Chapter 2

Diode Fundamentals

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Outline

- Introduction
- The Ideal Diode
- The real diode
- Diode Analyses (the diode models)
- Special Types of *p–n Junction Semiconductor* Diodes
- Applications of Diode

Recap of previous lecture

Recall-Lecture 2

- Introduction to Electronics
- Atomic structure of Group IV materials particularly on Silicon
- Intrinsic carrier concentration, n_i

$$n_i = BT^{3/2}\, e^{\left(\frac{-E_g}{2kT}\right)}$$

Recall-Lecture 2

- Extrinsic semiconductor
  - N-type – doped with materials from Group V
    - **Majority carriers = electron**
  - P-type – doped with materials from Group III
    - **Majority carriers = holes**
- concentration of carriers in doped semiconductors
  - $n_o p_o = ni^2$

Diffusion Current

- **The basic diffusion process**
  - Flow of particles from a region of high-concentration to a region of low-concentration.
  - The movement of the particles will then generate the diffusion current

Drift and Diffusion Currents

- **Current**
  Generated by the movement of charged particles (negatively charged electrons and positively charged holes).

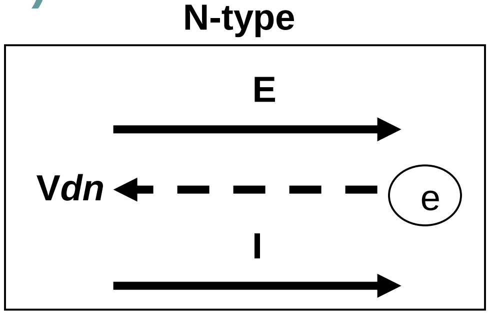
- **Carriers**
  The charged electrons and holes are referred to as **carriers**

- The two basic processes which cause electrons and holes move in a semiconductor:
  - **Drift** - the movement caused by electric field.
  - **Diffusion** - the flow caused by variations in the concentration.

Drift Currents

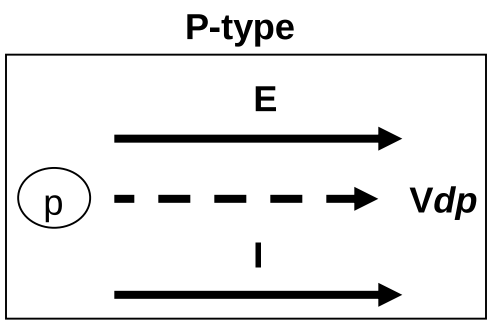
- **Drift Current Density** (n-type semiconductor)
  - An electric field *E* applied to n-type semiconductor with a large number of free electrons.

    - **Produces a force on the electrons in the opposite direction, because of the electrons' negative charge.**
    - **The electrons acquire a drift velocity, V_{dn} (in cm/s):**



Drift Currents

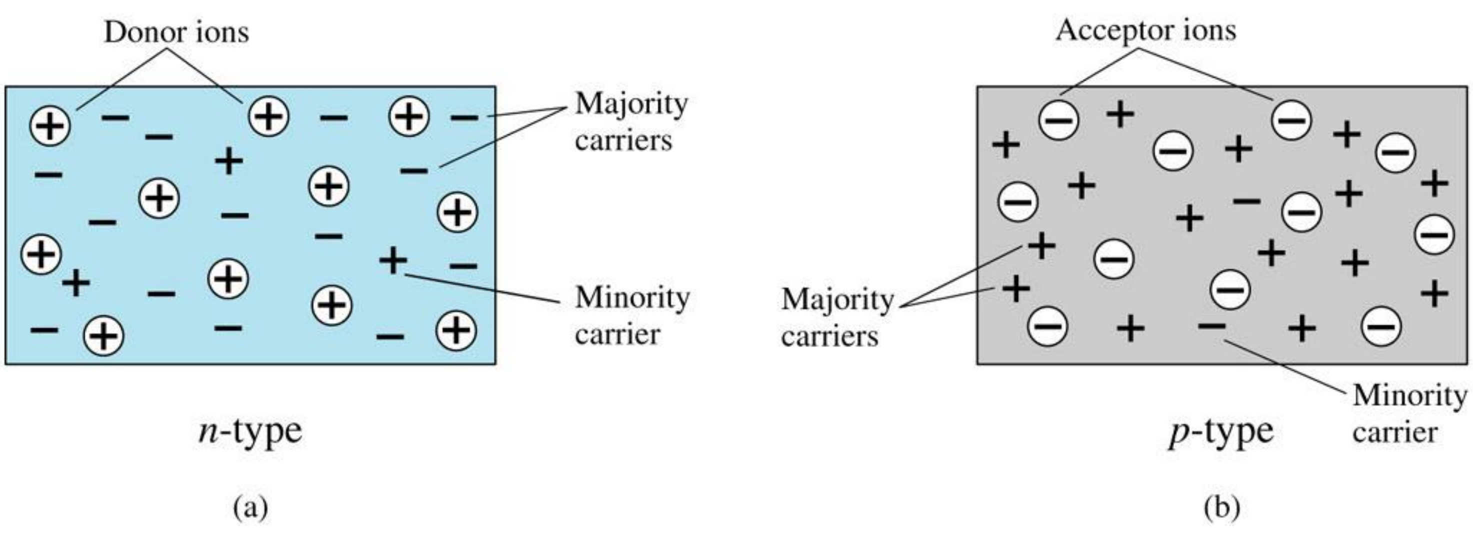
- **Drift Current Density** (p-type semiconductor)
  - An electric field *E* applied to p-type semiconductor with a large number of holes.
    - **Produces a force on the holes in the same direction, because of the positive charge on the holes.**
    - **The holes acquire a drift velocity, V_{dp}(in cm/s):**



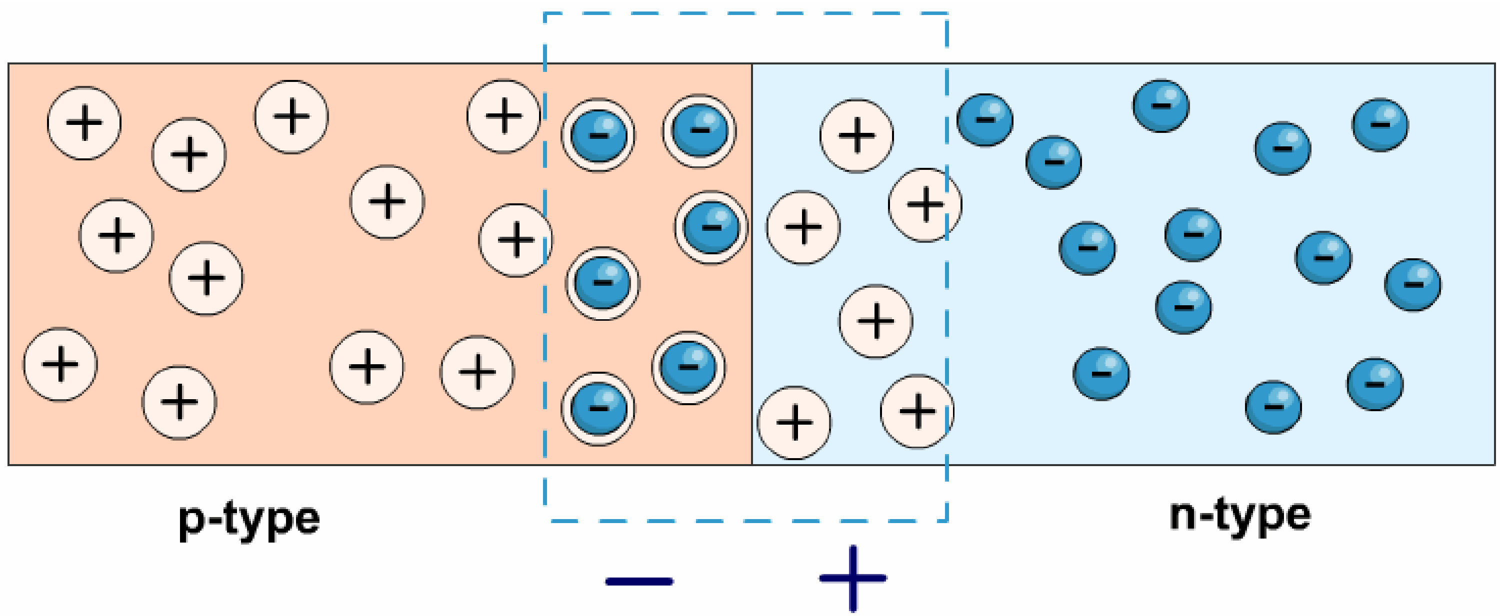
The pn Junction

n-type versus p-type

- In n-type - the electrons are the majority carriers and holes are the minority carriers.
- In p-type - the holes are called the majority carriers and electrons are the minority carriers.



Recap of previous lecture



-Semiconductors n-type and p-type are brought together

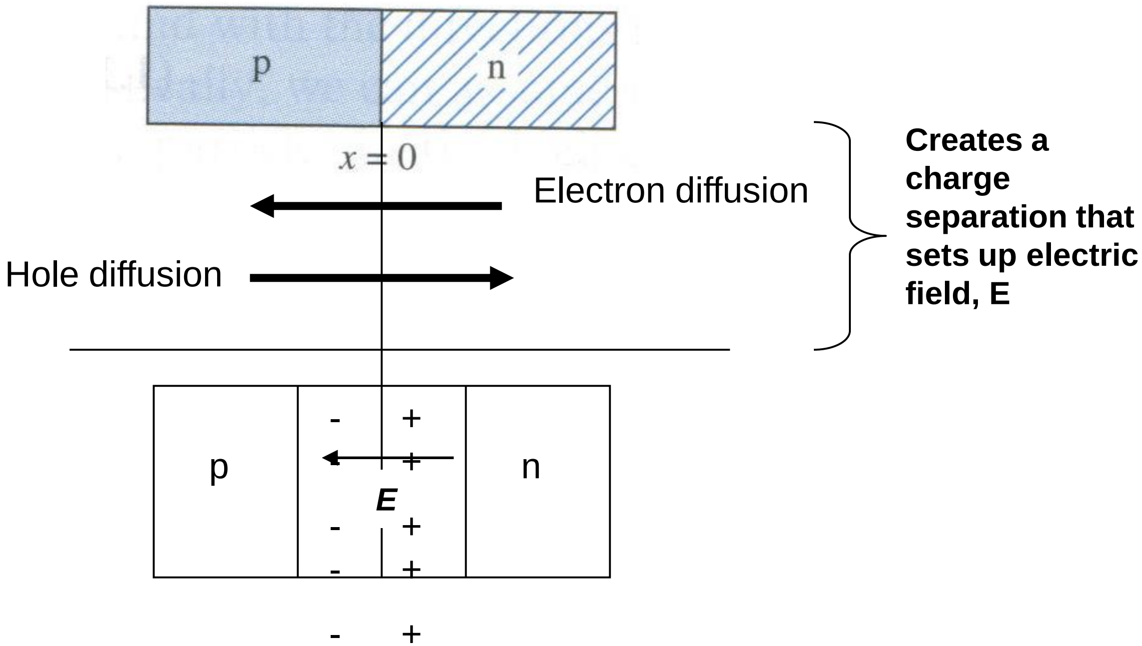
-Electrons and holes migrate across the junction

-The depletion layer is formed

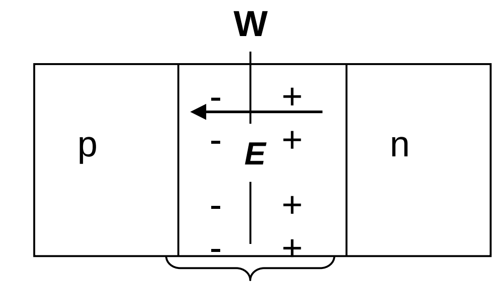
-A p.d. is set up across the depletion layer

The Equilibrium pn Junction

- Join n-type and p-type doped Silicon (or Germanium) to form a **p-n junction**.



