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Introduction to Diodes And Rectifiers

Chapter 3 - Diodes and Rectifiers

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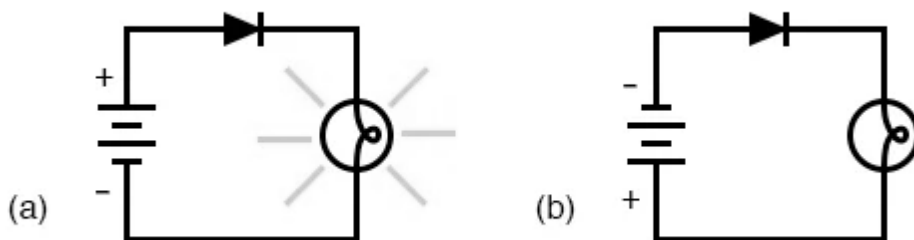
All About Diodes

A *diode* is an electrical device allowing current to move through it in one direction with far greater ease than in the other. The most common kind of diode in modern circuit design is the semiconductor diode, although other diode technologies exist. Semiconductor diodes are symbolized in schematic diagrams such as the figure below. The term “diode” is customarily reserved for small signal devices, $I \leq 1$ A. The term *rectifier* is used for power devices, $I > 1$ A.



Semiconductor diode schematic symbol: Arrows indicate the direction of Current flow.

When placed in a simple battery-lamp circuit, the diode will either allow or prevent current through the lamp, depending on the polarity of the applied voltage. (figure below)



Diode operation: (a) Current flow is permitted; the diode is forward biased. (b) Current flow is prohibited; the diode is reversed biased.

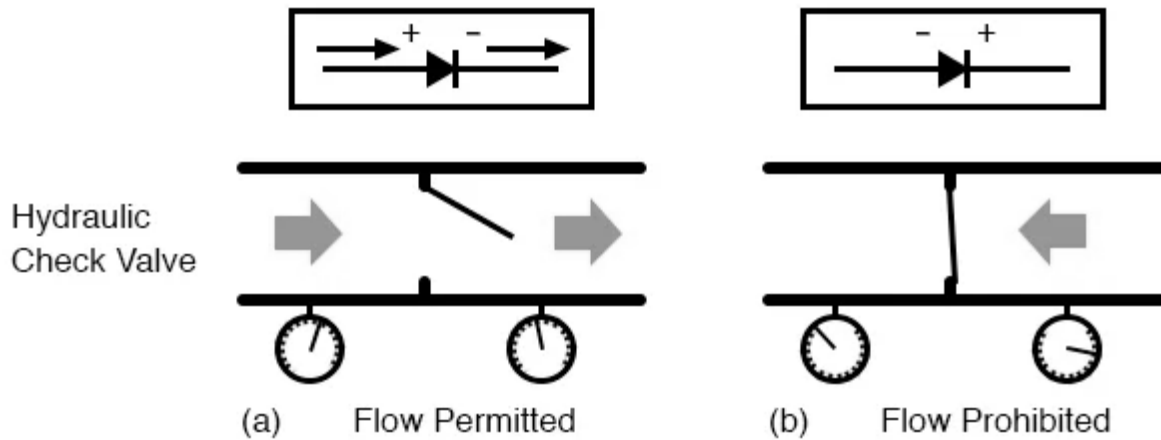
When the polarity of the battery is such that current is allowed to flow through the diode, the diode is said to be *forward-biased*. Conversely, when the battery is “backward” and the diode blocks current, the diode is said to be *reverse-biased*. A diode may be thought of as like a switch: “closed” when forward-biased and “open” when reverse-biased.

The direction of the diode symbol’s “arrowhead” points at the direction of the current in conventional flow. This convention holds true for all semiconductors possessing “arrowheads” in their schematics. The opposite is true.

when electron flow is used, where the current direction is against the “arrowhead”.

