	Li	6.941	2	1						1817	Solid
4	Beryllium	Be	9.01218	2	2						1798	Solid
5	Boron	B	10.81	2	3						1808	Solid
6	Carbon	C	12.011	2	4						Ancient	Semiconductor
7	Nitrogen	N	14.0067	2	5						1772	Gas
8	Oxygen	O	15.9994	2	6						1774	Gas
9	Fluorine	F	18.998403	2	7						1771	Active gas
10	Neon	Ne	20.179	2	8						1898	Inert gas
11	Sodium	Na	22.98977	2	8	1					1807	Solid
12	Magnesium	Mg	24.305	2	8	2					1755	Solid
13	Aluminum	Al	26.98154	2	8	3					1825	Metal conductor
14	Silicon	Si	28.0855	2	8	4					1823	Semiconductor
15	Phosphorus	P	30.97376	2	8	5					1669	Solid
16	Sulfur	S	32.06	2	8	6					Ancient	Solid

The element silicon has four electrons in its outer (M) ring

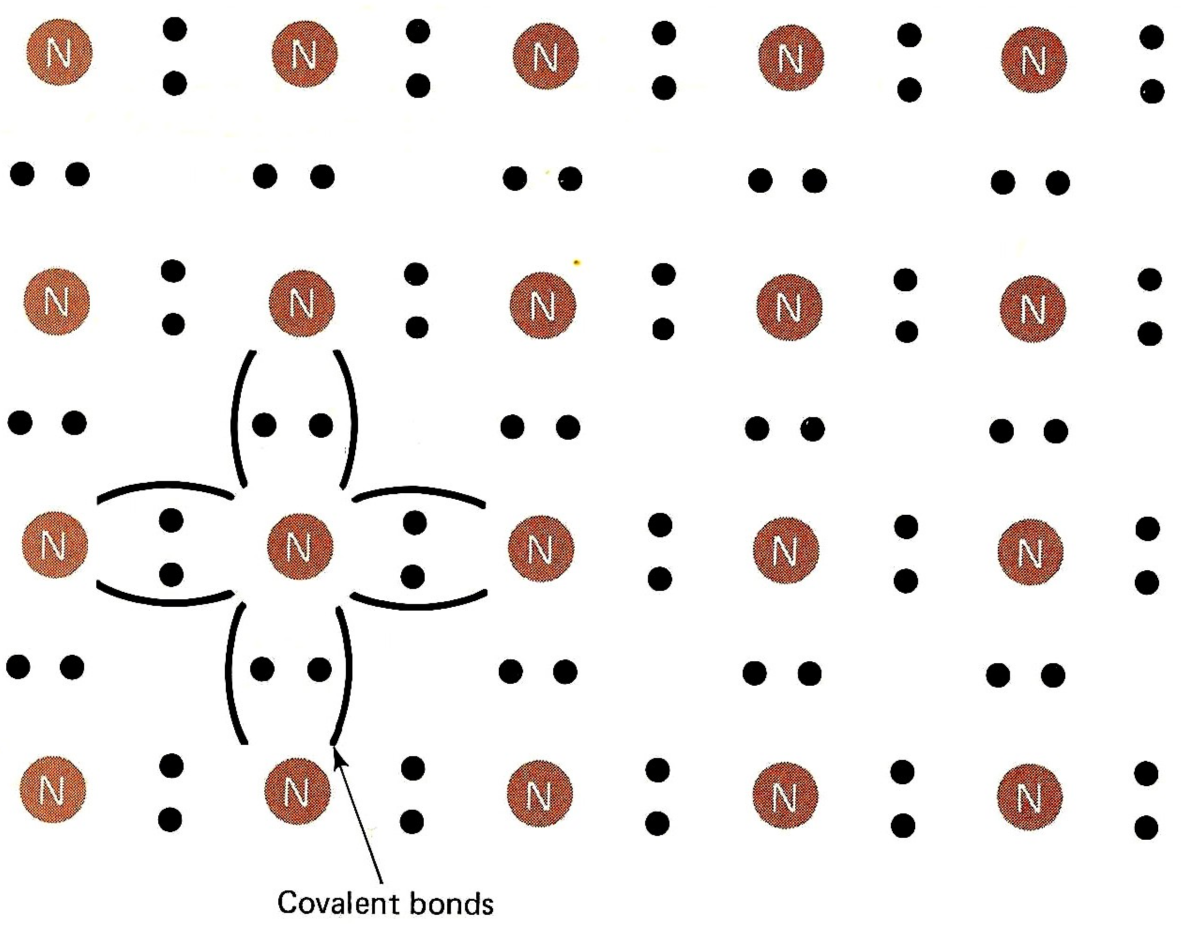
A silicon atom's four outer electrons



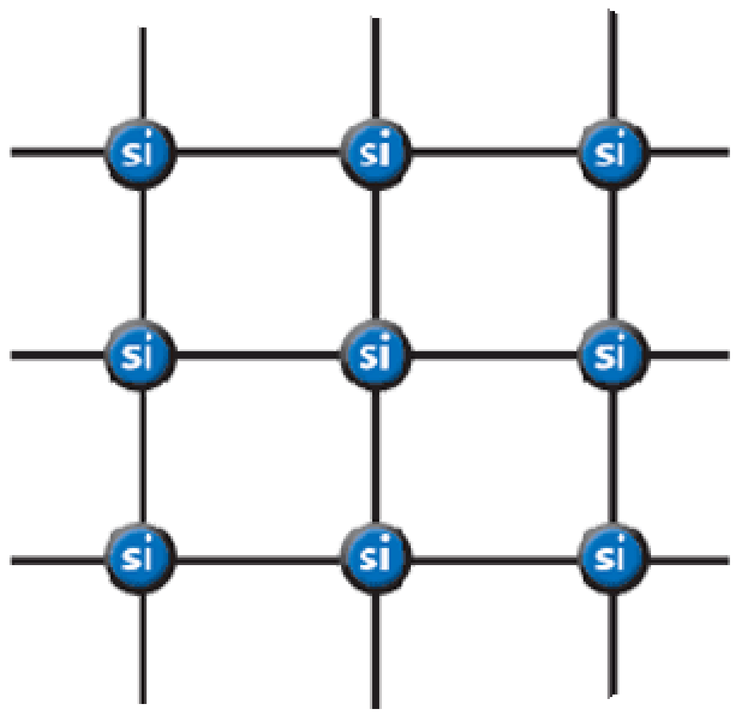
A simplified "view" of a silicon atom's outer valence ring



A crystal of pure silicon exhibits *co-valent bonds*

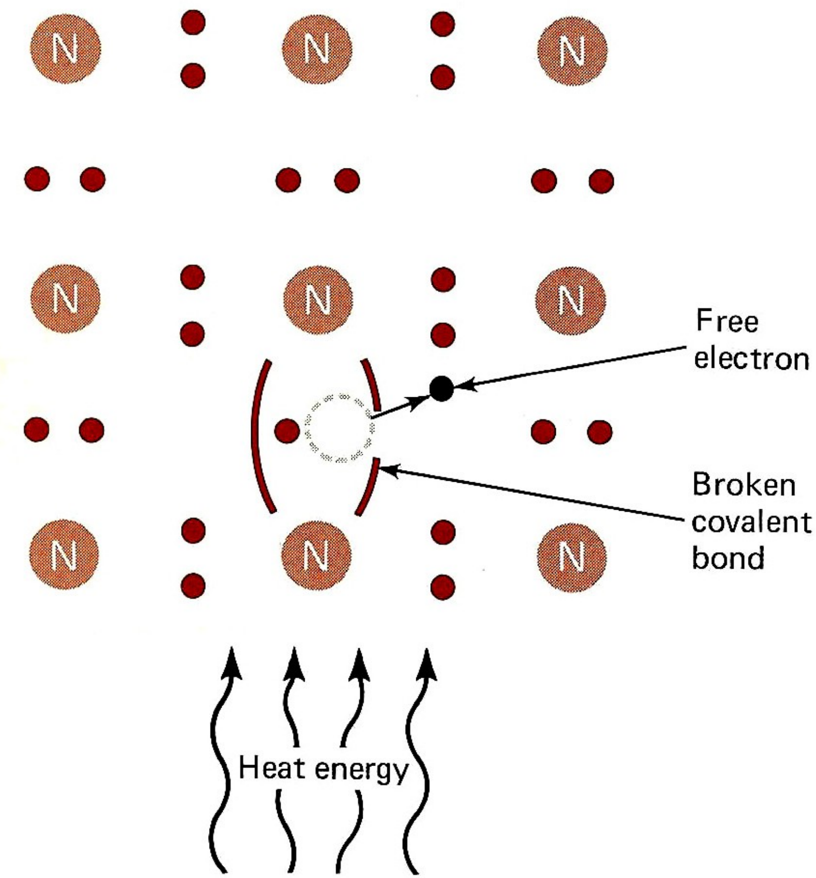


Silicon is a great insulator --- most of the time



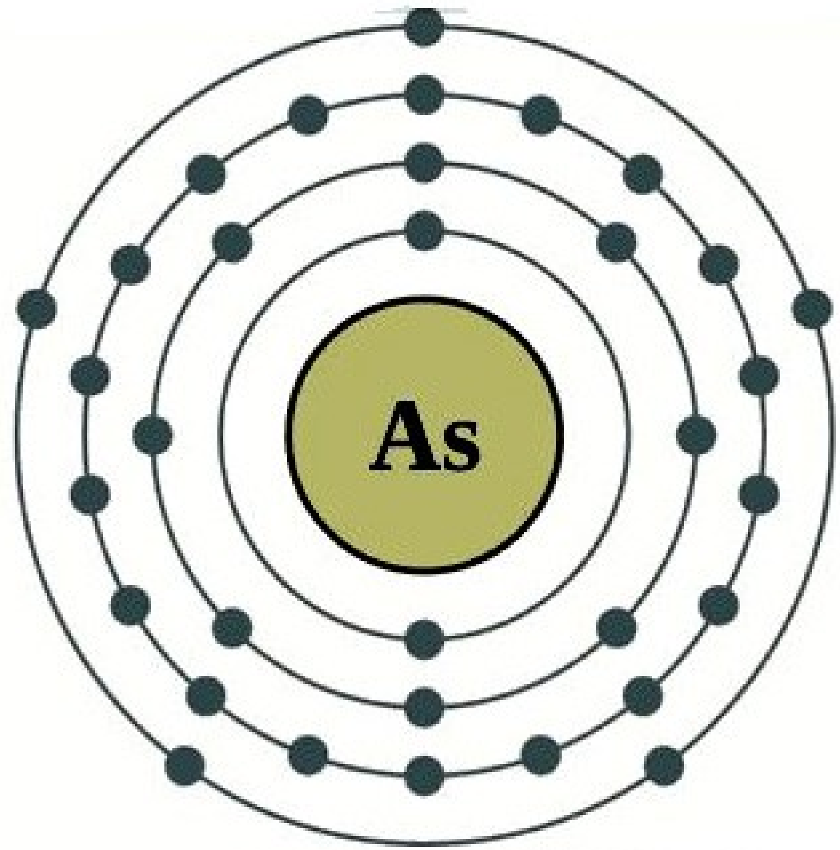
Heat can break, or “free,” electrons in silicon *