The Electric field will create a force that will stop the diffusion of carriers → reaches thermal equilibrium condition



Known as space charge region/depletion region.

Potential difference across the depletion region is called the <u>built-in potential</u> barrier, or built-in voltage:

$$\boxed{V_{bi} = \frac{kT}{e}\ln\left(\frac{N_a N_d}{n_i^2}\right) = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right)}$$

$V_T = kT/e$
k = Boltzmann's constant
T = absolute temperature
e = the magnitude of the electronic charge = 1 eV
N_a = the net acceptor concentration in the p-region
N_d = the net donor concentration in the n-region

V_T = **thermal voltage**, [V_T = kT / e] it is approximately **0.026 V at temp, T = 300 K**

The Equilibrium pn Junction

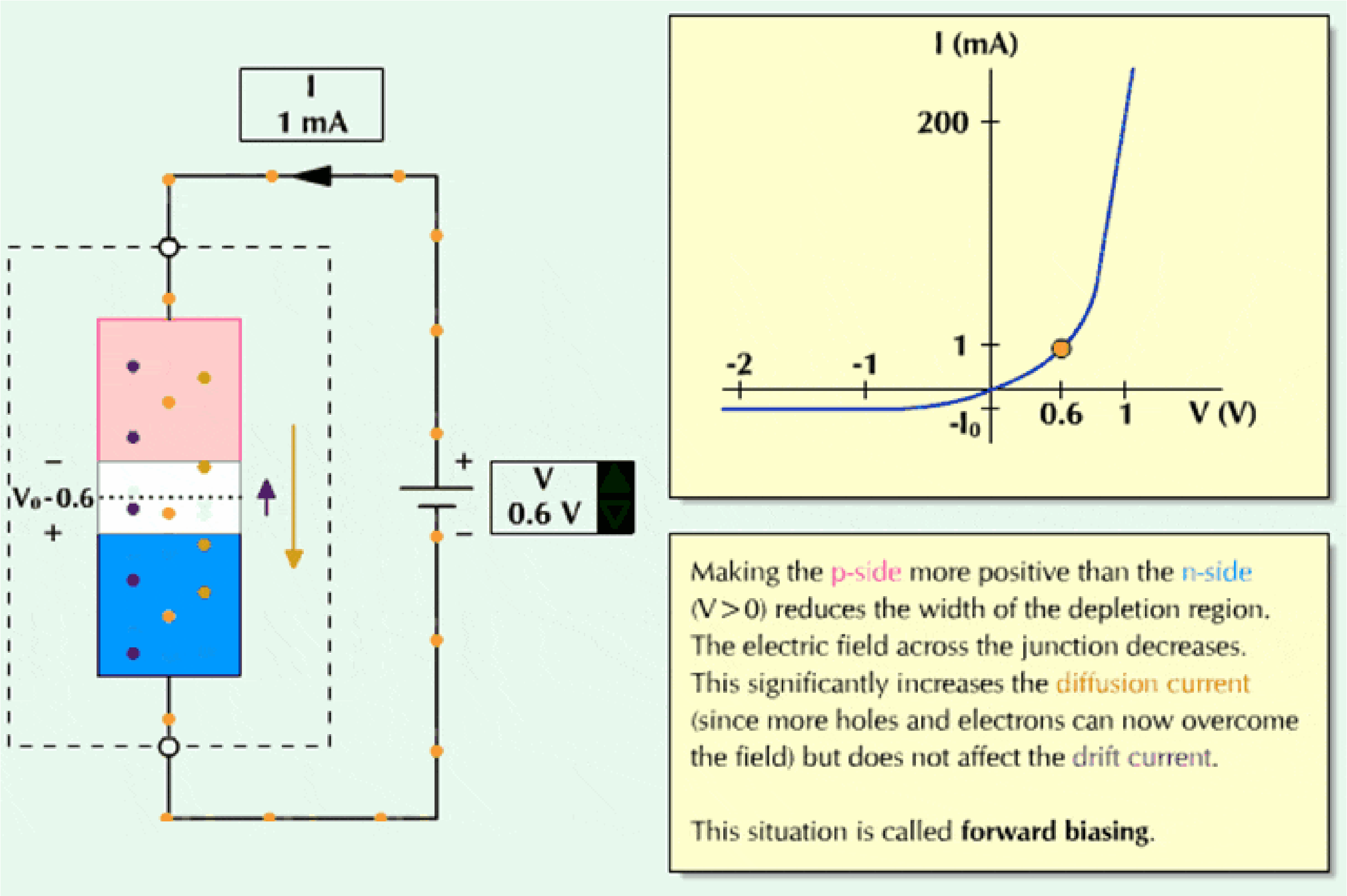
Example 1

Calculate the built-in potential barrier of a pn junction. Consider a silicon pn junction at T = 300 K, doped $N_a = 10^{16}$ cm^{-3} in the p-region, $N_d = 10^{17}$ cm^{-3} in the n-region and $n_i = 1.5 \times 10^{10}$ cm^{-3}.

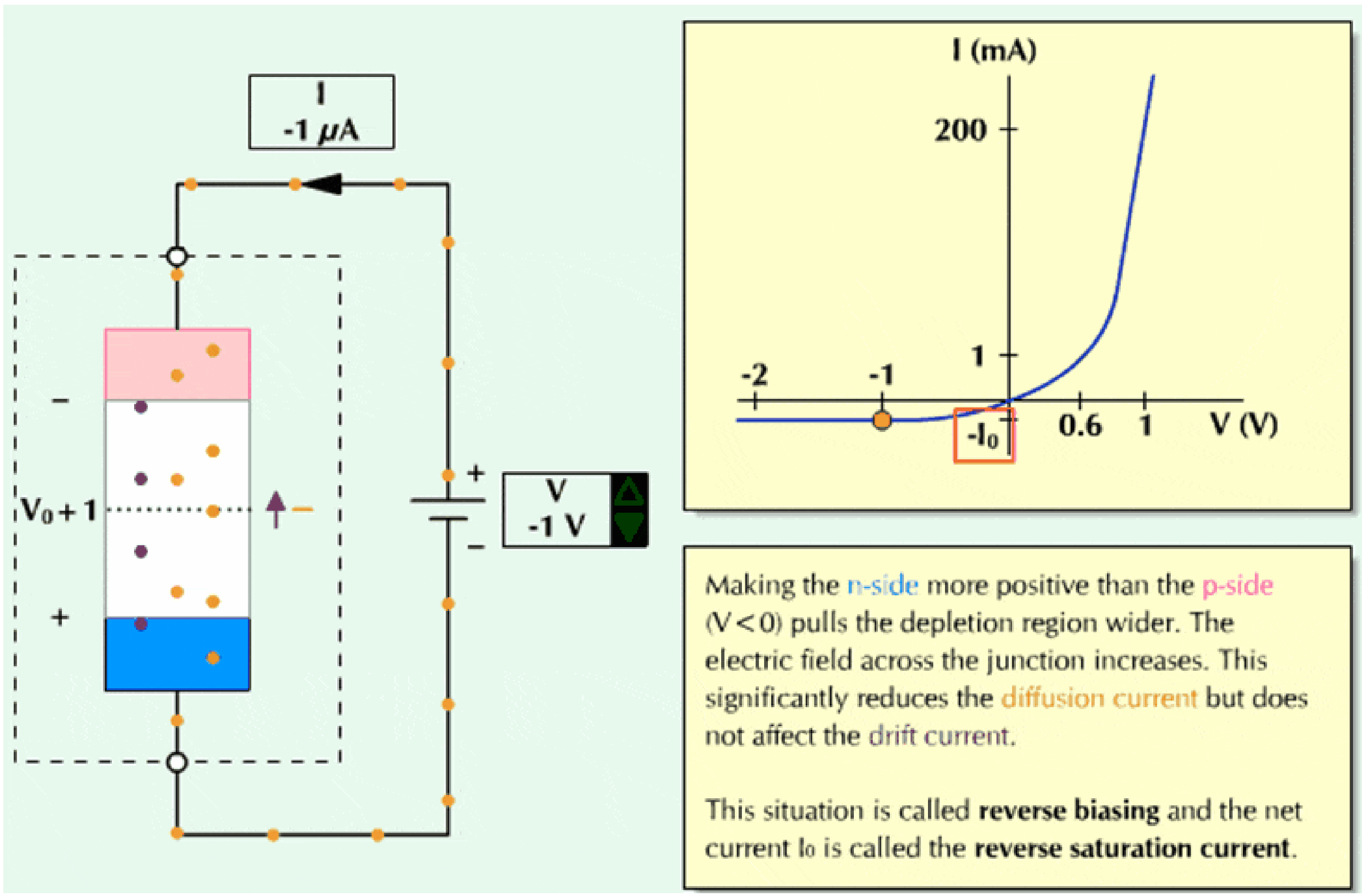
Solution

$$V_{bi} = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right) = (0.026)\ln\left[\frac{(10^{16})(10^{17})}{(1.5 \times 10^{10})^2}\right] = 0.757\,\text{V}$$