Hydraulic Check Valve Analogy

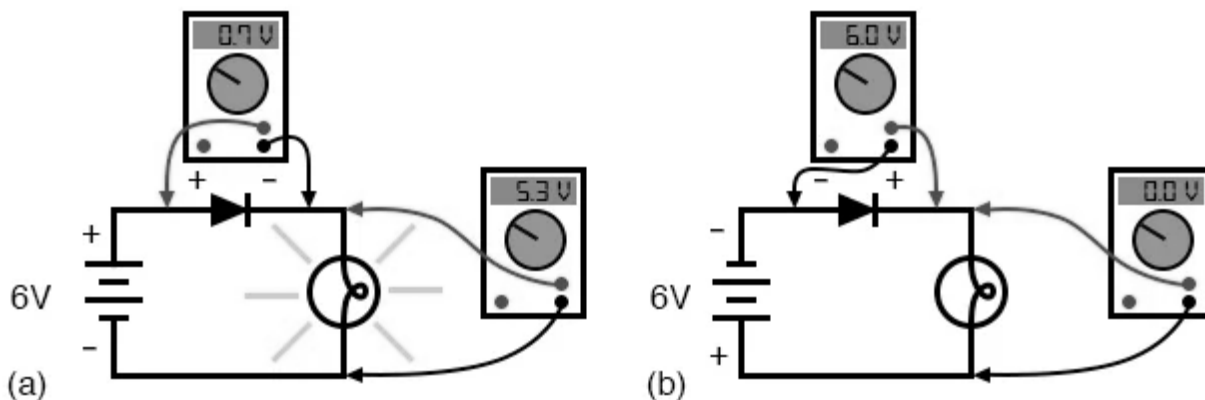
Diode behavior is analogous to the behavior of a hydraulic device called a *check valve*. A check valve allows fluid flow through it in only one direction as in the figure below.



Hydraulic check valve analogy: (a) Current flow permitted. (b) Current flow prohibited.

Check valves are essentially pressure-operated devices: they open and allow flow if the pressure across them is of the correct “polarity” to open the gate (in the analogy shown, greater fluid pressure on the right than on the left). If the pressure is of the opposite “polarity,” the pressure difference across the check valve will close and hold the gate so that no flow occurs.

Like check valves, diodes are essentially “pressure” operated (voltage-operated) devices. The essential difference between forward-bias and reverse-bias is the polarity of the voltage dropped across the diode. Let’s take a closer look at the simple battery-diode-lamp circuit shown earlier, this time investigating voltage drops across the various components in the figure below.



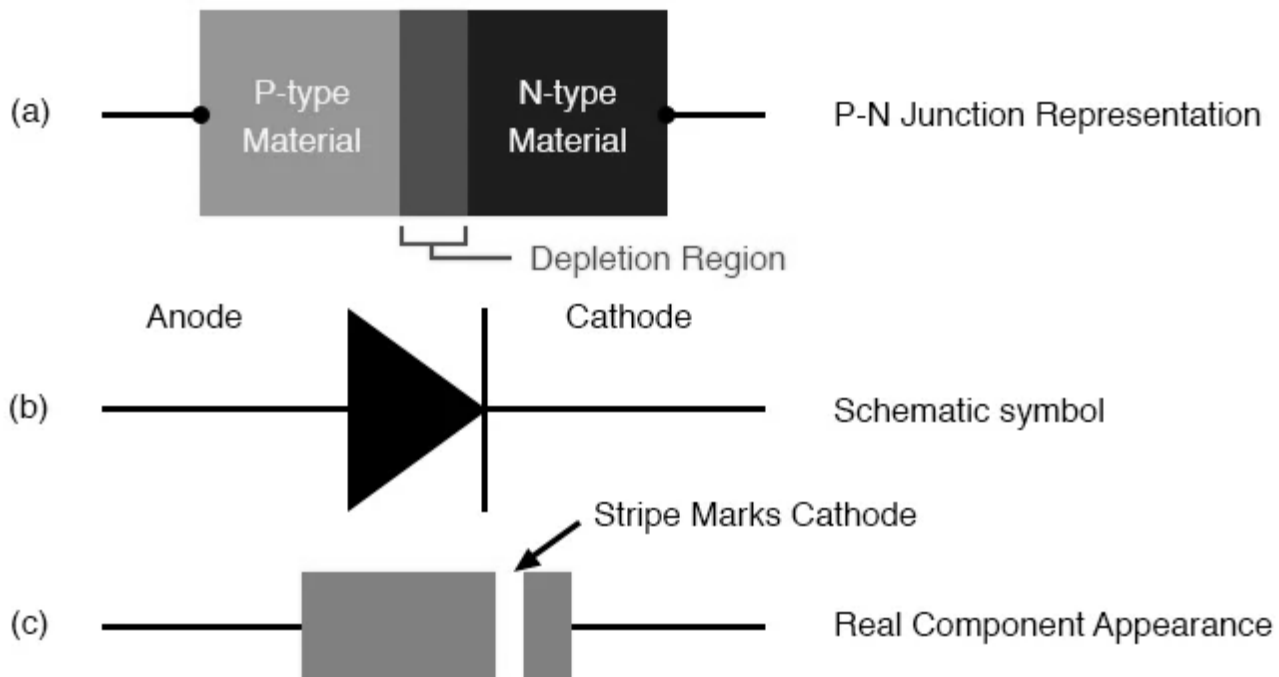
Diode circuit voltage measurements: (a) Forward biased. (b) Reverse biased.