*** So keep your power supply’s silicon diodes cool!***

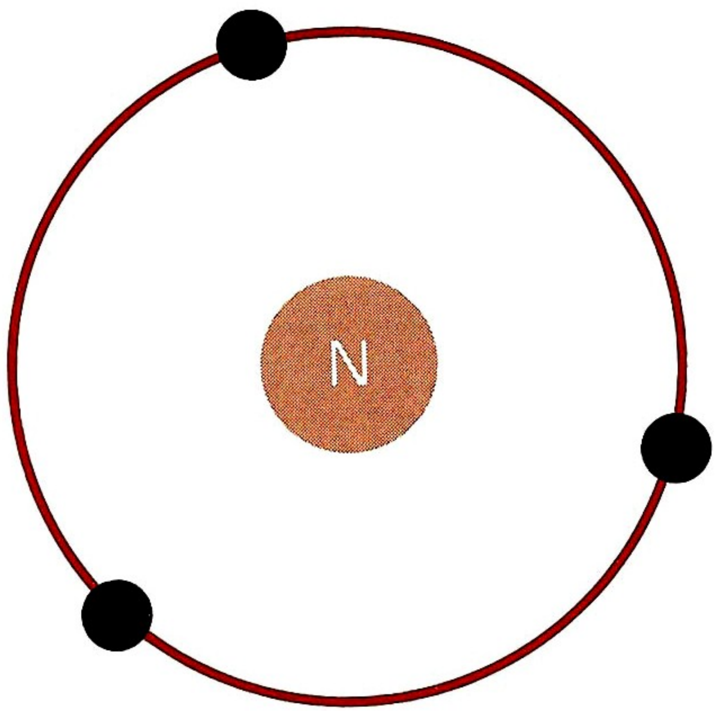


The arsenic atom

Five electrons are in this atom's outer valence ring



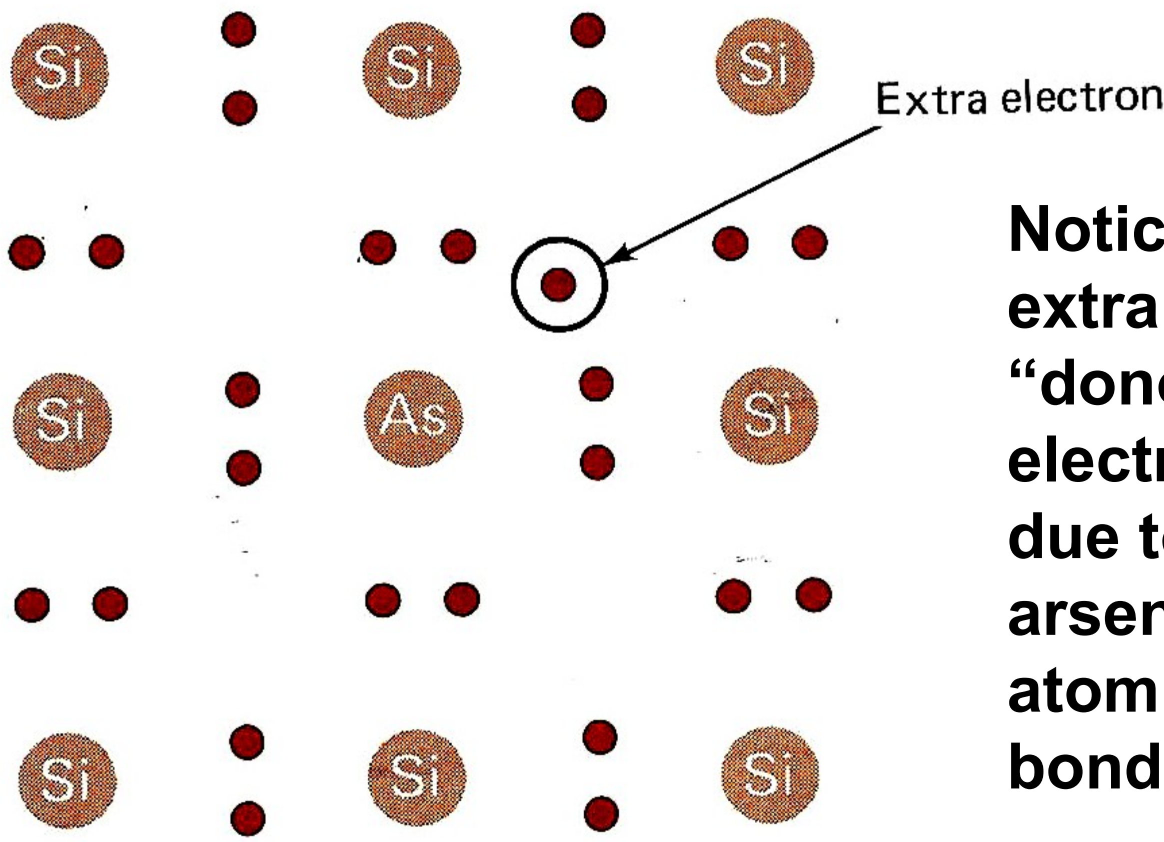
The boron atom's outer ring



It has three outer-ring electrons

Solid-state diodes comprise two types of "doped" silicon

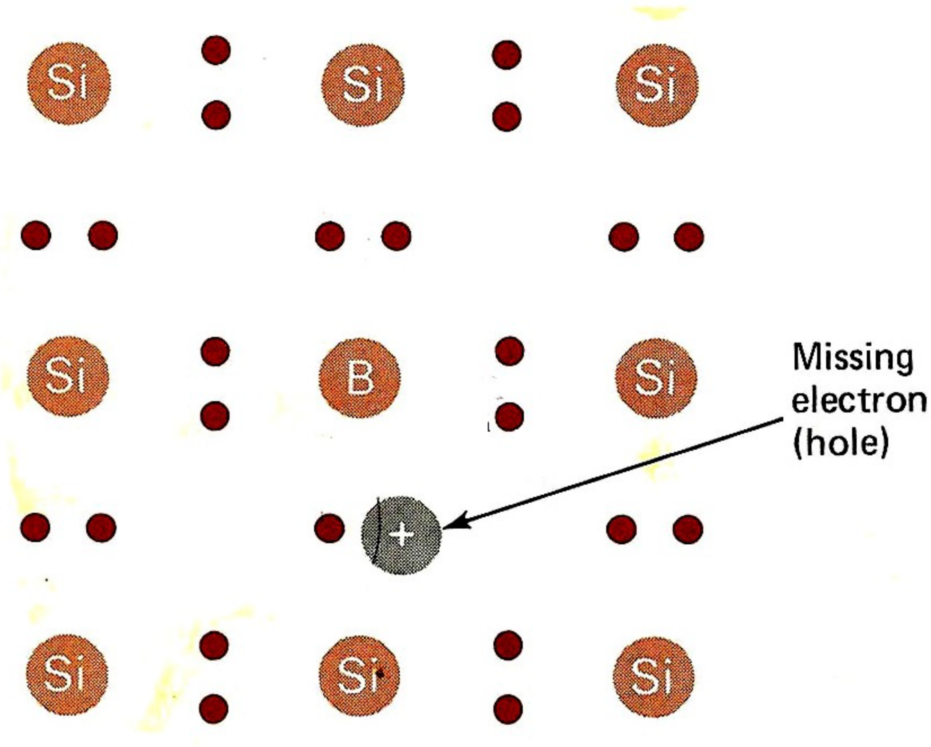
This is N-type silicon



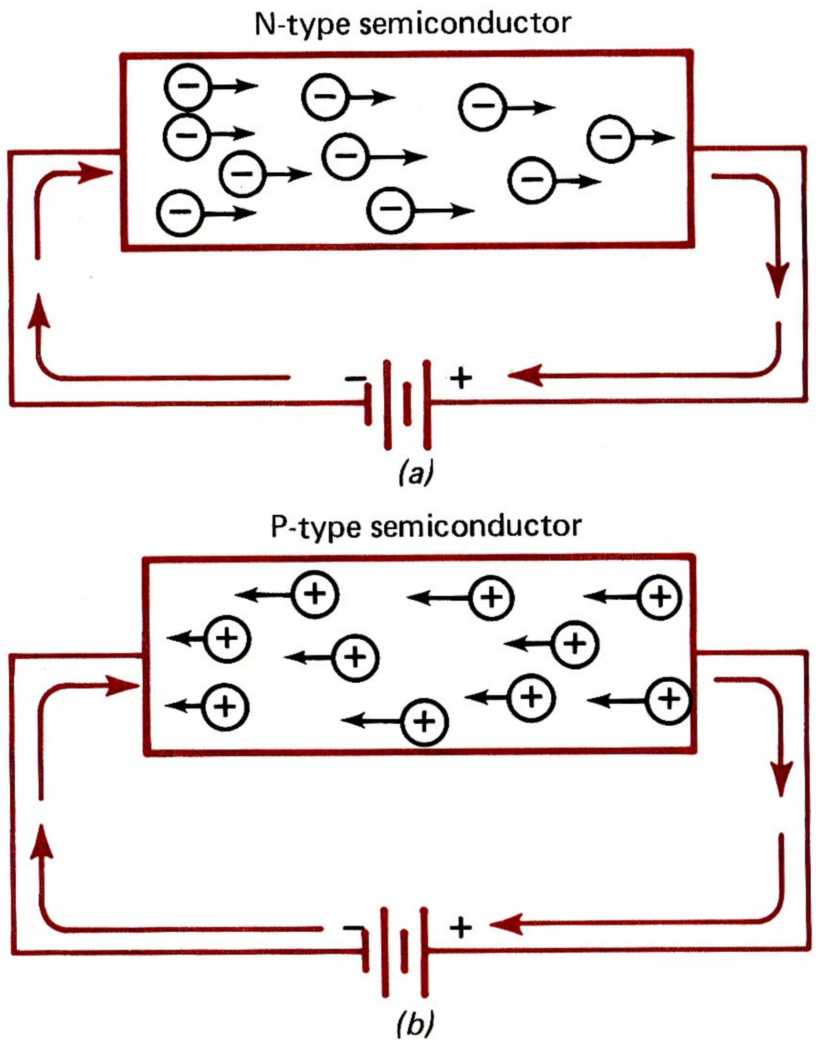
Notice the extra "donor" electron due to the arsenic atom bond

Silicon doped with boron

This is P-type silicon



The boron atom co-valent bond establishes a missing electron, or a "hole"



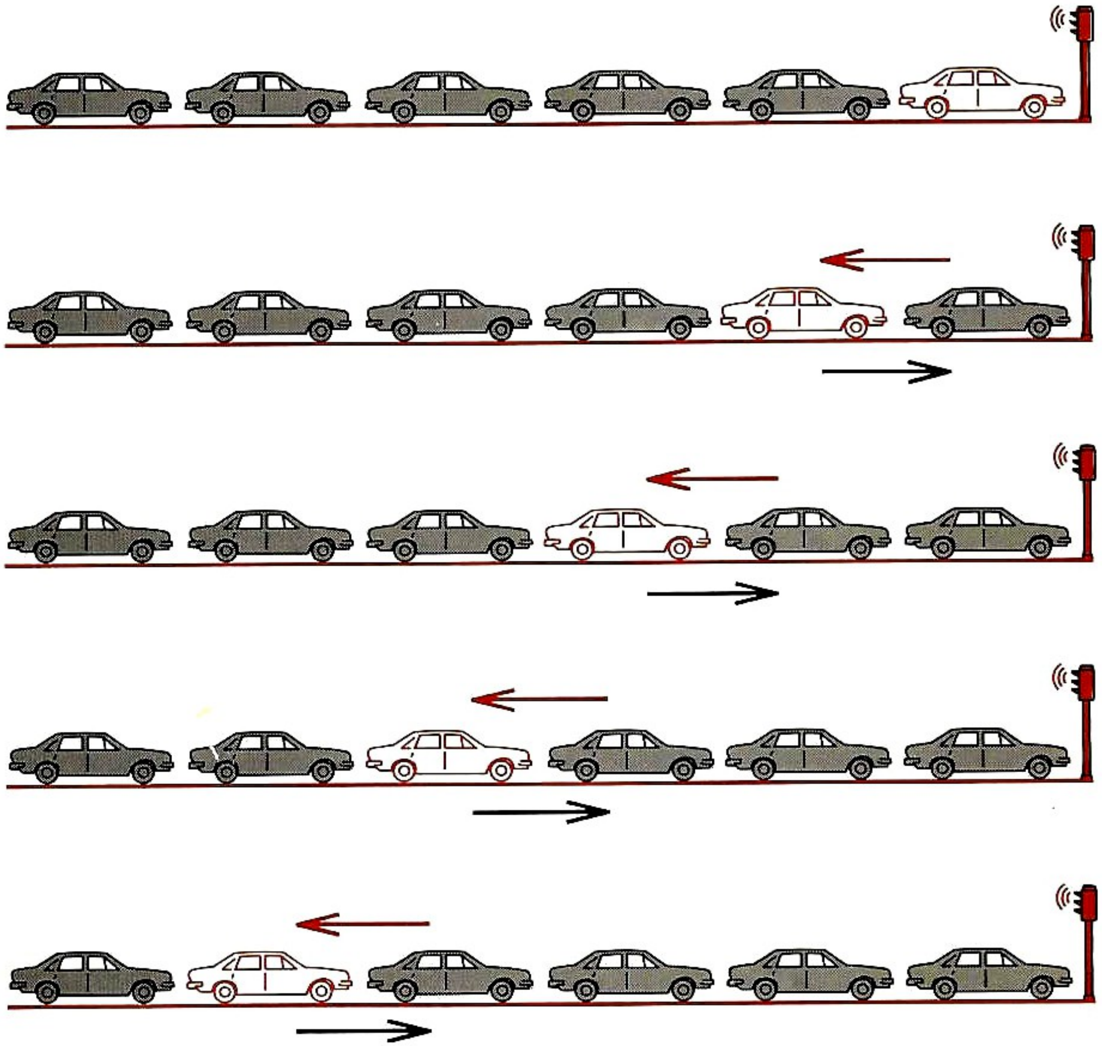
Conduction in N- and P-type silicon.

Free electrons move under the influence of a DC potential.

Holes move in the opposite direction *inside* the diode.