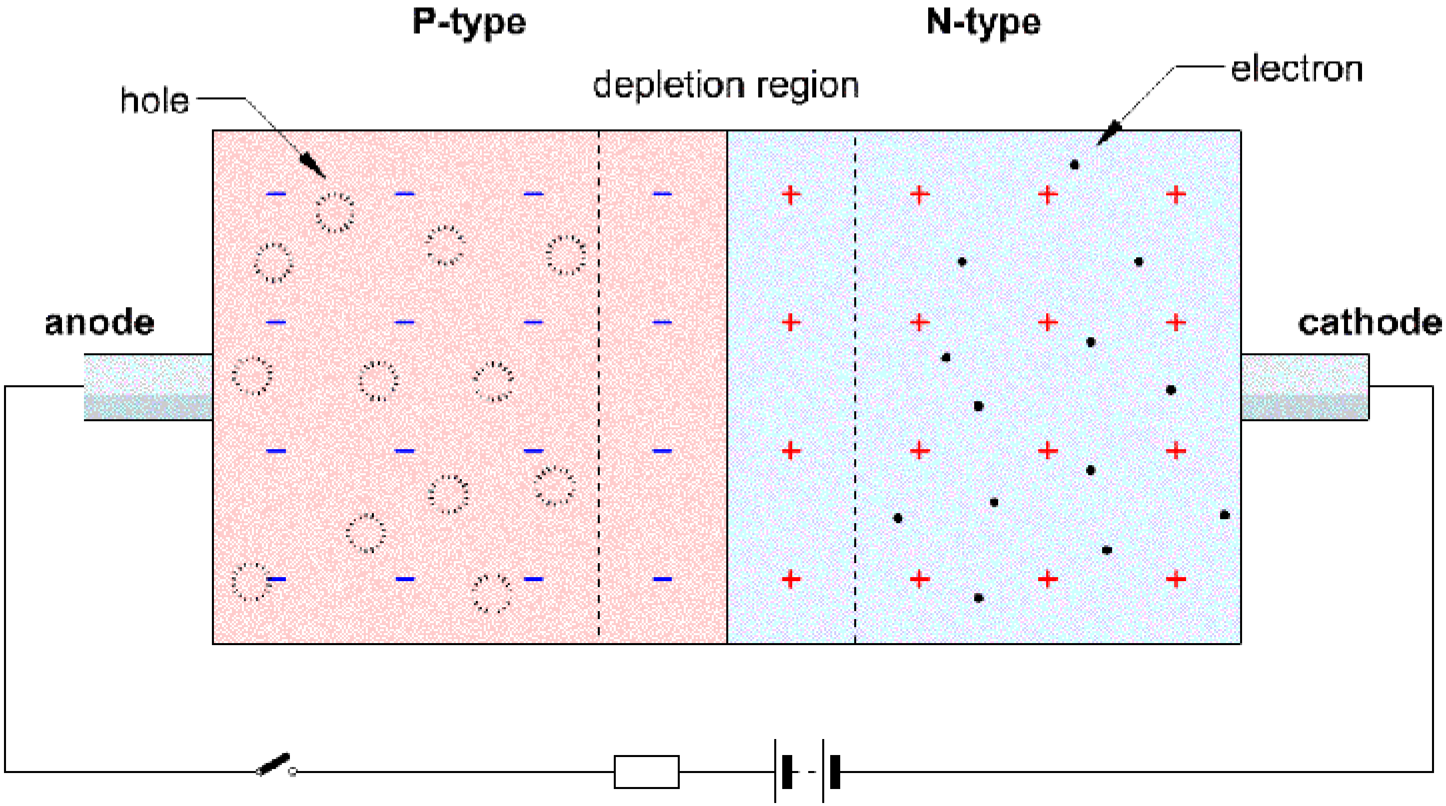
Forward Bias & Reverse Bias Diode Working Animation



Forward Bias & Reverse Bias Diode Working Animation



Forward Bias & Reverse Bias Diode Working Animation



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- Example 2

Consider a silicon pn junction at T = 400K, doped with concentrations of $N_d = 10^{18}$ cm^{-3} in n-region and $N_a = 10^{19}$ cm^{-3} in p-region. Calculate the built-in voltage V_{bi} of the pn junction, given Given B and Eg for silicon are 5.23 x 10^{15} cm^{-3} K$^{-3/2}$ and 1.1 eV respectively

$$\boxed{V_{bi} = \frac{kT}{e} \ln\left(\frac{N_a N_d}{n_i^2}\right) = V_T \ln\left(\frac{N_a N_d}{n_i^2}\right)}$$

ANSWER

- Calculation of $V_T = kT / e = 86 \times 10^{-6} (400) / 1eV = 0.0344$ V
- Calculation of $n_i = BT^{3/2} \exp(-Eg / 2kT)$

  $= 5.23 \times 10^{15} (400)^{3/2} \exp\left[-1.1 / 2 (86 \times 10^{-6})(400)\right]$

  $= 4.76 \times 10^{12}\ cm^{-3}$
- Calculation of $V_{bi} = V_T \ln (N_a N_d / n_i^2)$

  $= 0.0344 \ln\left[10^{18} (10^{19}) / (4.76 \times 10^{12})^2\right]$

  $= \underline{0.922V}$

Which of the following statements is false?

a). When atoms are packed closely together to form a crystal, the allowable energy levels broaden into bands of energy.

b). Between adjacent energy bands are gaps or forbidden regions where there are no allowable energy levels

c). The presence of electrons in the conduction band is crucial to the conduction process.

d). At 0 K, the electrons in the valence band are free to move under an applied electric field

Consider the following statement – electrons from the valence band are easily promoted to the acceptor level leaving behind holes that are very effective in carrying charge.- Which type of semiconductor is the above statement referring to?

a). P-type semiconductor

b). N-type semiconductor

c). P-N junction

d). None of the above

A hole in a semiconductor is defined as……………….

A. A free electron

B. The incomplete part of an electron pair bonds

C. A free proton

D. A free neutron

During the formation of a P-N junction the n side of the junction contains a net positive charge. Similarly in the p material, there will be a region close to the junction that is depleted of holes and contains a net negative charge. These charges are due to :

a). The diffusion current

b). The drift current

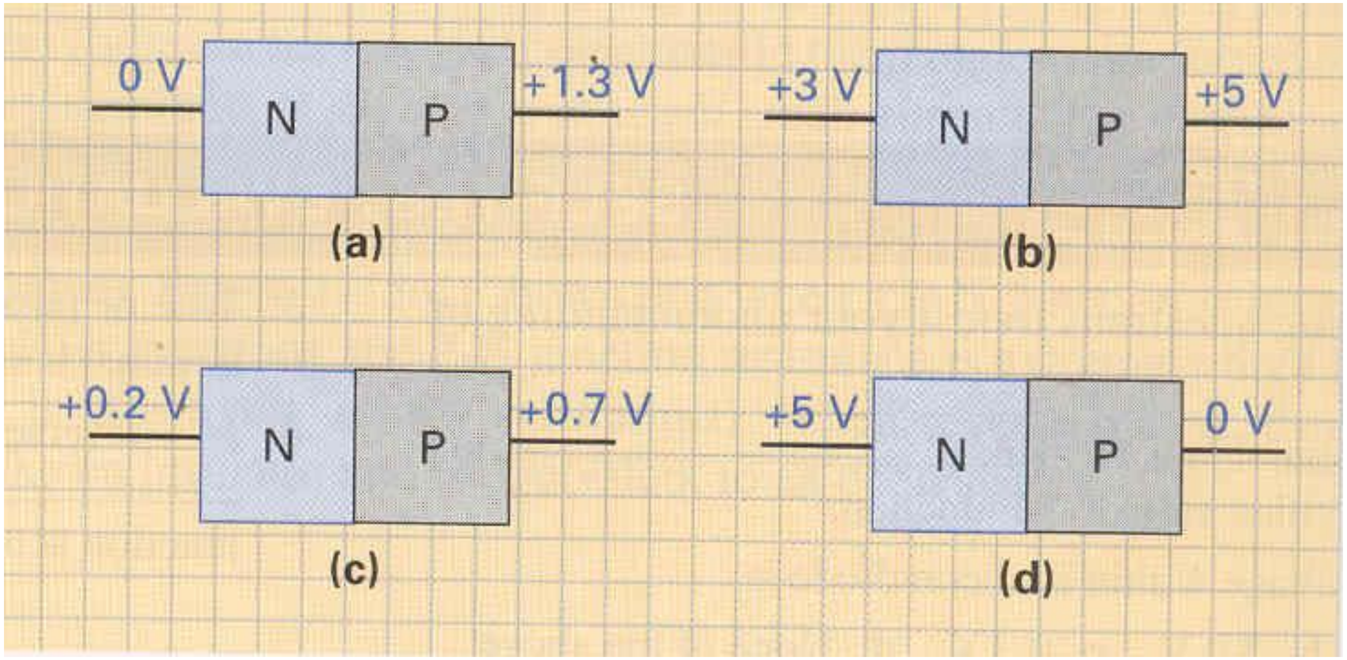
c). bound charges associated with donor and acceptor atoms

d). doping in the semiconductor

A semiconductor material has a _______________ temperature coefficient of resistance, which means that as temperature increases its resistance ___________

a)Positive, increase
b)Positive, decrease
c)Negative, increase
d)Negative, decrease

Which of the silicon P-N junctions in the figure below are forward biased and which are reverse biased? Write the answer in the space provided



Under open circuit conditions, the movement of charge carriers in a semiconductor as a result of differences in concentration gives rise to a current called

a). Diffusion current
b). Drift current
c). Drift velocity
d). Saturation current

Which of the following is false? For a reverse biased P-N junction

A. The electric field within the junction increases

B. The barrier potential increases

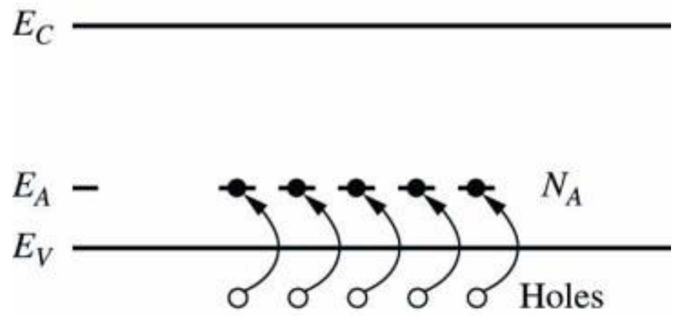
C. The only contribution to current flow are thermally generated minority carriers

D. The width of the space charged region decreases

Zener breakdown occurs when

a. The electric field in the depletion layer increases to the point where it can break covalent bonds and generate electron-hole pairs
b. The minority carriers that cross the depletion region under the influence of the electric field gain sufficient kinetic energy to be able to break bonds and generate electron hole pairs.
c. When the voltage drop across a fully conducting diode exceeds 0.7 V
d. Non of the above

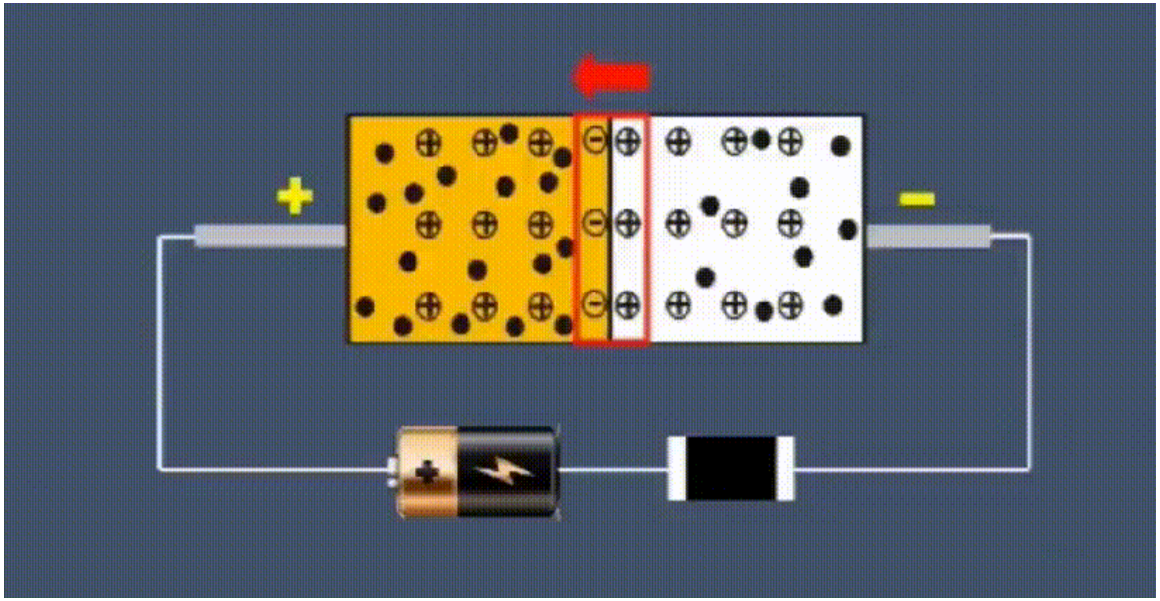
The diagram in figure 1 shows the energy band model for a p-type doped semiconductor. Which of the following statements is false?