Forward Bias Diode Configuration

A forward-biased diode conducts current and drops a small voltage across it, leaving most of the battery voltage dropped across the lamp. If the battery’s polarity is reversed, the diode becomes reverse-biased, and drops *all of*

the battery's voltage leaving none for the lamp. If we consider the diode to be a self-actuating switch (closed in the forward-bias mode and open in the reverse-bias mode), this behavior makes sense. The most substantial difference is that the diode drops a lot more voltage when conducting than the average mechanical switch (0.7 volts versus tens of millivolts).

This forward-bias voltage drop exhibited by the diode is due to the action of the depletion region formed by the P-N junction under the influence of an applied voltage. If no voltage applied is across a semiconductor diode, a thin depletion region exists around the region of the P-N junction, preventing current flow. (Figure below (a)) The depletion region is almost devoid of available charge carriers, and acts as an insulator:



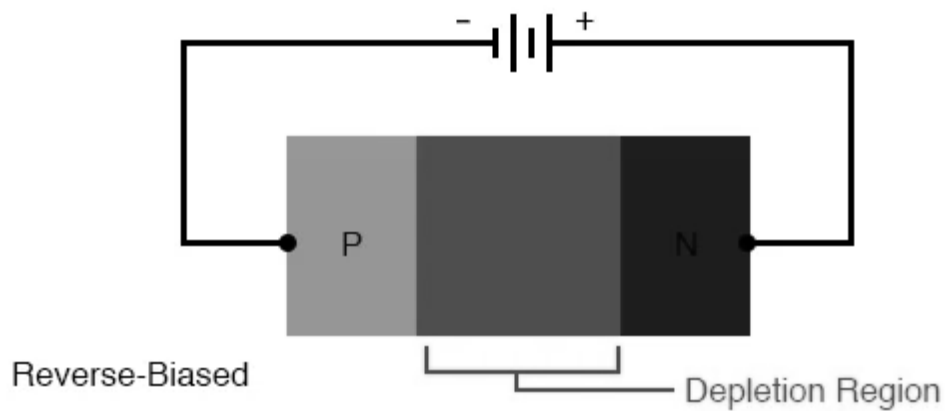
Diode representations: PN-junction model, schematic symbol, physical part.

The schematic symbol of the diode is shown in the figure above (b) such that the anode (pointing end) corresponds to the P-type semiconductor at (a). The cathode bar, non-pointing end, at (b) corresponds to the N-type material at (a). Also note that the cathode stripe on the physical part (c) corresponds to the cathode on the symbol.