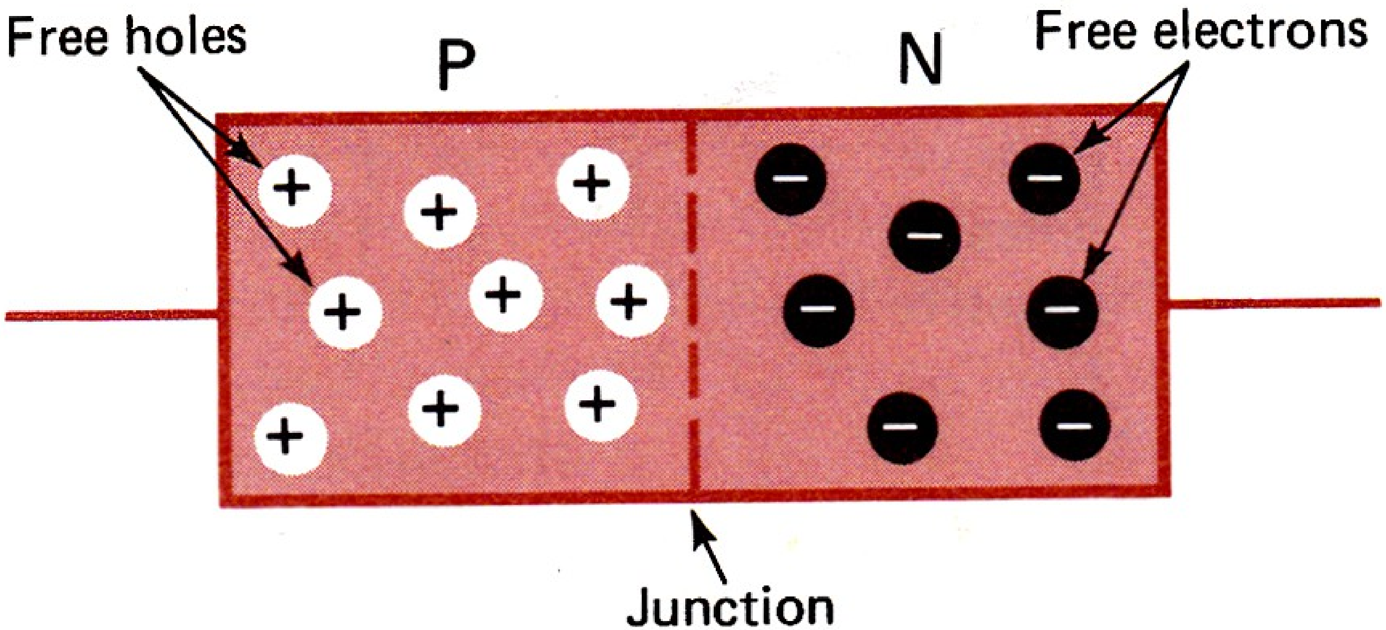
The external current flows in the same direction (a) and (b), from negative to positive

"Hole current" analogy

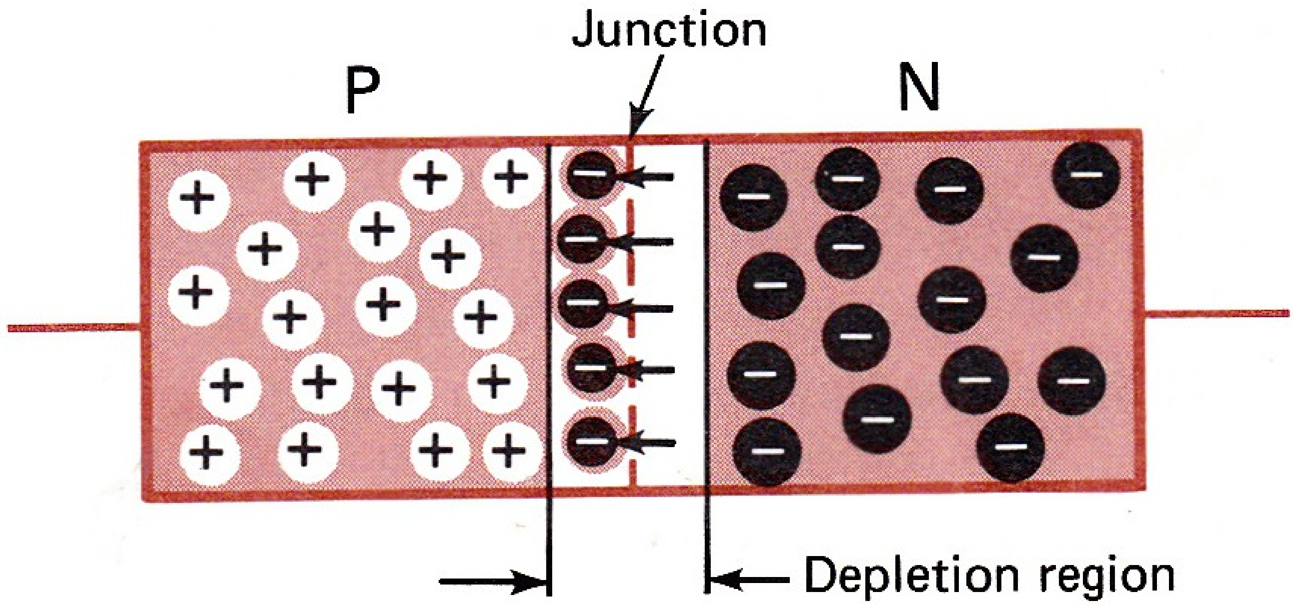


Putting it together

The structure of a solid-state junction diode

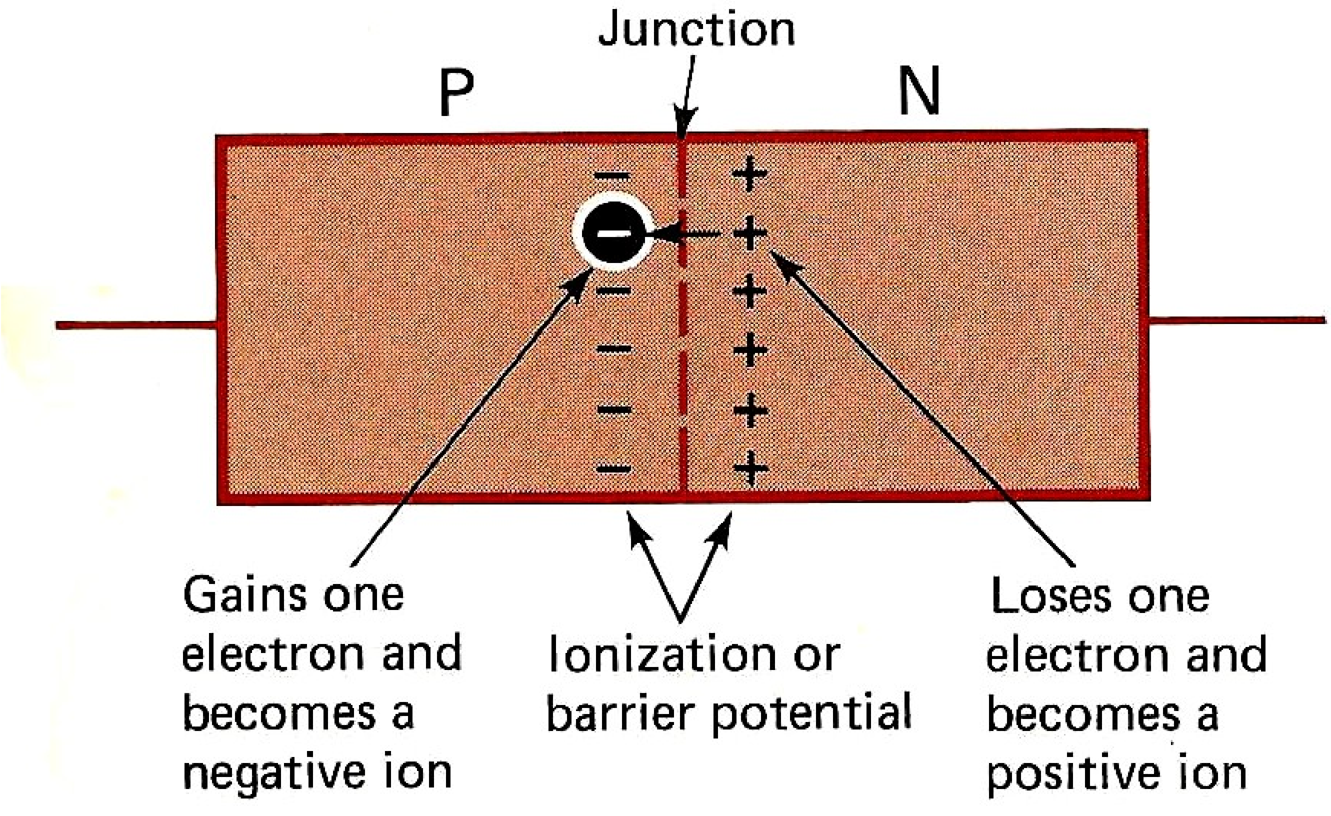


A diode's depletion region



Some electrons cross the junction to fill some of the holes. They're now "captured" and cannot support current flow.

A “barrier” forms



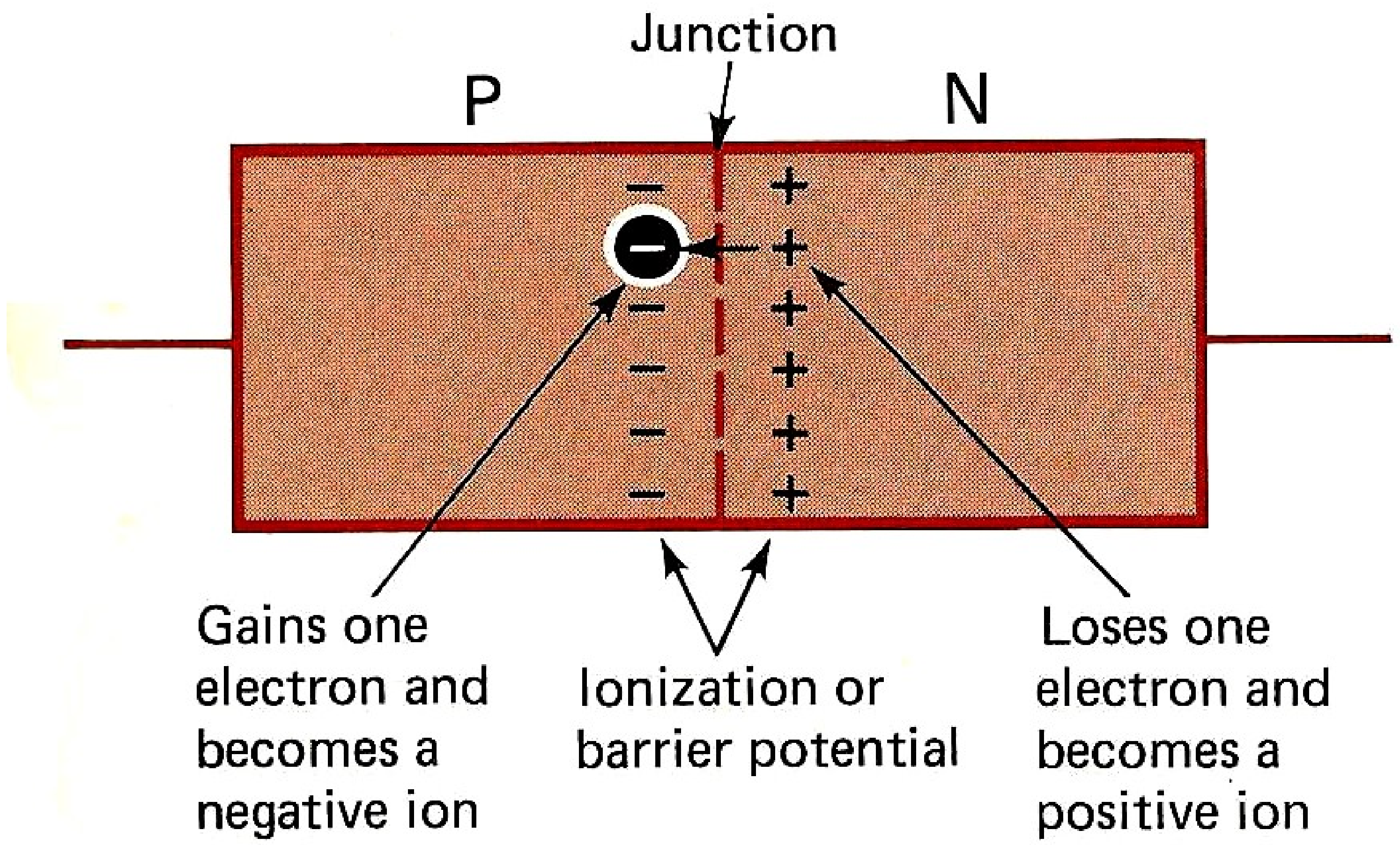
What happens at the PN junction?

(1) When one of the free electrons in the N-type material leaves its parent atom, that atom becomes positive (an ion).

(2) When the electron joins another atom on the P-type side of the diode, that atom becomes a negative ion.