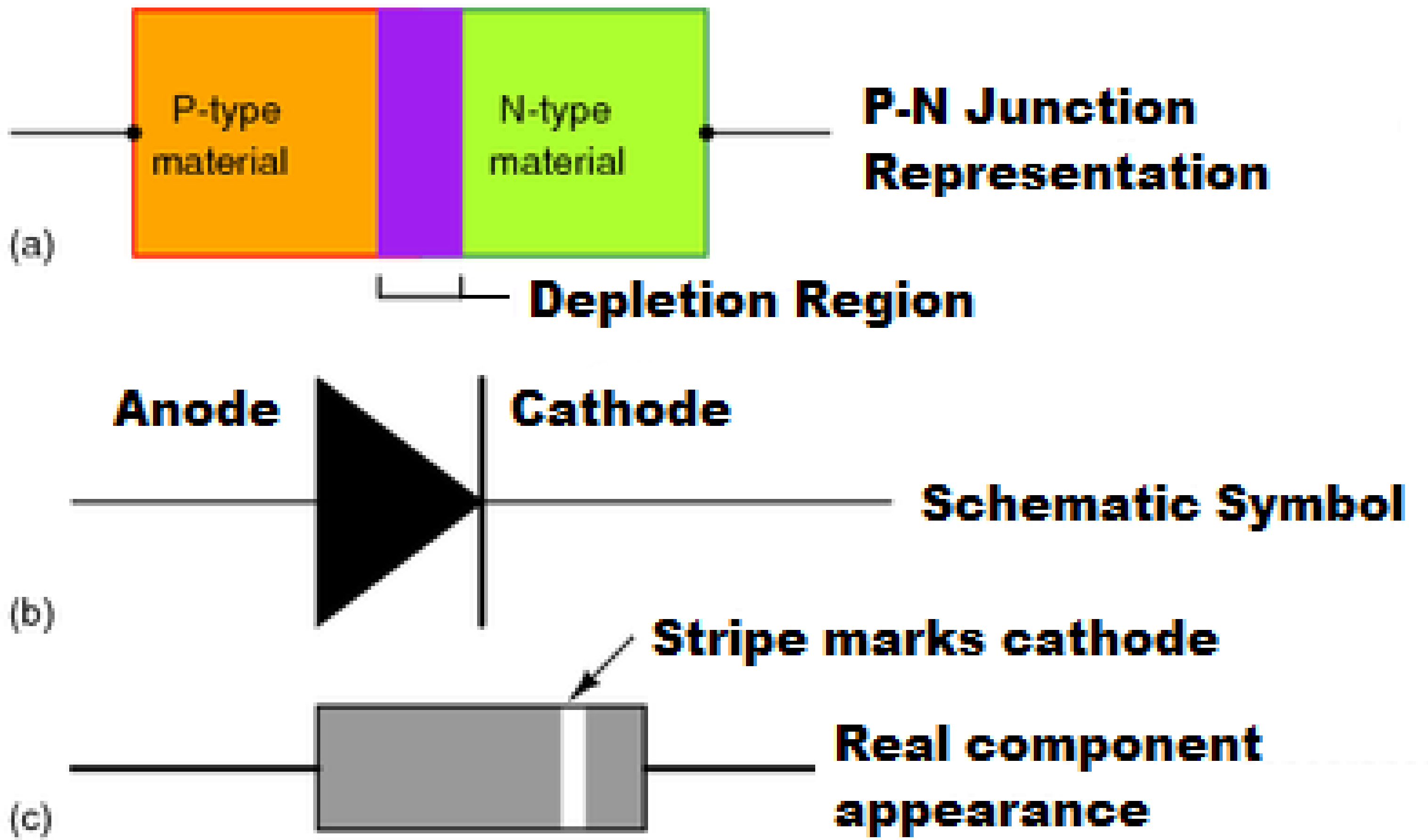
a) At 0 K an electron participating in a covalent bond is in a lower energy state in the valence band.
b) The acceptor atoms have unfilled covalent bonds with energy state E_A.
c) Movement of electrons to acceptor sites, complete covalent bond pairs, and create holes.
d) Movement of electrons to acceptor sites, break covalent bond pairs, and create holes.

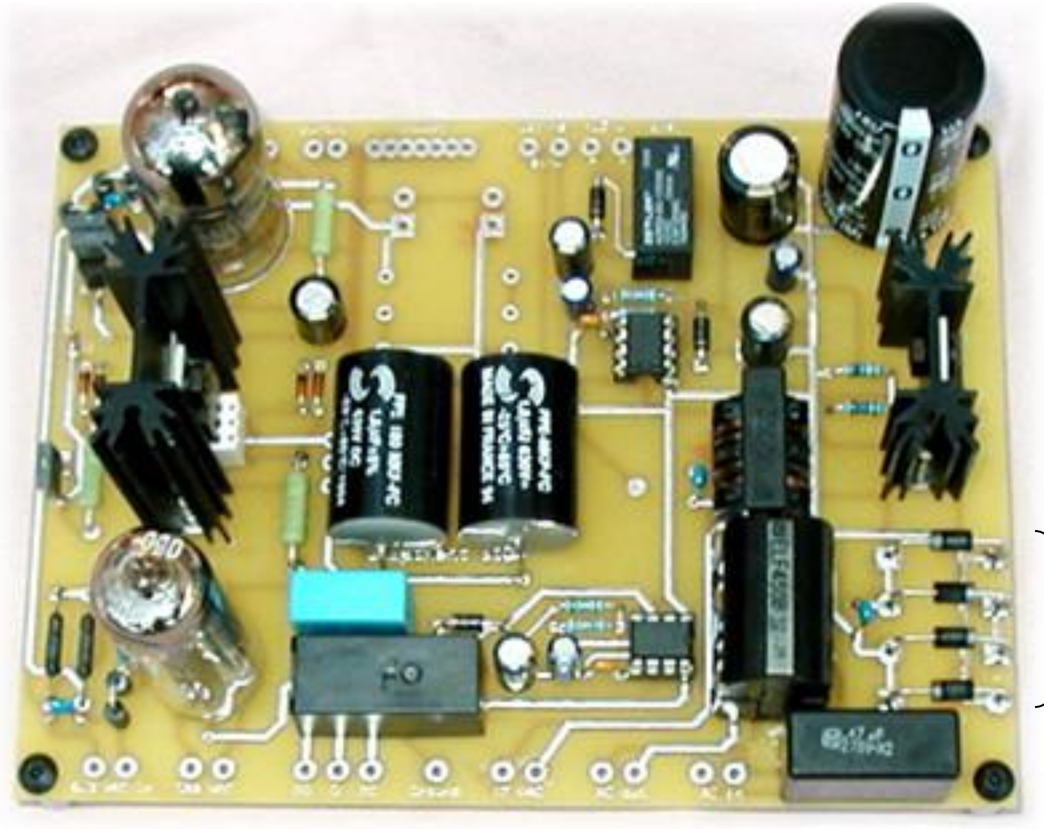
INTRODUCTION TO THE DIODE

The main function of a diode is to control the *direction* that current can flow in a circuit. It's sort of like a backflow preventor (or one-way valve) used in plumbing which only lets water flow in a single direction. In electronics we refer to this direction as the *forward direction*. Current that attempts to flow in the reverse direction is blocked.



The Physical Structure

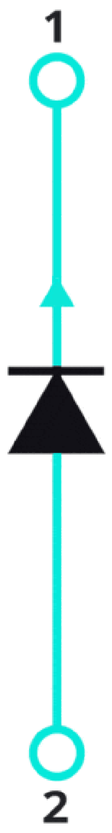


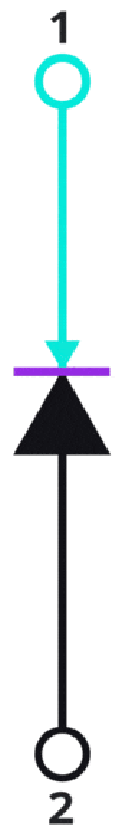


diode bridge

Characteristics

- Conducting in one direction and not in the other is the I-V characteristic of the diode.
- The arrowlike circuit symbol shows the direction of conducting current.
- Forward biasing voltage makes it turn on.
- Reverse biasing voltage makes it turn off.