Reverse Bias Diode Configuration

If a reverse-biasing voltage is applied across the P-N junction, this depletion region expands, further resisting any current through it. (Figure below)

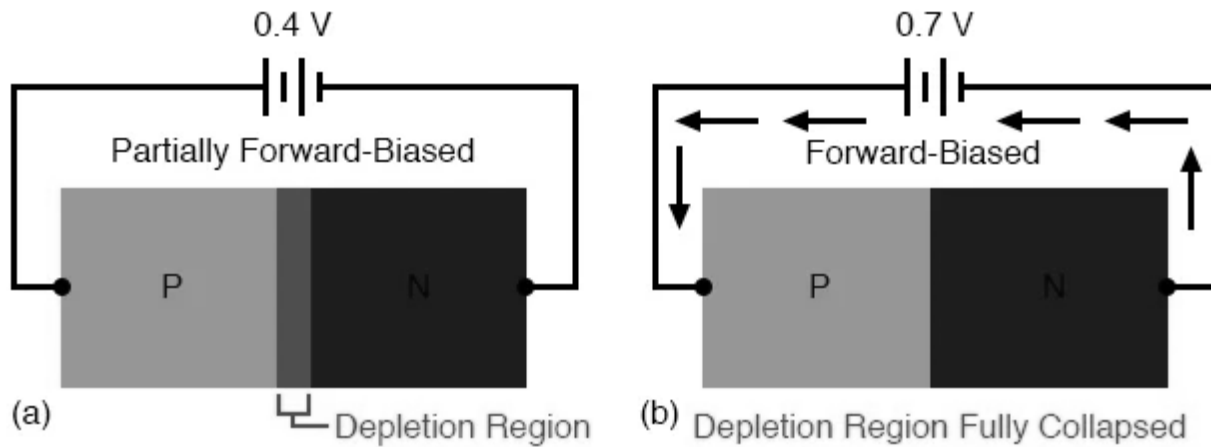
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Depletion region expands with reverse bias.

Forward Voltage

Conversely, if a forward-biasing voltage is applied across the P-N junction, the depletion region collapses becoming thinner. The diode becomes less resistive to current through it. In order for a sustained current to go through the diode; though, the depletion region must be fully collapsed by the applied voltage. This takes a certain minimum voltage to accomplish, called the *forward voltage* as illustrated in the figure below.



Increasing forward bias from (a) to (b) decreases depletion region thickness.

For silicon diodes, the typical forward voltage is 0.7 volts, nominal. For germanium diodes, the forward voltage is only 0.3 volts. The chemical constituency of the P-N junction comprising the diode accounts for its nominal forward voltage figure, which is why silicon and germanium diodes have such different forward voltages. Forward voltage drop remains approximately constant for a wide range of diode currents, meaning that diode voltage drop is not like that of a resistor or even a normal (closed) switch. For most simplified circuit analysis, the voltage drop across a conducting diode may be considered constant at the nominal figure and not related to the amount of current.

Diode Equation

Actually, forward voltage drop is more complex. An equation describes the exact current through a diode, given the voltage dropped across the junction, the temperature of the junction, and several physical constants. It is commonly known as the *diode equation*:

$$I_D = I_S (e^{qV_D / NkT} - 1)$$

Where,

I_D = Diode current in amps

I_S = Saturation current in amps
(typically 1×10^{-12} amps)

e = Euler's constant (~ 2.718281828)

q = charge of electron (1.6×10^{-19} coulombs)

V_D = Voltage applied across diode in volts

N = "Nonideality" or "Emission" coefficient
(typically between 1 and 2)

k = Boltzmann's constant (1.38×10^{-23})

T = Junction Temperature in Kelvins

The term kT/q describes the voltage produced within the P-N junction due to the action of temperature, and is called the *thermal voltage*, or V_t of the junction. At room temperature, this is about 26 millivolts. Knowing this, and assuming a "nonideality" coefficient of 1, we may simplify the diode equation and rewrite it as such:

$$I_D = I_S (e^{V_D / 0.026} - 1)$$

Where,

I_D = Diode current in amps

I_S = Saturation current in amps
(typically 1×10^{-12} amps)

e = Euler's Number (~ 2.718281828)

V_D = Voltage applied across diode in volts

You need not be familiar with the "diode equation" to analyze simple diode circuits. Just understand that the voltage dropped across a current-conducting diode *does* change with the amount of current going through it, but that this change is fairly small over a wide range of currents. This is why many textbooks simply say the voltage drop across a conducting, semiconductor diode remains constant at 0.7 volts for silicon and 0.3 volts for germanium.