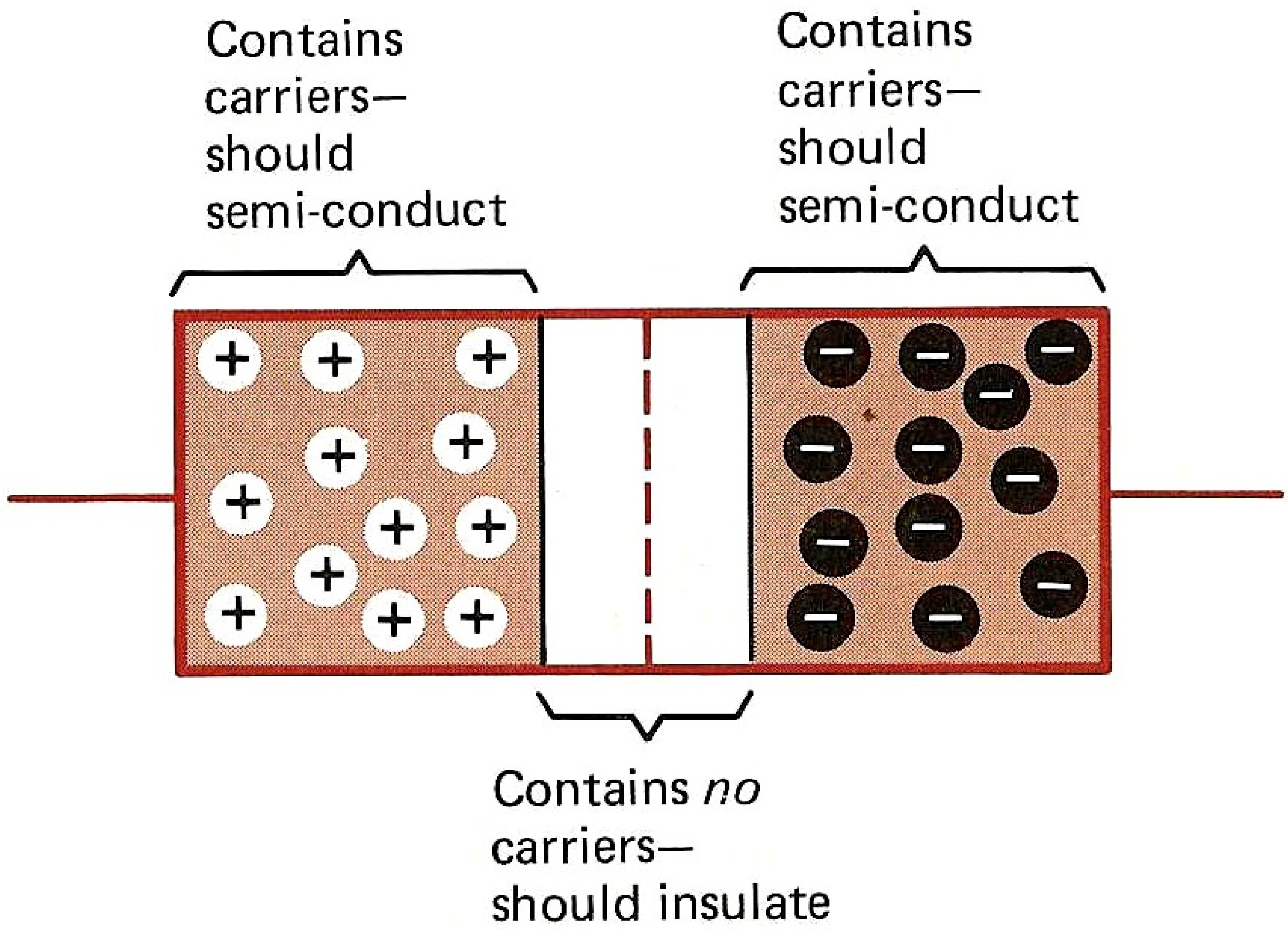
(3) The ions form a charge that prevents any more electrons from crossing the junction!

Some of the free electrons cross the junction to fill some of the holes!



A negative charge forms on the P side to repel any more electrons. No more electrons can cross!

The barrier forms the moment the diode is manufactured!



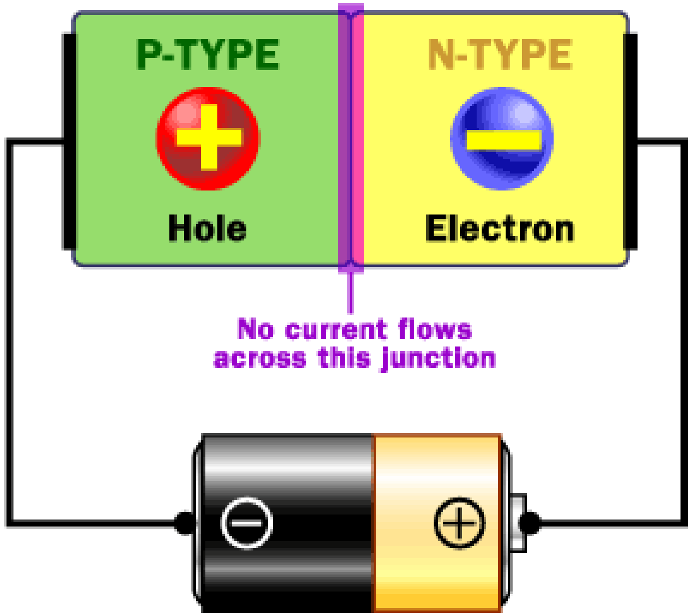
Let's connect an outside source of DC

The negative electrons in the N-type silicon get attracted to the positive terminal of the “battery” (actually a cell).

The positive holes in the P-type silicon get attracted to the negative terminal of the battery.

The holes and the electrons each move in the “wrong” direction.

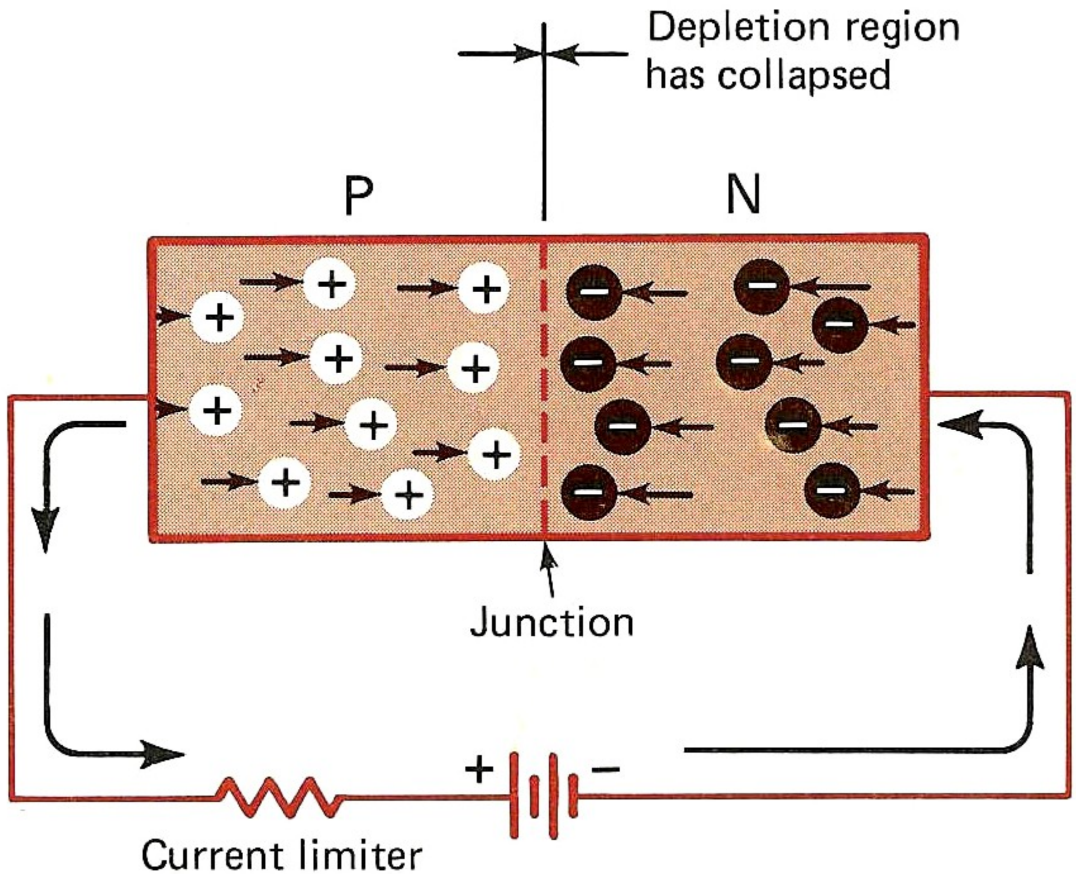
<u>No current</u> flows across the junction. The diode is said to be ***reverse biased***.



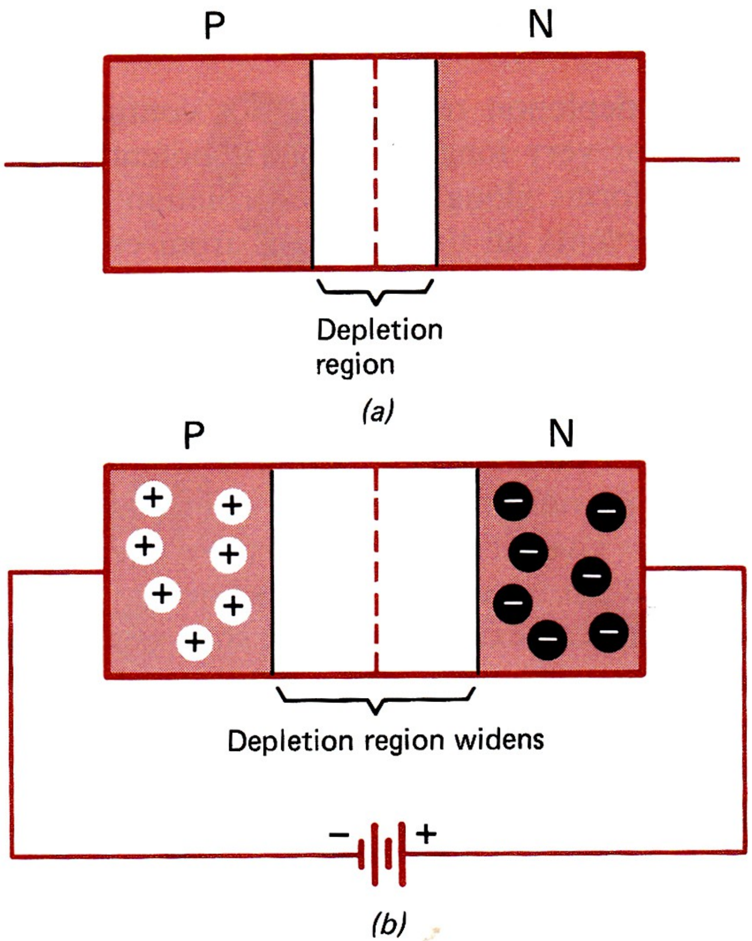
When the diode conducts it is said to be *forward biased*

The + battery terminal repels the holes.

The negative battery terminal repels the electrons, pushing them towards the depletion region



When the diode does not conduct it is reverse biased

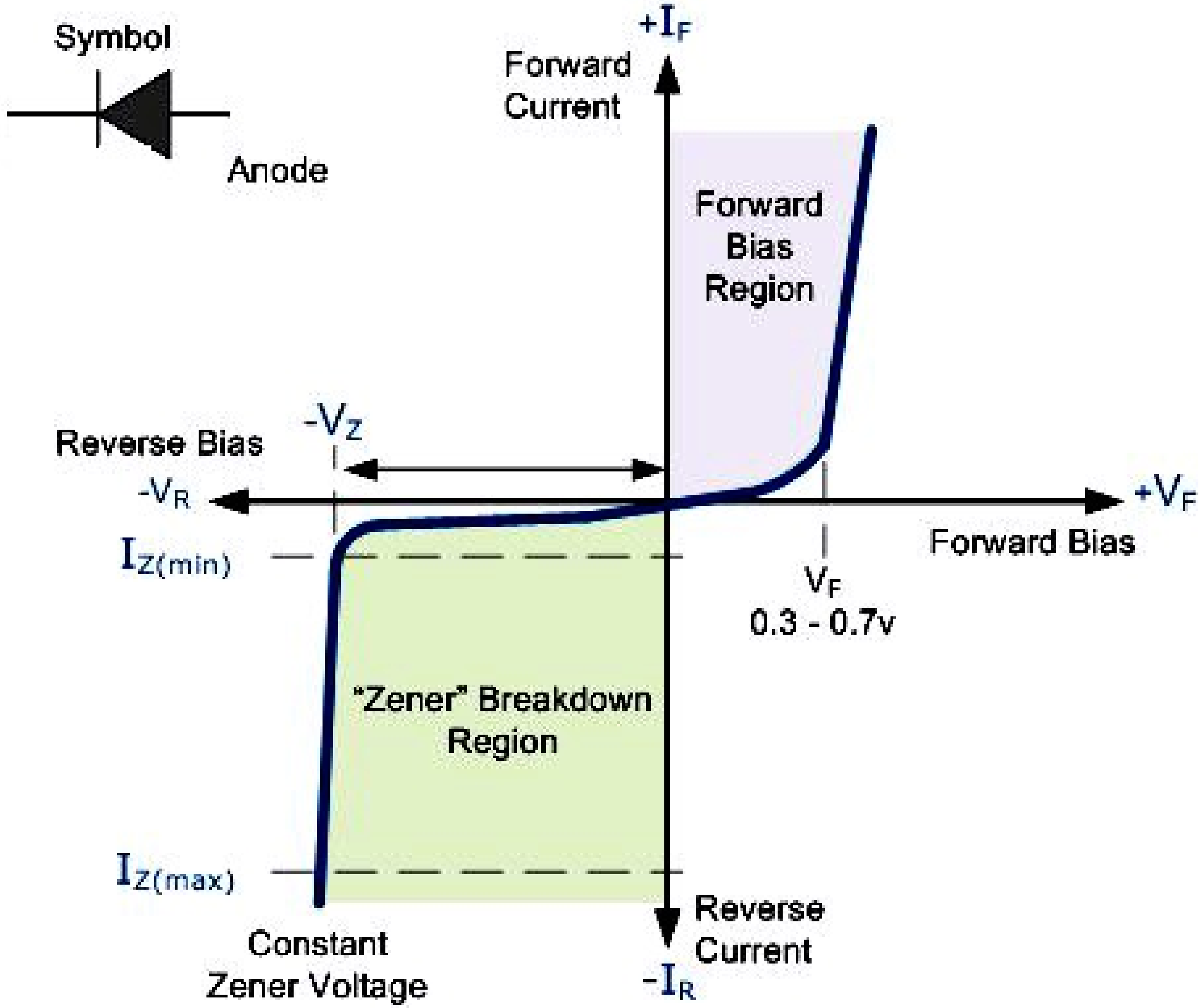


The positive terminal of the battery attracts electrons, or draws them away from the depletion region *inside* the semiconductor crystal.