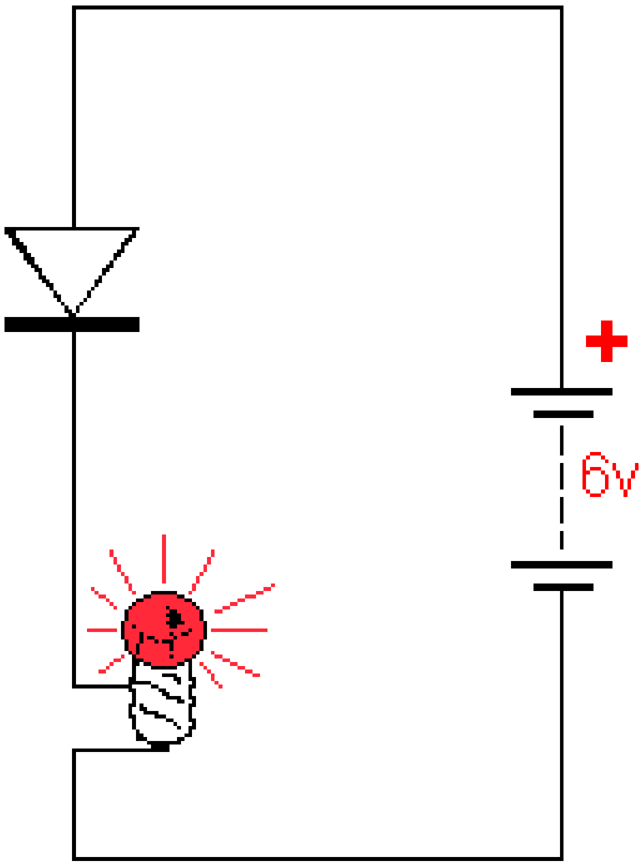




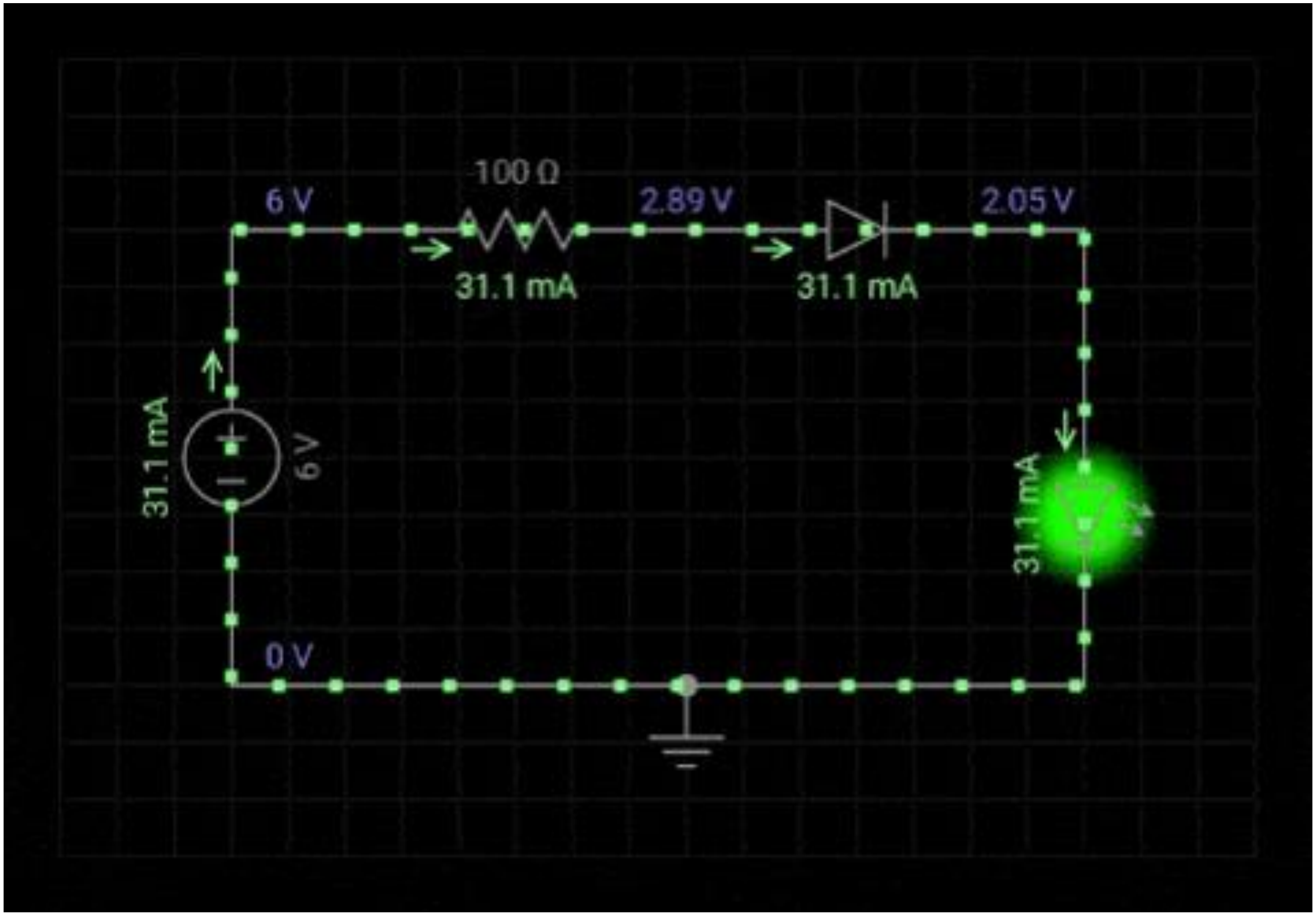
Diode symbol

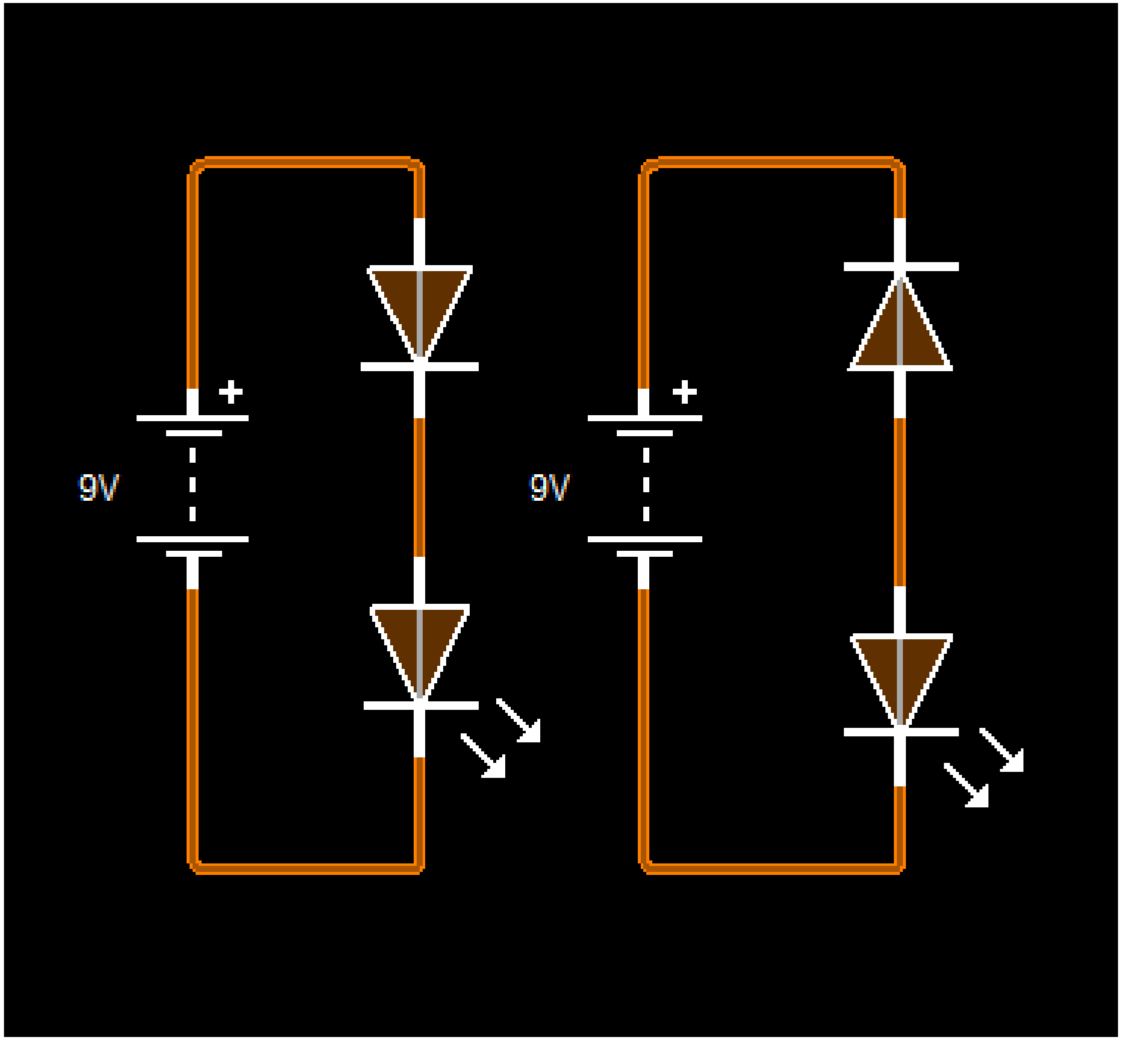
Actual symbol

REALPARS



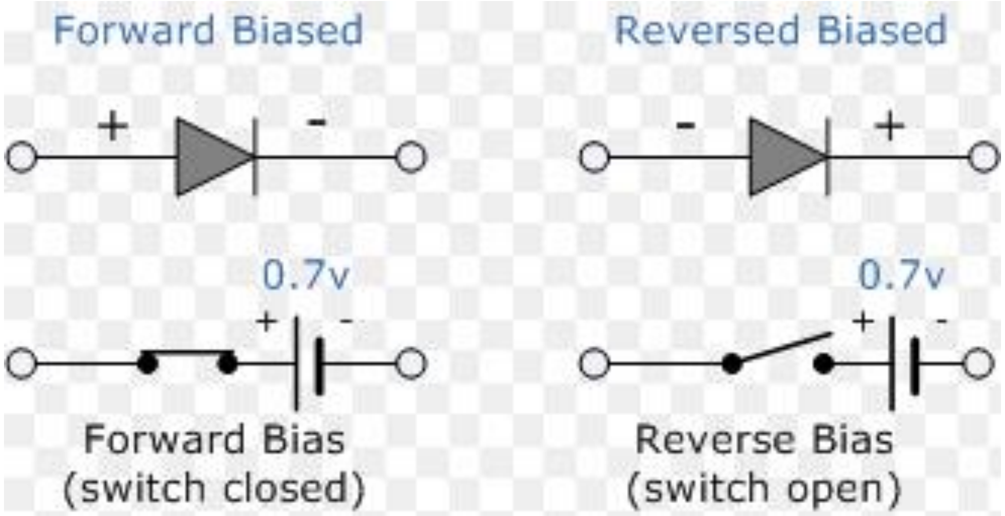
How a diode works


100 Ω
6 V
2.89 V
2.05 V
31.1 mA
31.1 mA
31.1 mA
6 V
31.1 mA
0 V


9V
9V

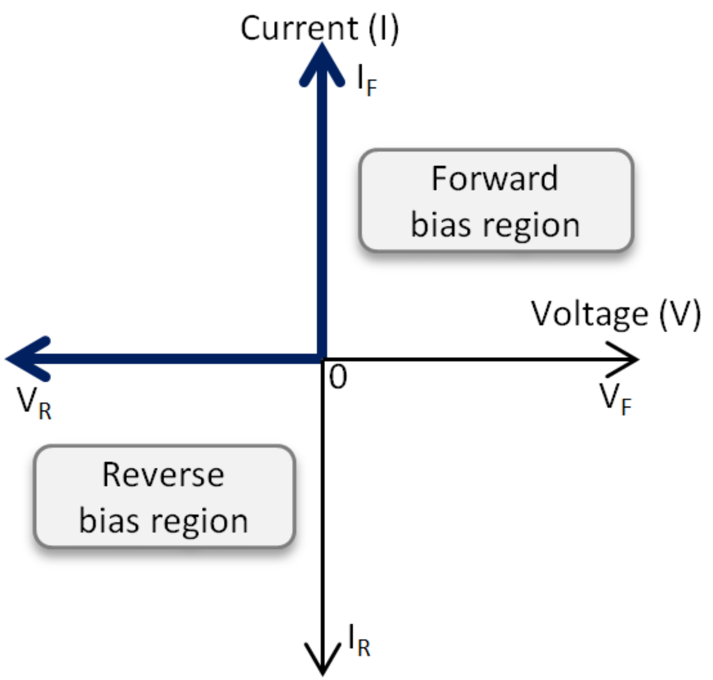
THE IDEAL DIODE

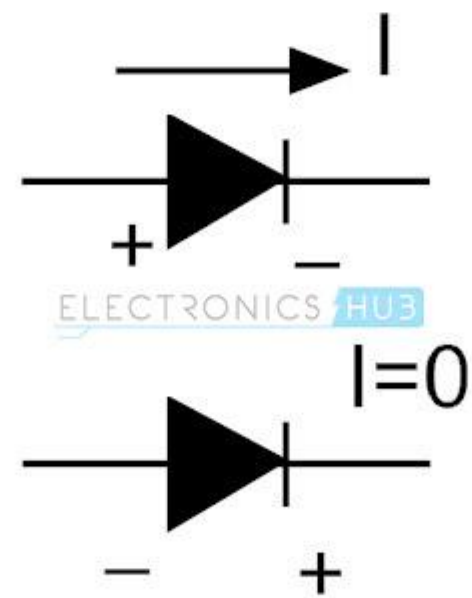
It is important to understand that there is no such thing (at least yet) as a perfect diode. A theoretical perfect diode is referred to as an *ideal* diode. In an ideal diode current flowing in the verse direction would react the same as an open circuit (open switch) and no current would pass.