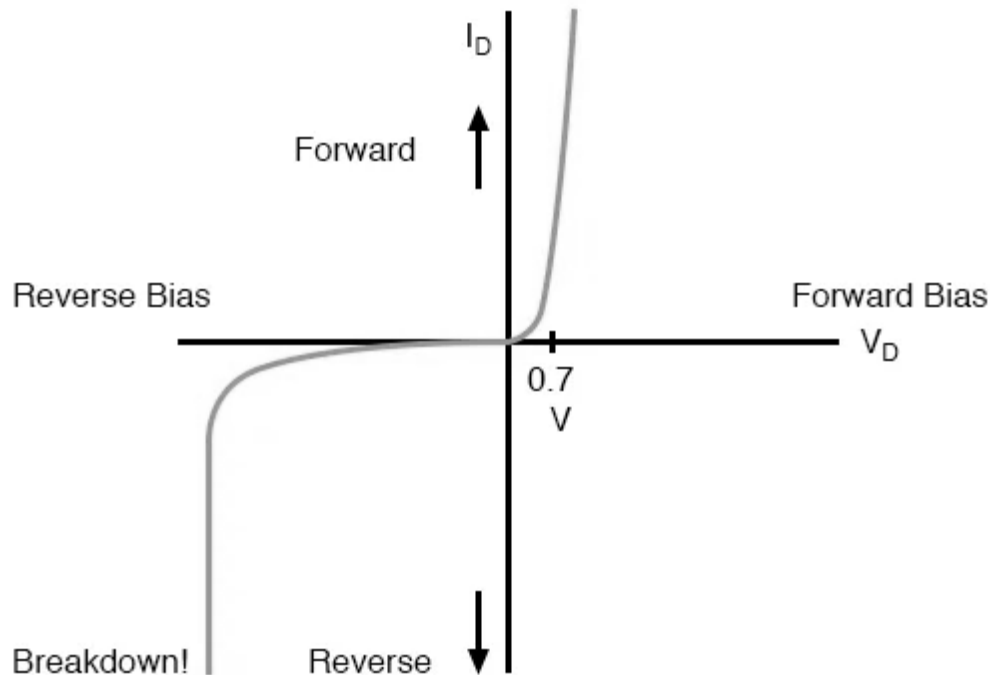
However, some circuits intentionally make use of the P-N junction's inherent exponential current/voltage relationship and thus can only be understood in the context of this equation. Also, since temperature is a factor in the diode equation, a forward-biased P-N junction may also be used as a temperature-sensing device, and thus can only be understood if one has a conceptual grasp on this mathematical relationship.

Reverse-Biased Operation

A reverse-biased diode prevents current from going through it, due to the expanded depletion region. In actuality, a very small amount of current can and does go through a reverse-biased diode, called the *leakage current*, but it can be ignored for most purposes.

The ability of a diode to withstand reverse-bias voltages is limited, as it is for any insulator. If the applied reverse-bias voltage becomes too great, the diode will experience a condition known as *breakdown* (figure below), which is usually destructive.

A diode's maximum reverse-bias voltage rating is known as the Peak Inverse Voltage, or *PIV*, and may be obtained from the manufacturer. Like forward voltage, the PIV rating of a diode varies with temperature, except that PIV *increases* with increased temperature and *decreases* as the diode becomes cooler—exactly opposite that of forward voltage.



Diode curve: showing knee at 0.7 V forward bias for Si, and reverse breakdown.

Typically, the PIV rating of a generic “rectifier” diode is at least 50 volts at room temperature. Diodes with PIV ratings in the many thousands of volts are available for modest prices.

REVIEW:

- A *diode* is an electrical component acting as a one-way valve for current.
- When voltage is applied across a diode in such a way that the diode allows current, the diode is said to be *forward-biased*.
- When voltage is applied across a diode in such a way that the diode prohibits current, the diode is said to be *reverse-biased*.

- The voltage dropped across a conducting, forward-biased diode is called the *forward voltage*. Forward voltage for a diode varies only slightly for changes in forward current and temperature, and is fixed by the chemical composition of the P-N junction.
- Silicon diodes have a forward voltage of approximately 0.7 volts.
- Germanium diodes have a forward voltage of approximately 0.3 volts.
- The maximum reverse-bias voltage that a diode can withstand without “breaking down” is called the *Peak Inverse Voltage*, or *PIV* rating.

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