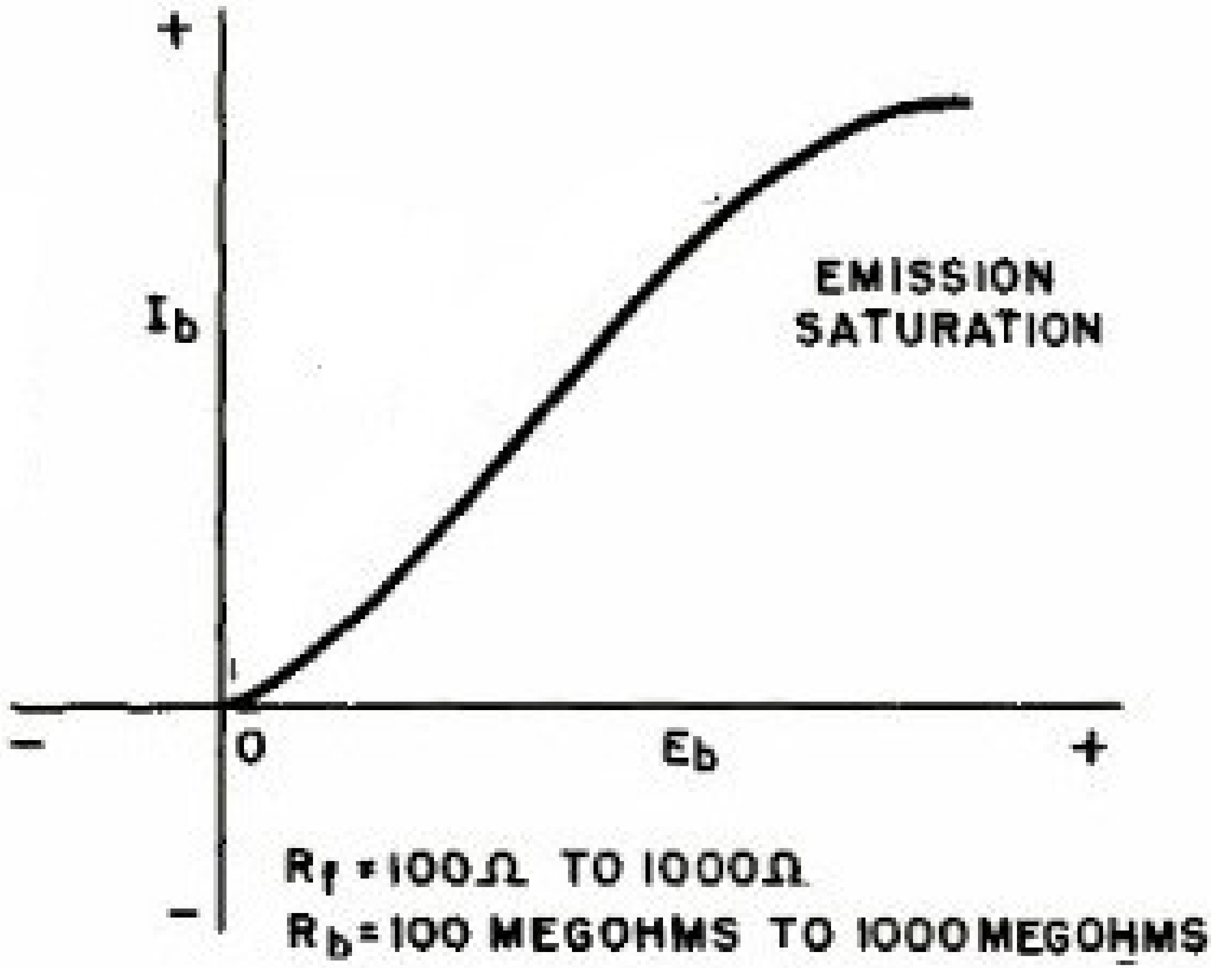
The negative terminal of the battery attracts holes *inside* the semiconductor. The result is a widened depletion region. No *external* current flows.

The current through a solid-state diode flows predictably. The current and voltages can be plotted in an X-Y graph.

Here's a silicon rectifier's *transfer curve*.

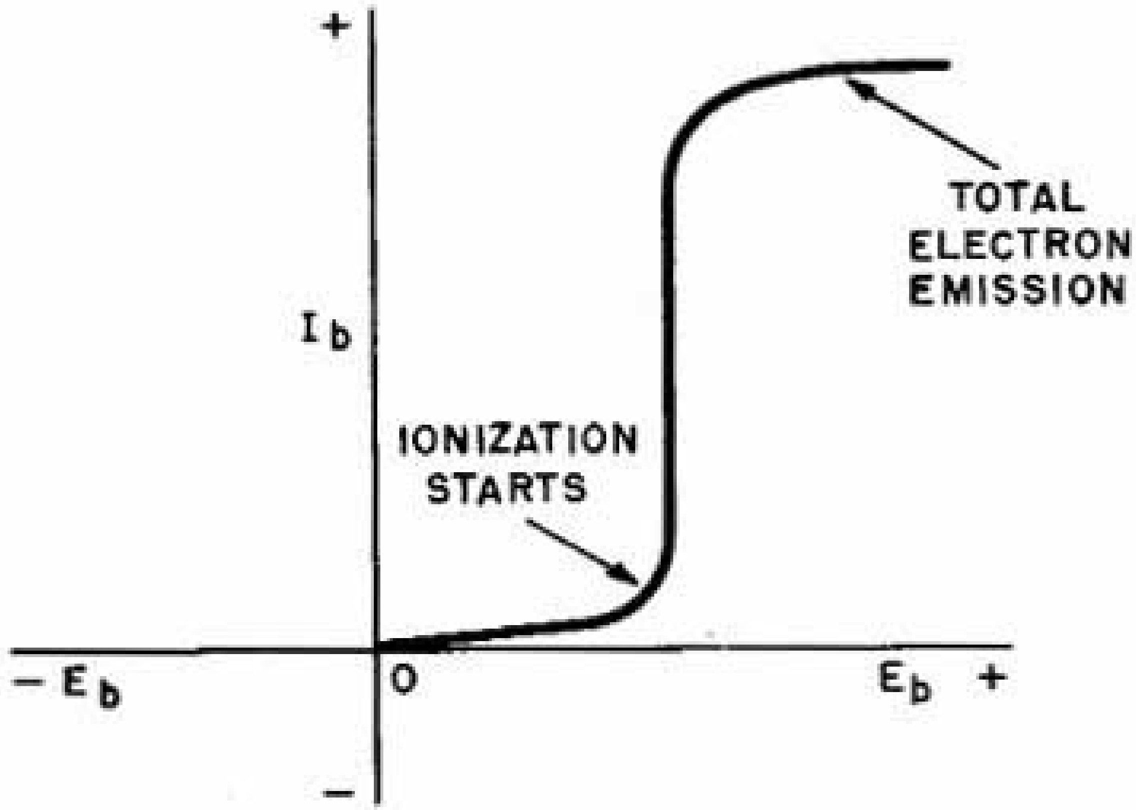


The vacuum tube rectifier's transfer curve.



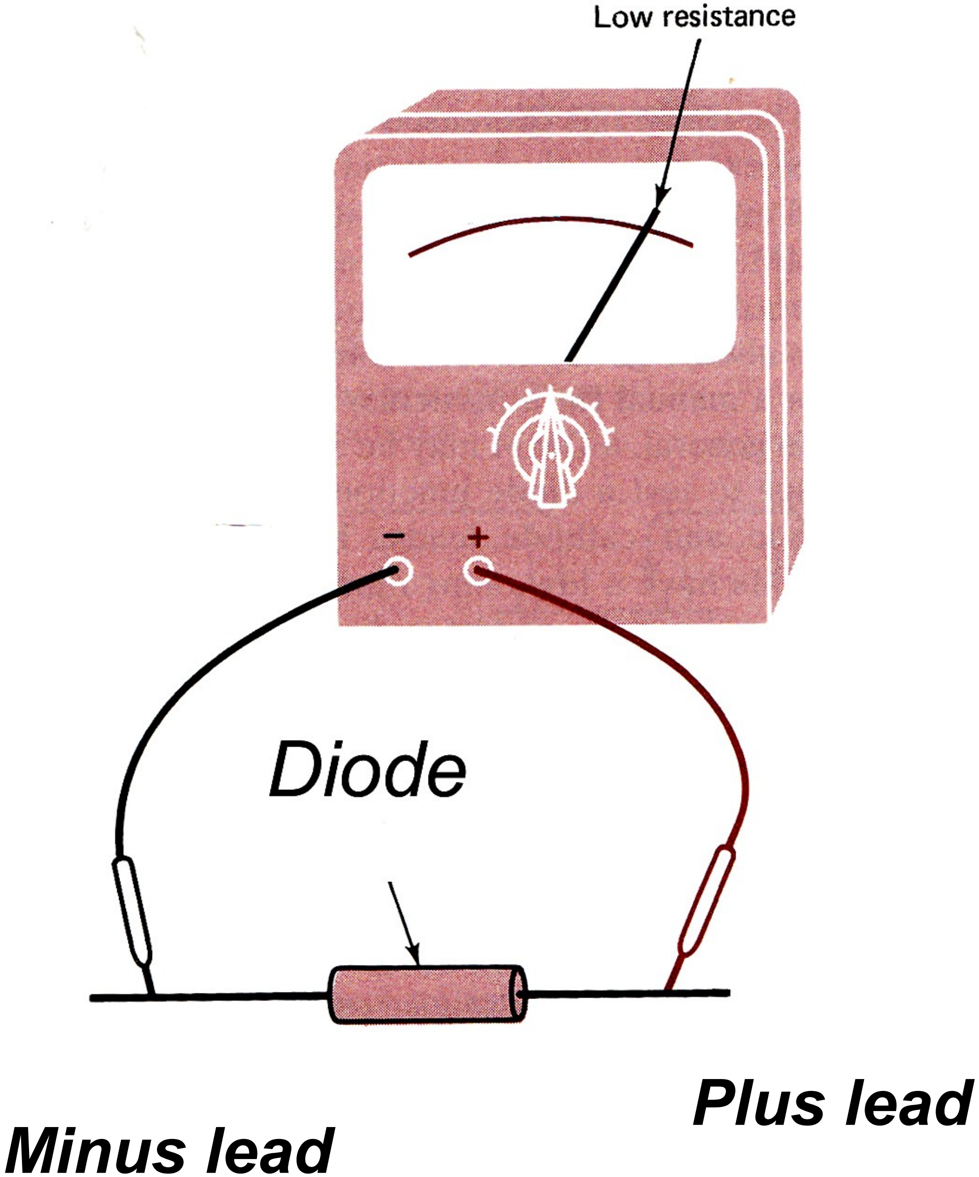
There is no avalanche or reverse current.

Here's the transfer curve for a gaseous rectifier:

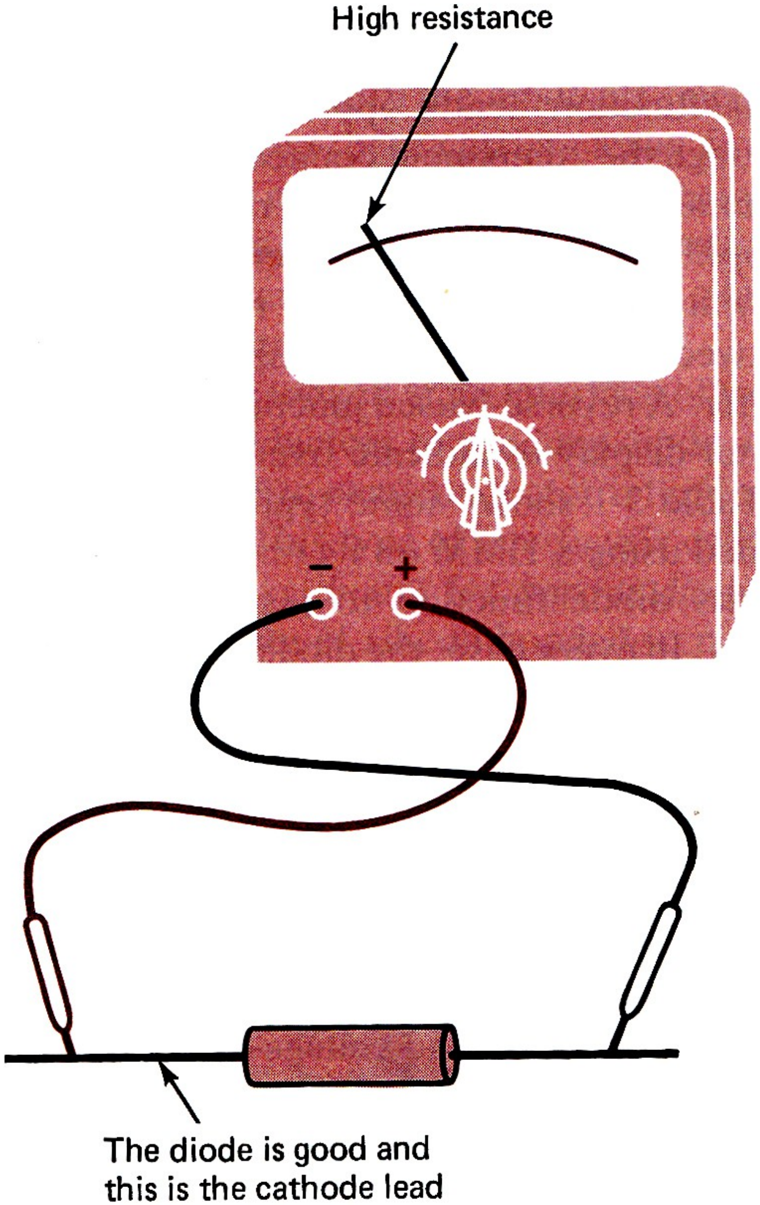


R f = 1.5 Ω TO 100 Ω
R b ABOVE 100 MEGOHMS

A practical test of diode theory



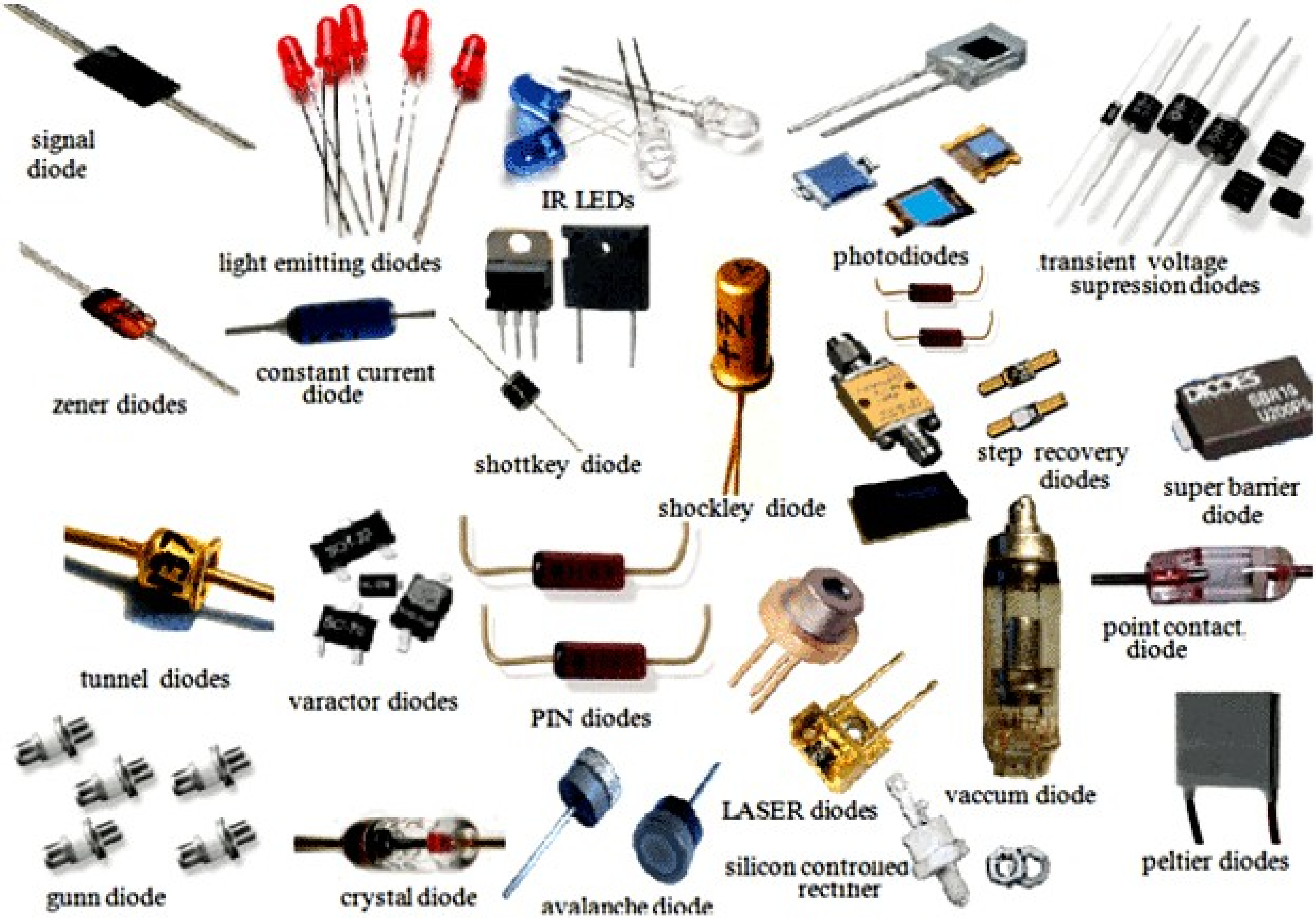
Forward biasing **the diode with an ohmmeter**



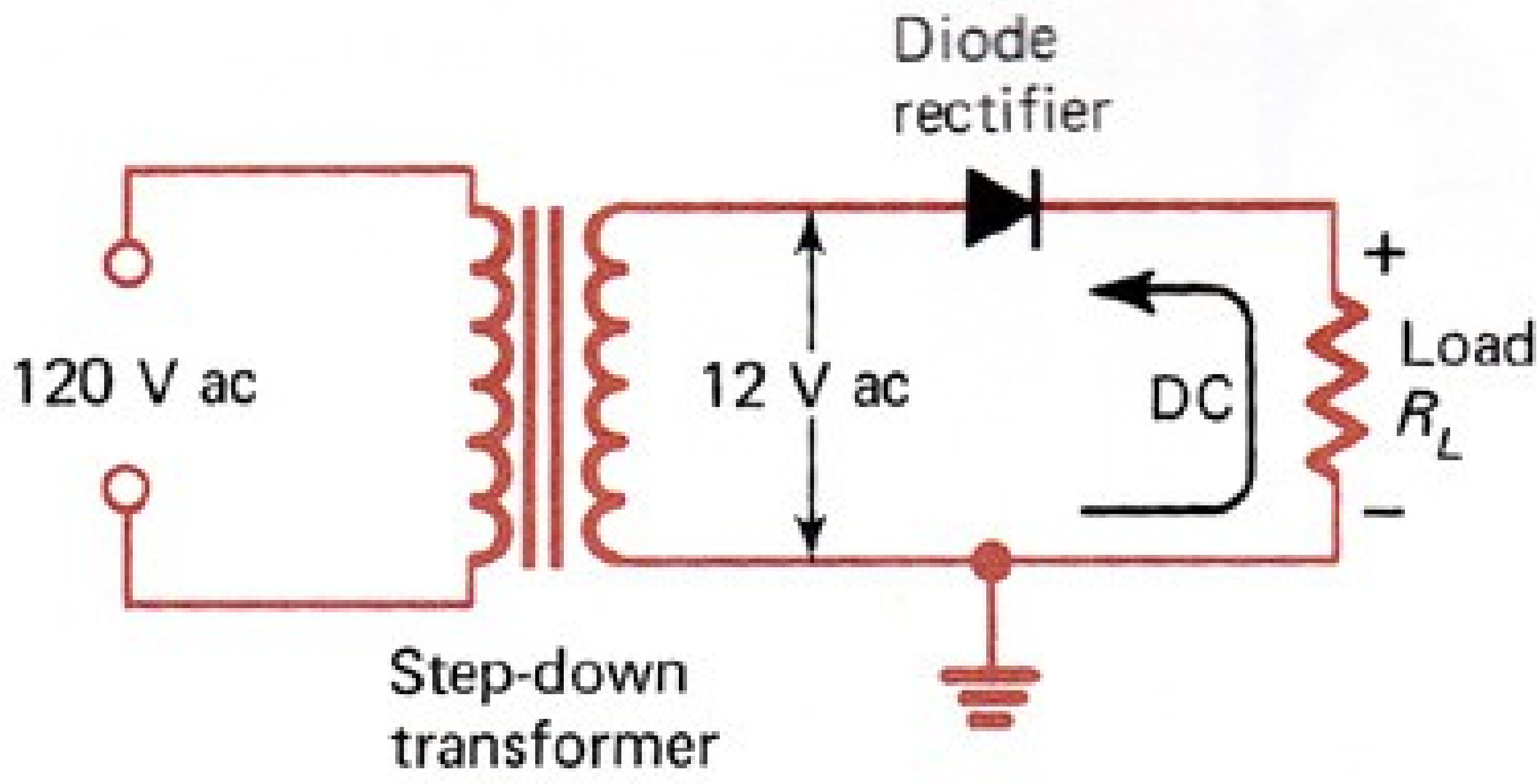
When making these tests remember that that your ohmmeter leads must have high enough voltage across them to “turn on” the diode junction!

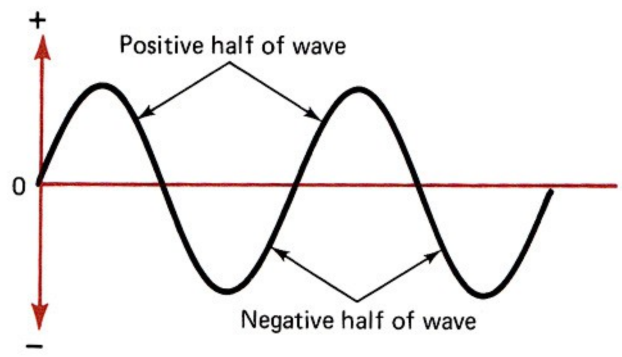
Typical Results of Diode Testing With a Digital Multimeter (DMM)

Device Tested	Results	
	Ohms Function kΩ	Diode Function
Small silicon diode	19	0.571
1-A silicon diode	17	0.525
5-A silicon diode	14	0.439
100-A silicon diode	8.5	0.394
Small Schottky diode	7	0.339
Small germanium diode	3	0.277

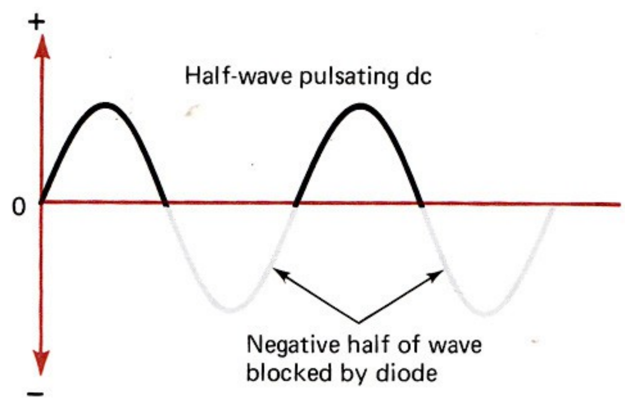

signal diode
light emitting diodes
IR LEDs
photodiodes
transient voltage supression diodes
zener diodes
constant current diode
shottkey diode
shockley diode
step recovery diodes
DIODES
super barrier diode
tunnel diodes
varactor diodes
PIN diodes
point contact diode
LASER diodes
vaccum diode
silicon controlled rectifier
peltier diodes
gunn diode
crystal diode
avalanche diode

Let's set up a simple rectifier, using a transformer, a single solid-state diode, and a load resistor.