THE IDEAL DIODE

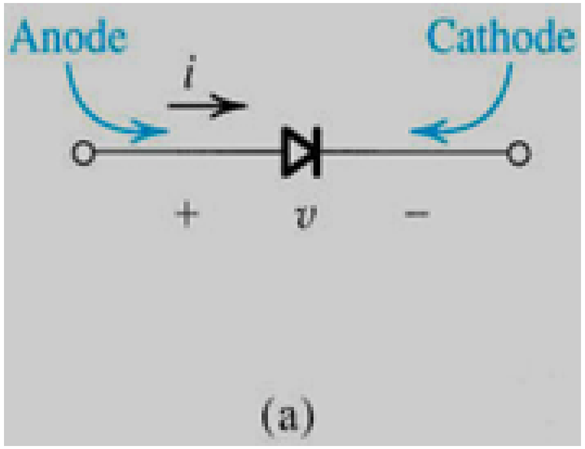
In order to understand the essence of diode function (diode behavior), we begin with a ‘’fictitious ‘’ element, the ideal diode. The ideal diode may be considered the most fundamental non-linear element. It is a two-terminal device having the circuit symbol



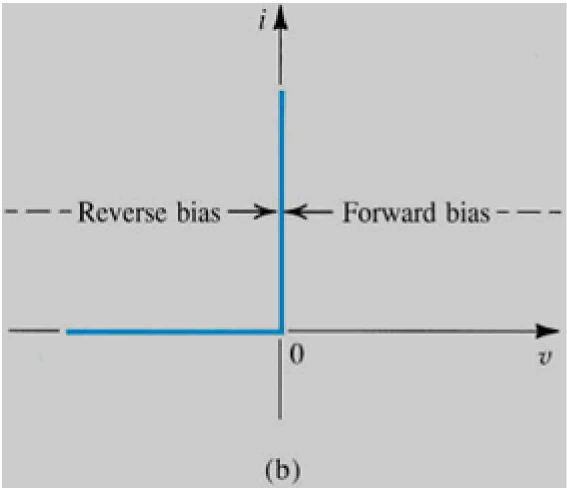


3.1 The ideal Diode

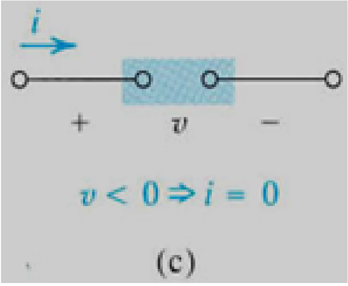
Current-Voltage characteristic



(a) diode circuit symbol

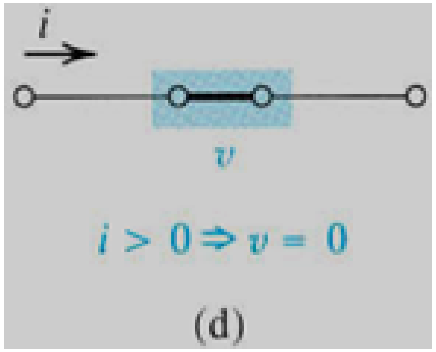


(b) *i–v* characteristic;



(c) equivalent circuit

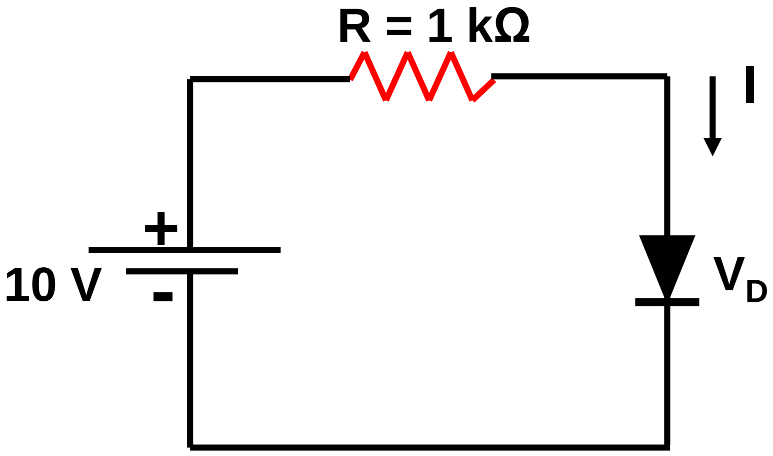
in the reverse direction;

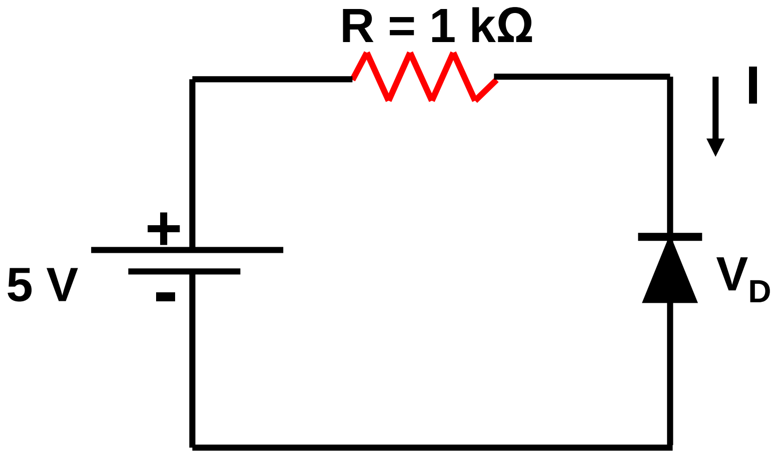


(d) equivalent circuit

in the forward direction.

Assume both diodes are ideal





diode is turned ON

Writing a loop equation yields:

$$10 - 0 = IR$$

$$I = \frac{10}{R} = \frac{10}{1} = 10mA$$

diode is turned of

Writing a loop equation yields:

$$V_D = 5\ \mathrm{V}$$

3.1 The ideal Diode

Current-Voltage characteristic

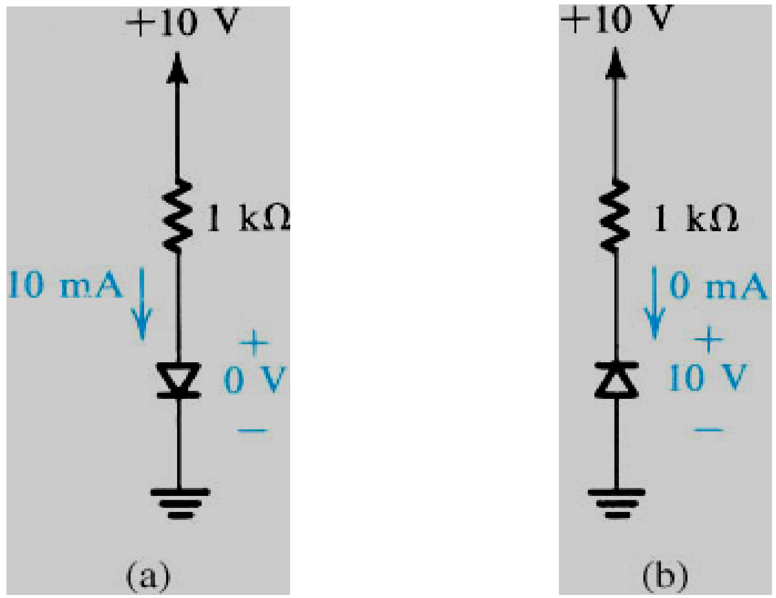
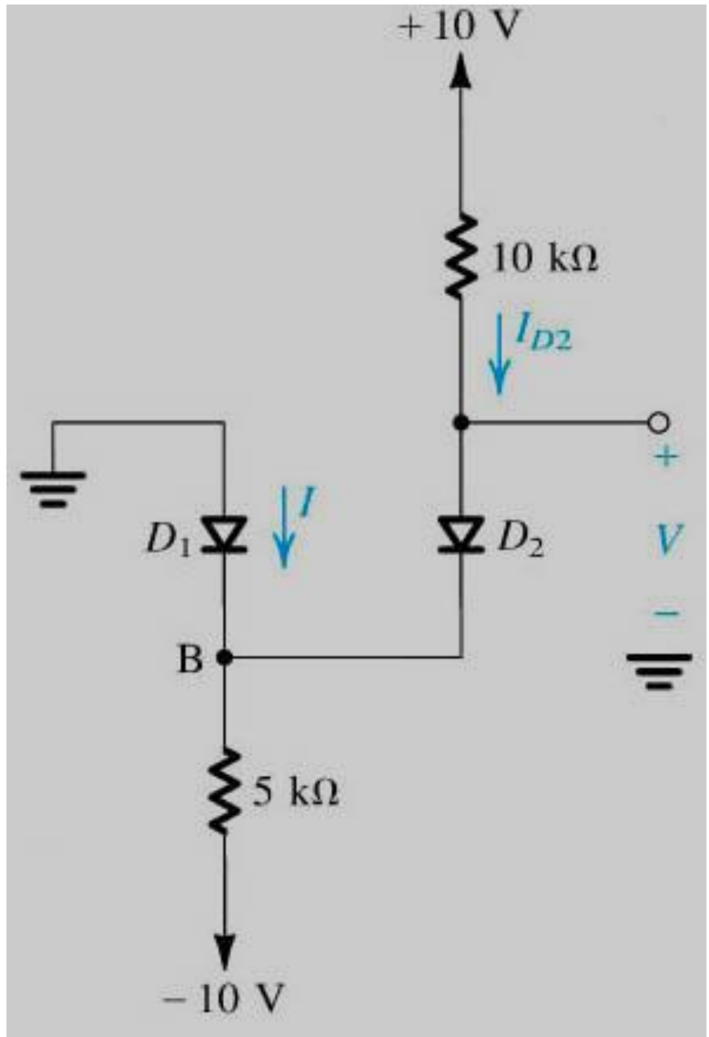


Figure 3.2 The two modes of operation of ideal diodes and the use of an external circuit to limit the forward current **(a)** and the reverse voltage **(b)**.

EXAMPLE 2

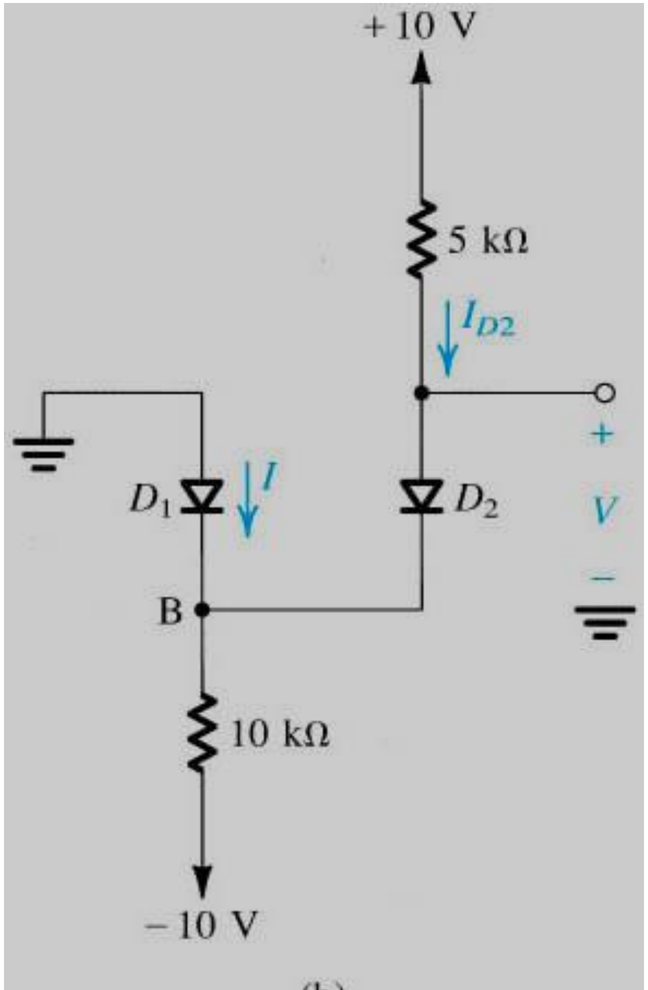
Assume the diodes in figure a and b are ideal. Find ***I*** and ***V***.