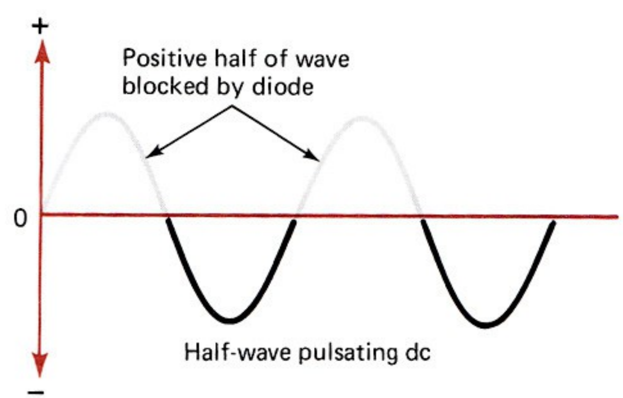




AC waveform from xfmr

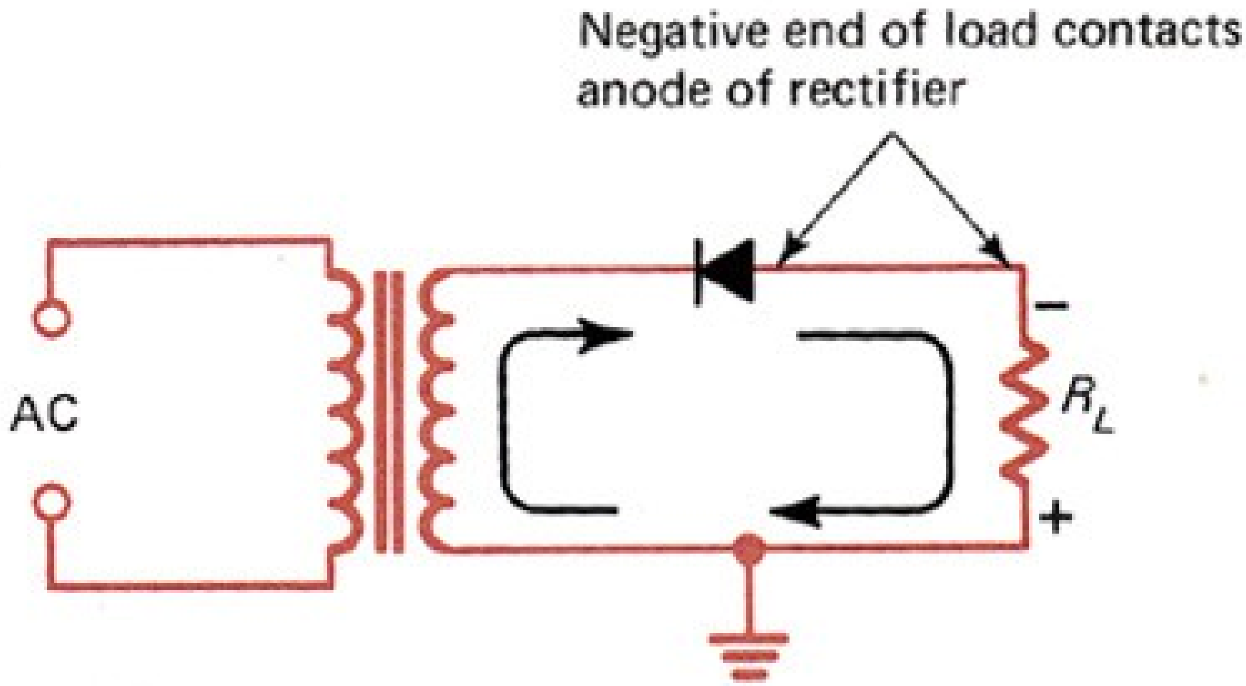


Pulsating positive DC across the load



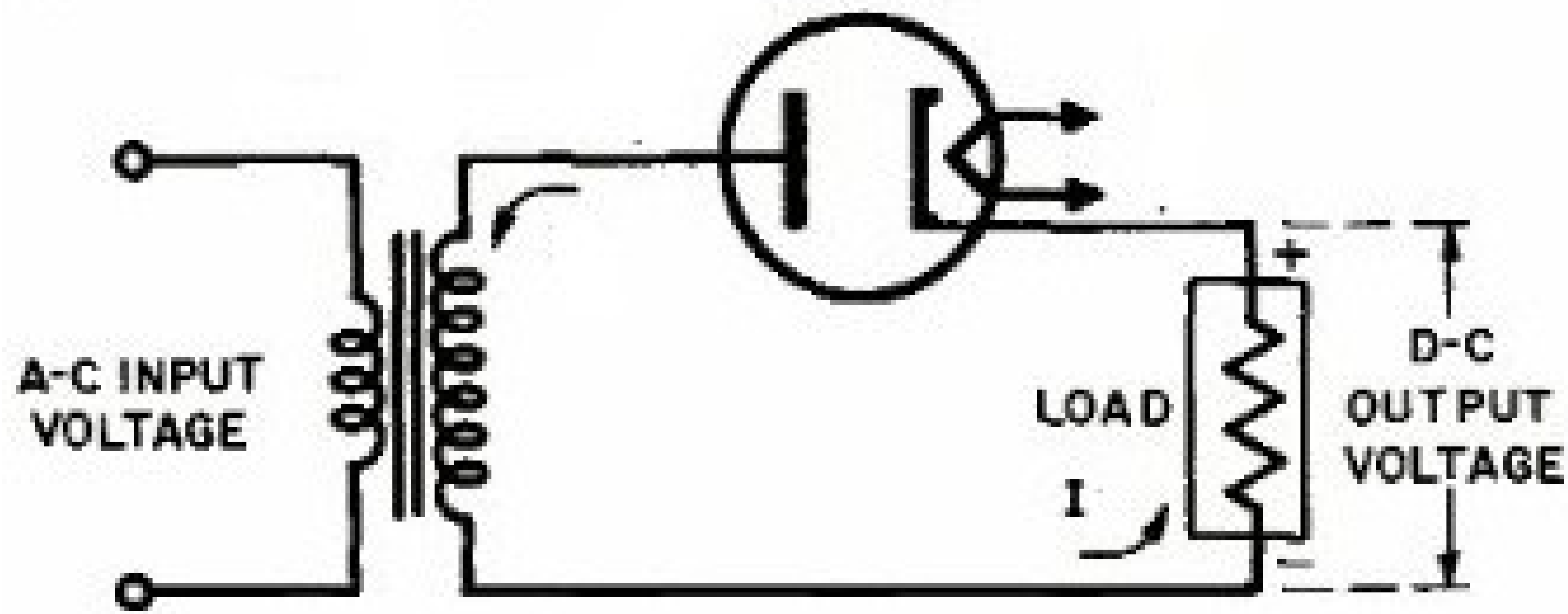
Pulsating negative DC

Now “flip” the rectifier.



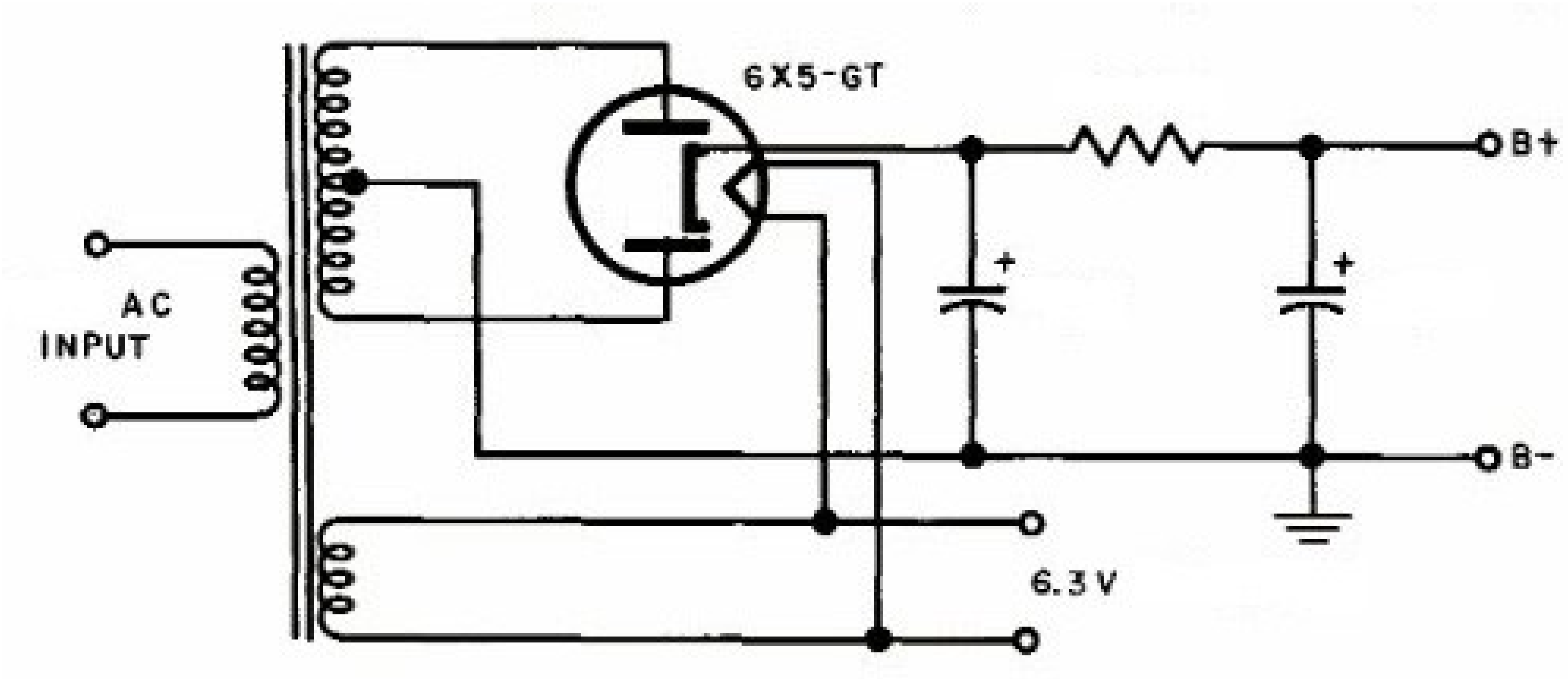
The output flips polarity, too.

Here's a transformer-operated ½-wave rectifier and load. The filament power source is assumed.

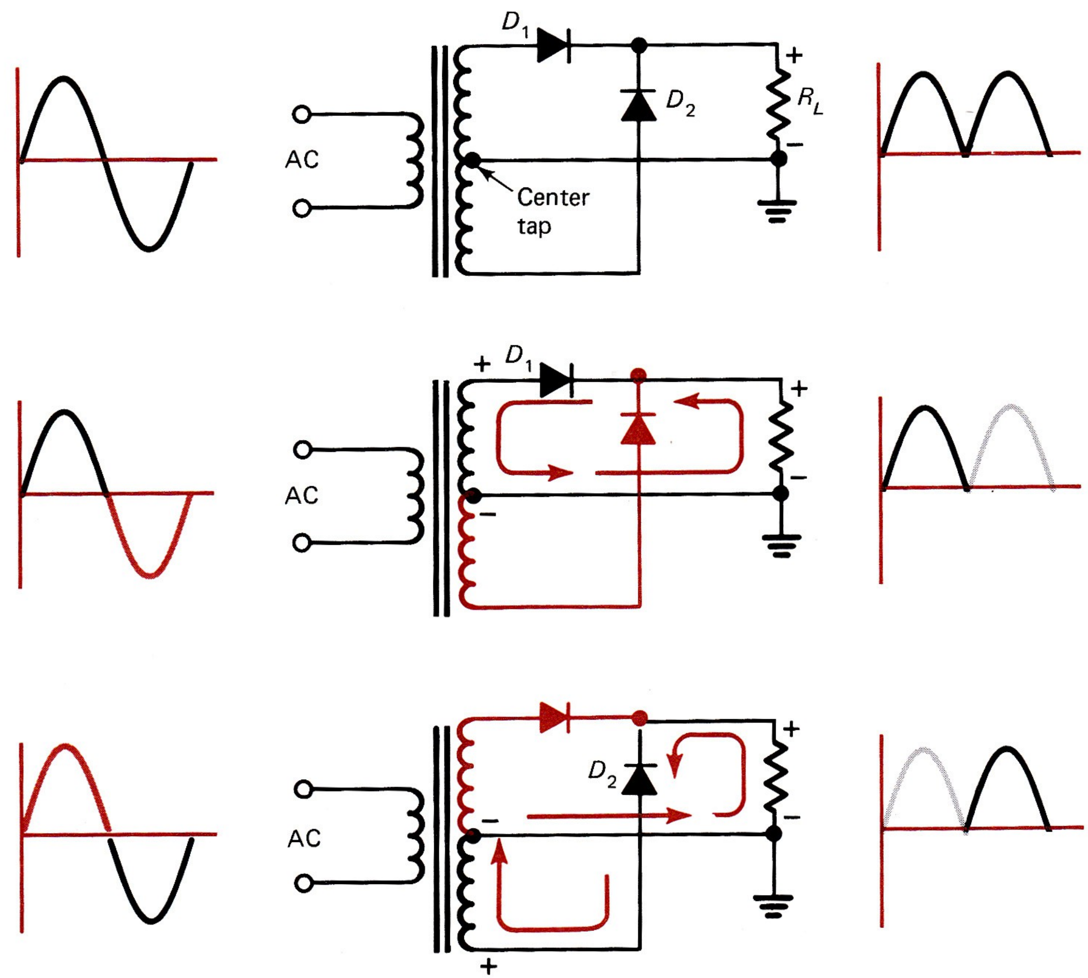


This schematic shows a transformer operated full-wave configuration using a 6X5 dual-diode glass rectifier vacuum tube. One cathode serves both anodes.

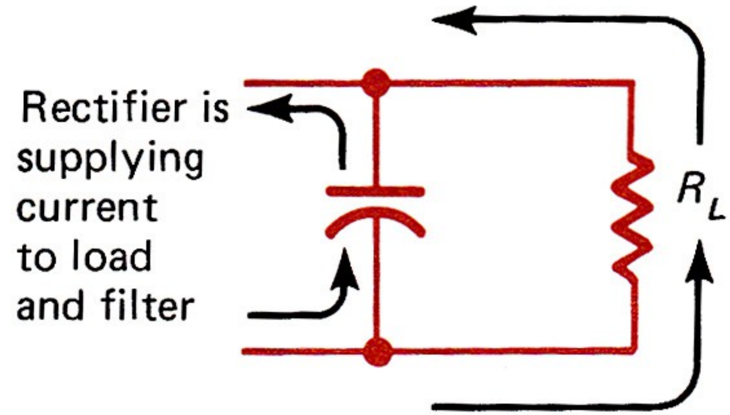
This circuit includes a *pi-filter*.



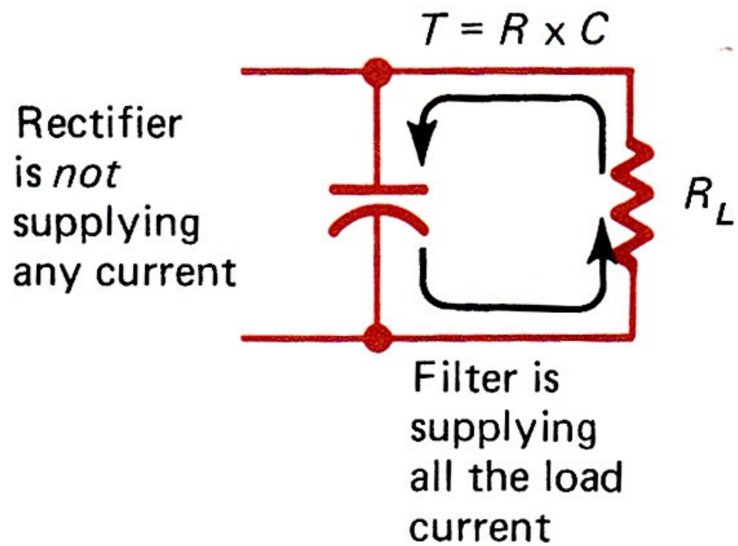
This is the schematic for a full-wave transformer-operated rectifier using solid-state diodes. No filtering is shown in this diagram.