(a)

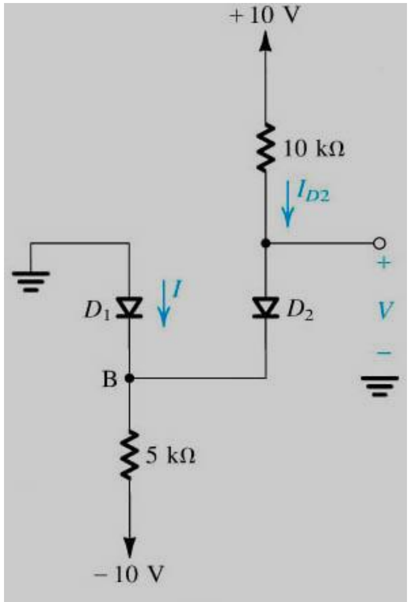
EXAMPLE 3

Assume the diodes in figure a and b are ideal. Find *I* and *V*.

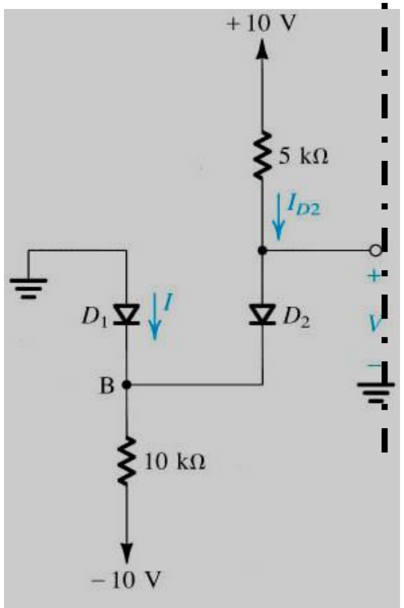


(b)

EXAMPLES



(a)



(b)

Assume the diodes in figure a and b are ideal. Find ***I*** and ***V***.

Sol) We don't know whether none, one, or both diodes are conducting.

Make a plausible assumption, proceed with the analysis, and then check whether we end up with a consistent solution !

(a) Assume that both diodes are conducting.

$$V_B = 0,\ V = 0 \qquad I_{D2} = \frac{10-0}{10} = 1\ \text{mA}$$

Writing a node equation at B, $I + I_{D2} = \dfrac{V_B - (-10)}{5}$

$$I + 1 = \frac{0-(-10)}{5},\quad I = 1\ \text{mA},\quad V = 0\ \text{V}$$

(b) Assume that both diodes are conducting.

$$V_B = 0,\ V = 0 \qquad I_{D2} = \frac{10-0}{5} = 2\ \text{mA}$$

Writing a node equation at B, $I + I_{D2} = \dfrac{V_B - (-10)}{10}$

$$I + 2 = \frac{0-(-10)}{10},\quad I = -1\ \text{mA}$$ Impossible !!

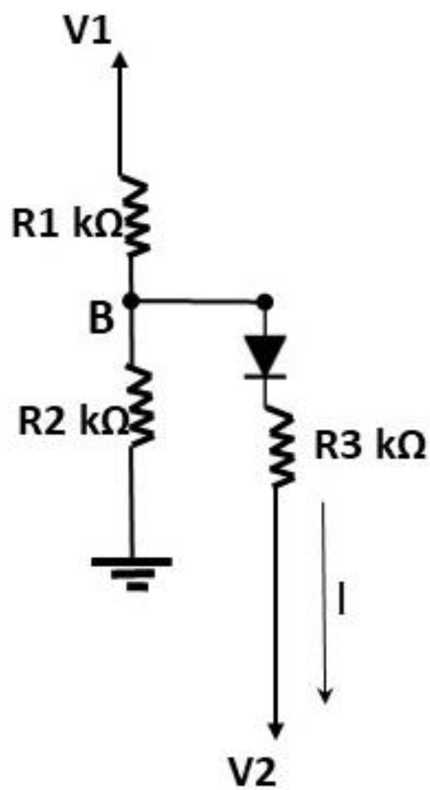
Assume that D_1 is off, and D_2 is on.

$$I_{D2} = \frac{10-(-10)}{15} = 1.33\ \text{mA}$$

$$V_B = -10 + 10 \times 1.33 = +3.3\ \text{V}$$

$$I = 0,\quad V = 3.3\ \text{V}$$

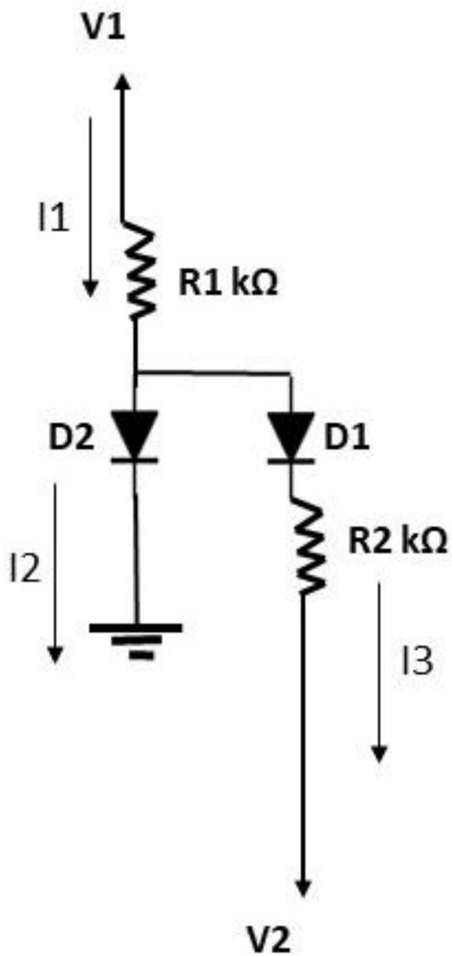
Quiz 1



The circuit in the figure, has V1 = 20 V, V2 = -10 V, R1 = 20 kΩ, R2 = 20 kΩ and R3 = 20 kΩ determine the voltage at node B,

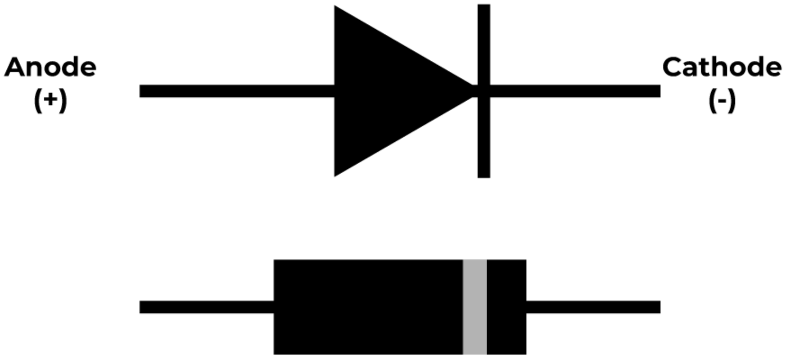
Assume the diodes are ideal

Quiz 2

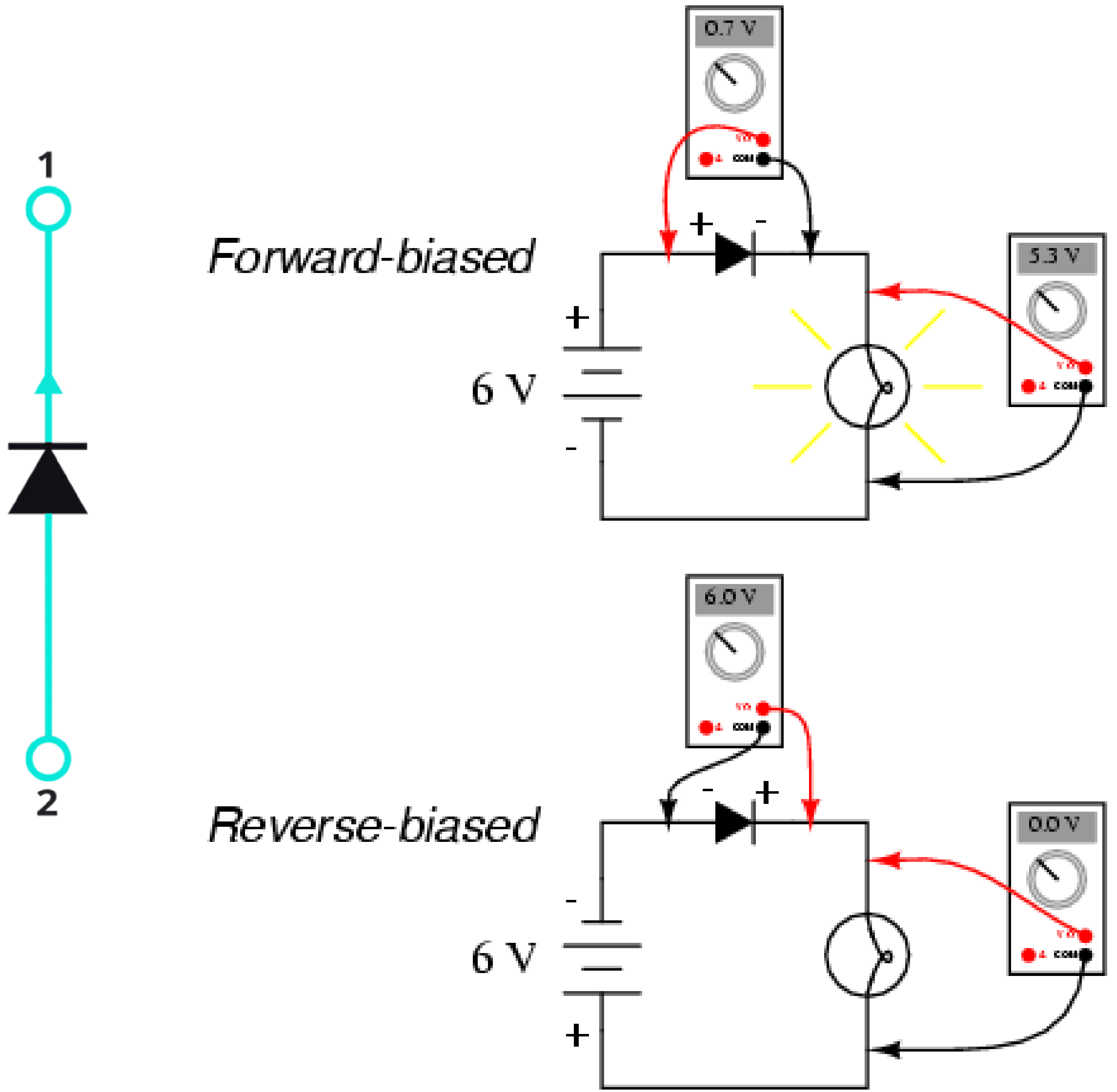


Referring to the circuit shown. If the diodes D1 and D2 are ideal, find the value of the current I2. Take V1 = 15 V, V2 = -10 V, R1 = 5 kΩ, R2 = 10 kΩ