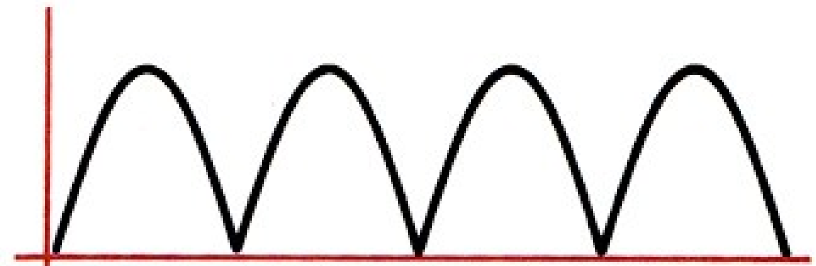
A filter capacitor across the load charges up when the rectifier supplies current to the load.



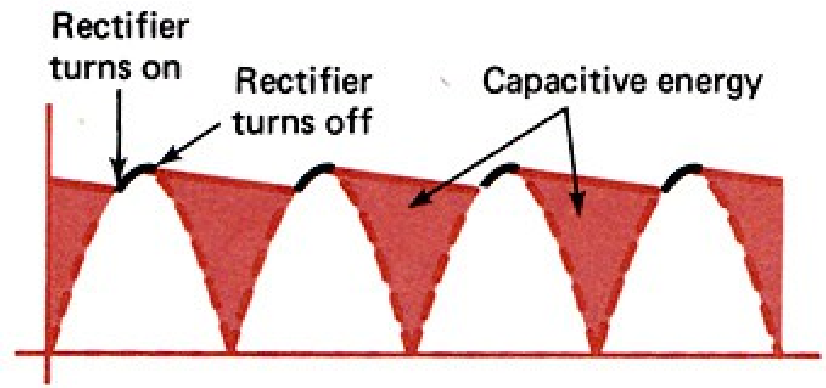
The filter capacitor discharges through the load when the rectifier does not supply current to the load.



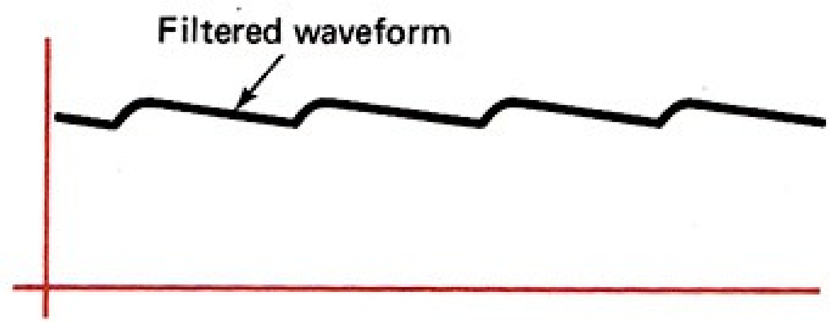
Full-wave unfiltered pulsating DC



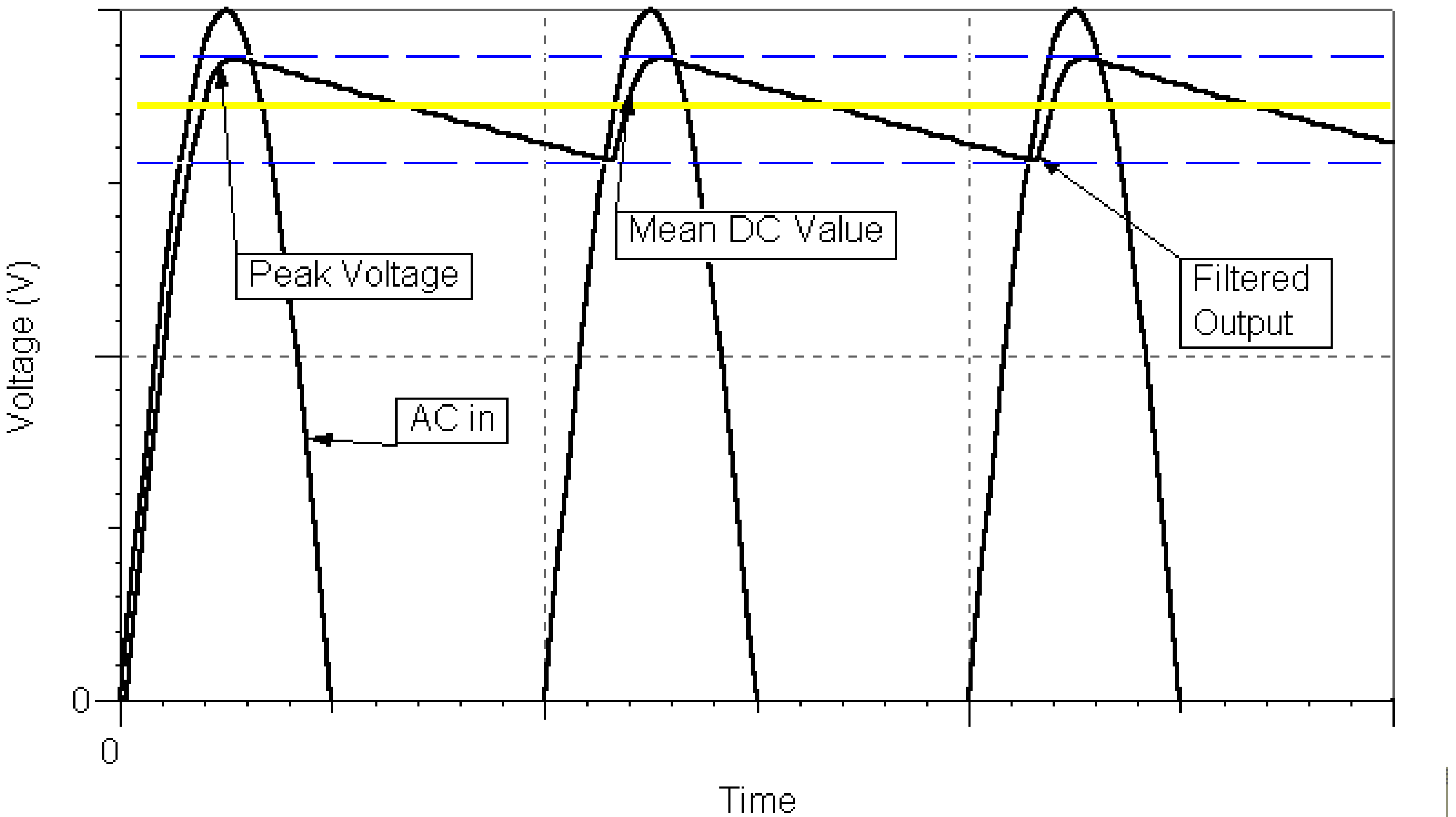
The filter cap "fills in" during the time the rectifier is not conducting

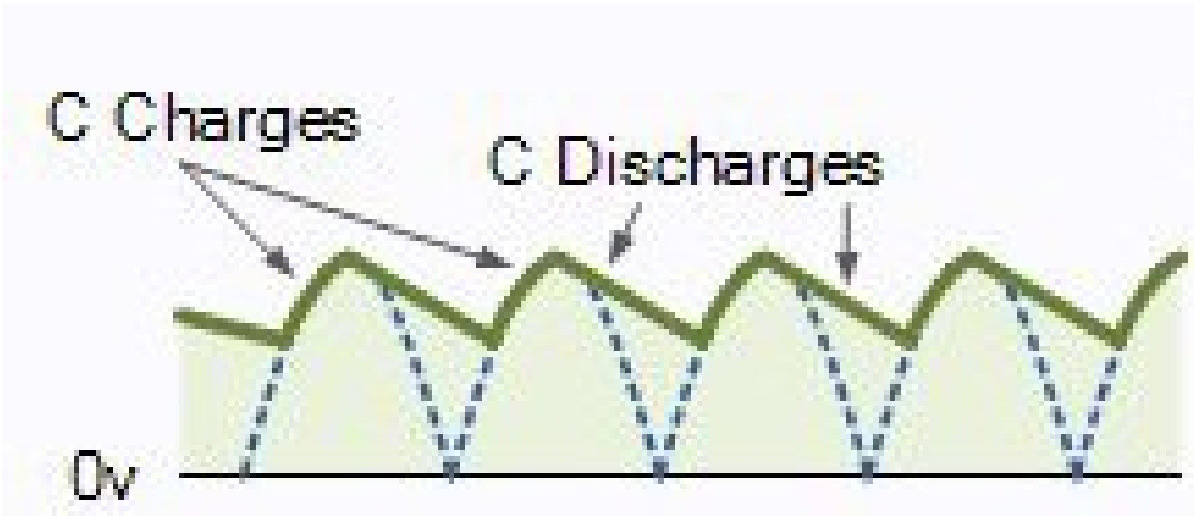


The result is filtered DC, showing some "ripple"



Filtering effect in a half-wave supply

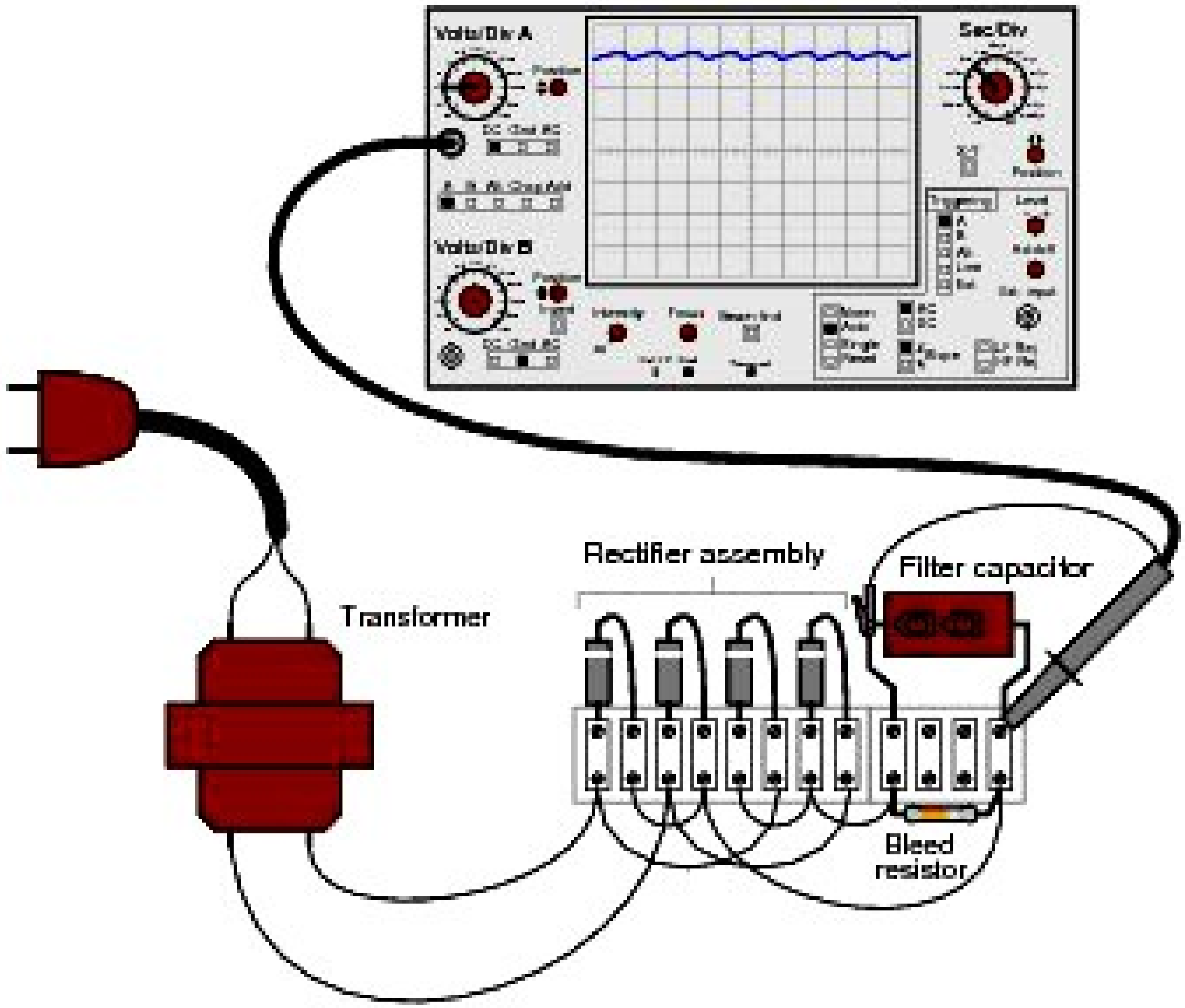




Ripple is a normal part of any AC-operated filtered power supply's operation in the shack.

The amount of ripple that's tolerated depends on the application for your supply.

An oscilloscope and 'scope probe can ease measurement of power supply ripple.



Questions?

Thank you.

Vy 73, AI2Q