if the diode D2 is reverse biased, what would be the value of the current I3

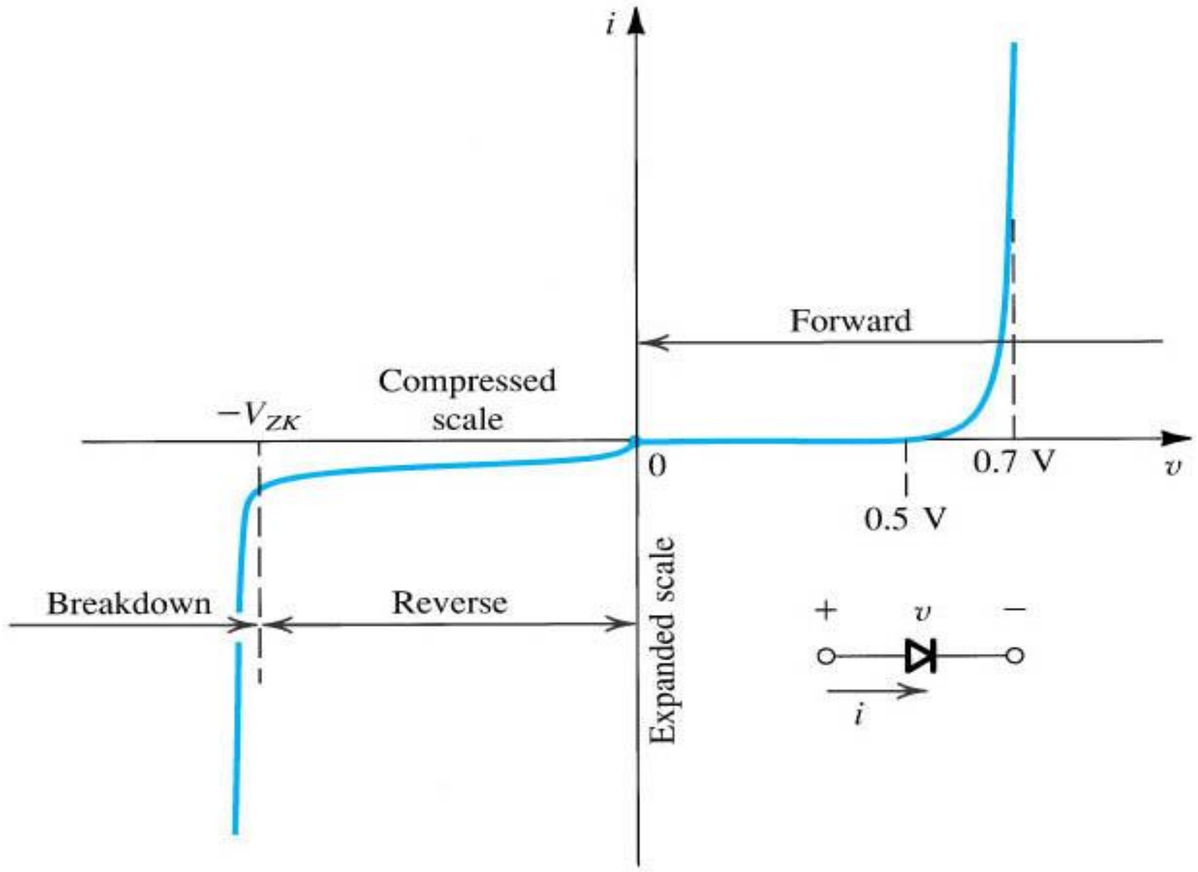


THE REAL DIODE



1
2
Forward-biased
0.7 V
5.3 V
6 V
Reverse-biased
6.0 V
0.0 V
6 V

I-V Characteristics

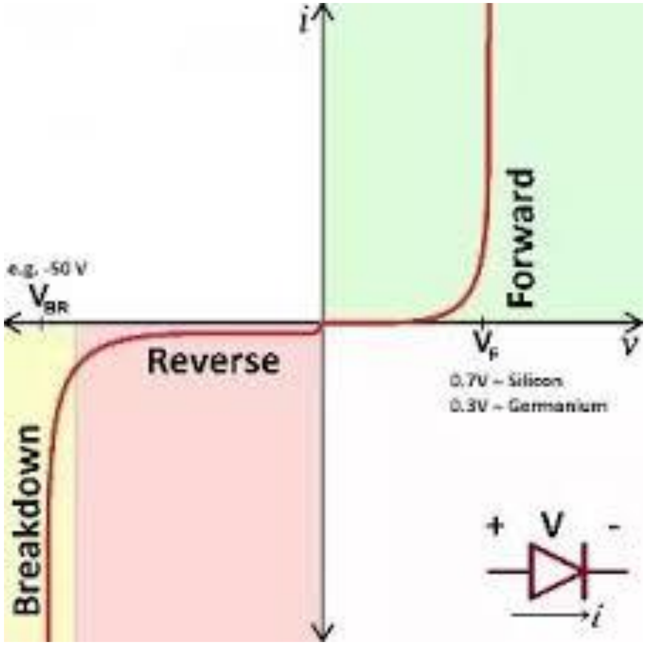


The diode *i–v* relationship with some scales expanded and others compressed in order to reveal details

I-V Characteristic Curve

Terminal Characteristic of Junction Diodes

- The Forward-Bias Region, determined by $v > o$
- The Reverse-Bias Region, determined by $-V_{ZK} < v < 0$
- The Breakdown Region, determined by $v < -V_{ZK}$



The *pn* Junction Under Forward-Bias Conditions

I-V characteristic equation:

$$\boxed{i = I_s\left(e^{v/nV_T} - 1\right)}$$

V

- Exponential relationship, nonlinear.
- I_s is called saturation current, strongly depends on temperature.
- $n = 1$ or 2， in general $n = 1$
- V_T is thermal voltage.

$$\boxed{V_T \equiv \frac{kT}{q}}$$

where *k* is the Boltzmann constant, *T* is the absolute temperature of the p–n junction, and *q* is the magnitude of charge of an electron (the elementary charge)

Ideal Current-Voltage Relationship

- So, the current i_D is

$$\boxed{i_D = I_S\left[e^{\left(\frac{v_D}{nV_T}\right)} - 1\right]}$$

I_S = the reverse-bias saturation current (for silicon 10^{-15} to 10^{-13} A)

V_T = the thermal voltage (0.026 V at room temperature)

n = the emission coefficient ($1 \le n \le 2$)

Ideal Current-Voltage Relationship

Example
Determine the current in a pn junction diode.
Consider a pn junction at T = 300 K in which $I_S = 10^{-14}$ A and n = 1.
Find the diode current for v_D = +0.70 V and v_D = -0.70 V.

Solution: For $v_D = +0.70\,\text{V}$, the pn junction is forward-biased and we find

$$i_D = I_S\left[e^{\left(\frac{v_D}{V_T}\right)} - 1\right] = (10^{-14})\left[e^{\left(\frac{+0.70}{0.026}\right)} - 1\right] \Rightarrow 4.93\,\text{mA}$$

For $v_D = -0.70\,\text{V}$, the pn junction is reverse-biased and we find

$$i_D = I_S\left[e^{\left(\frac{v_D}{V_T}\right)} - 1\right] = (10^{-14})\left[e^{\left(\frac{-0.70}{0.026}\right)} - 1\right] \cong -10^{-14}\,\text{A}$$

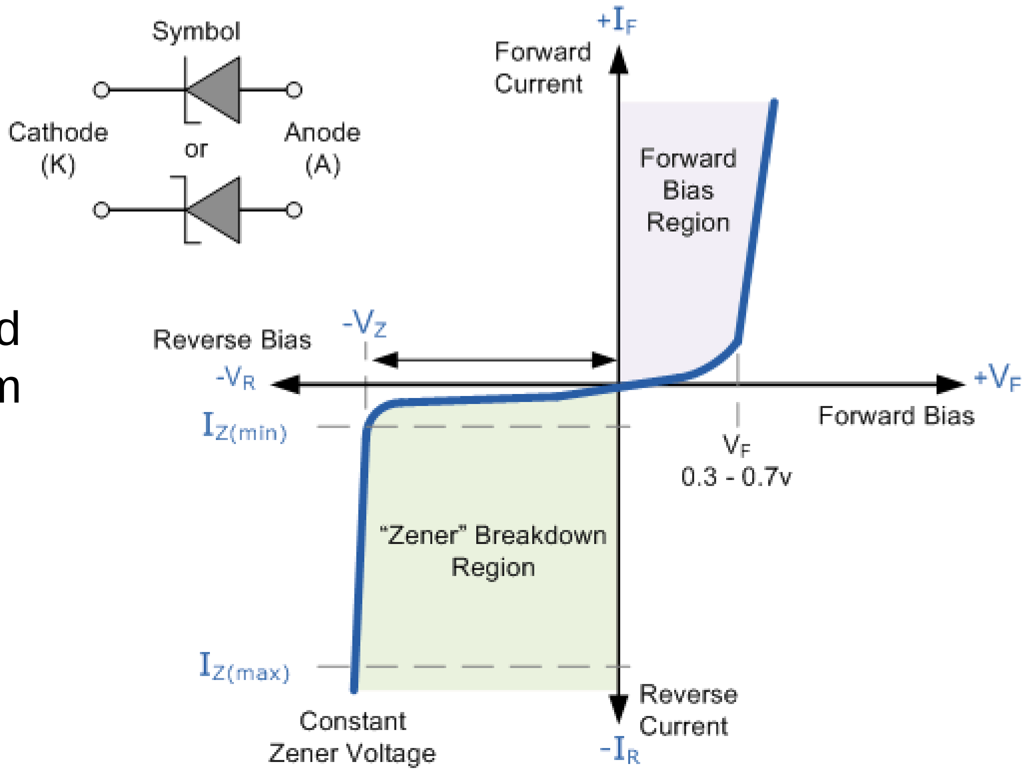
Very small current

For appreciable current in the forward direction, ($i >> I_s$)

$$i = I_S\left(e^{V/nV_T}\right)$$

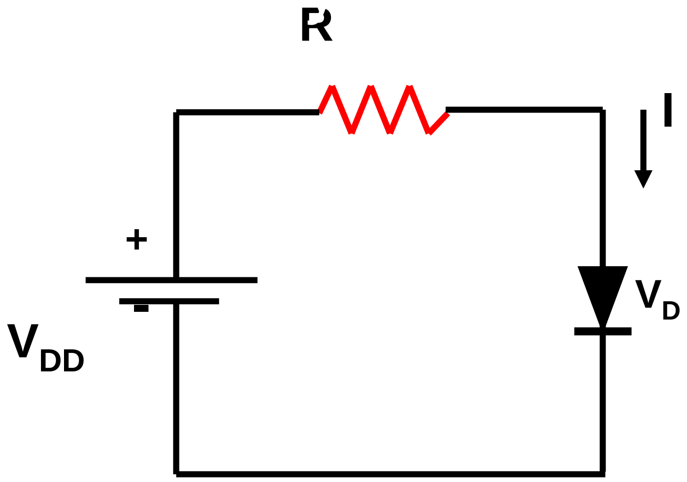
This relationship can be expressed alternatively in the logarithmic form

$$v = nV_T \ln\left(\frac{i}{I_S}\right)$$



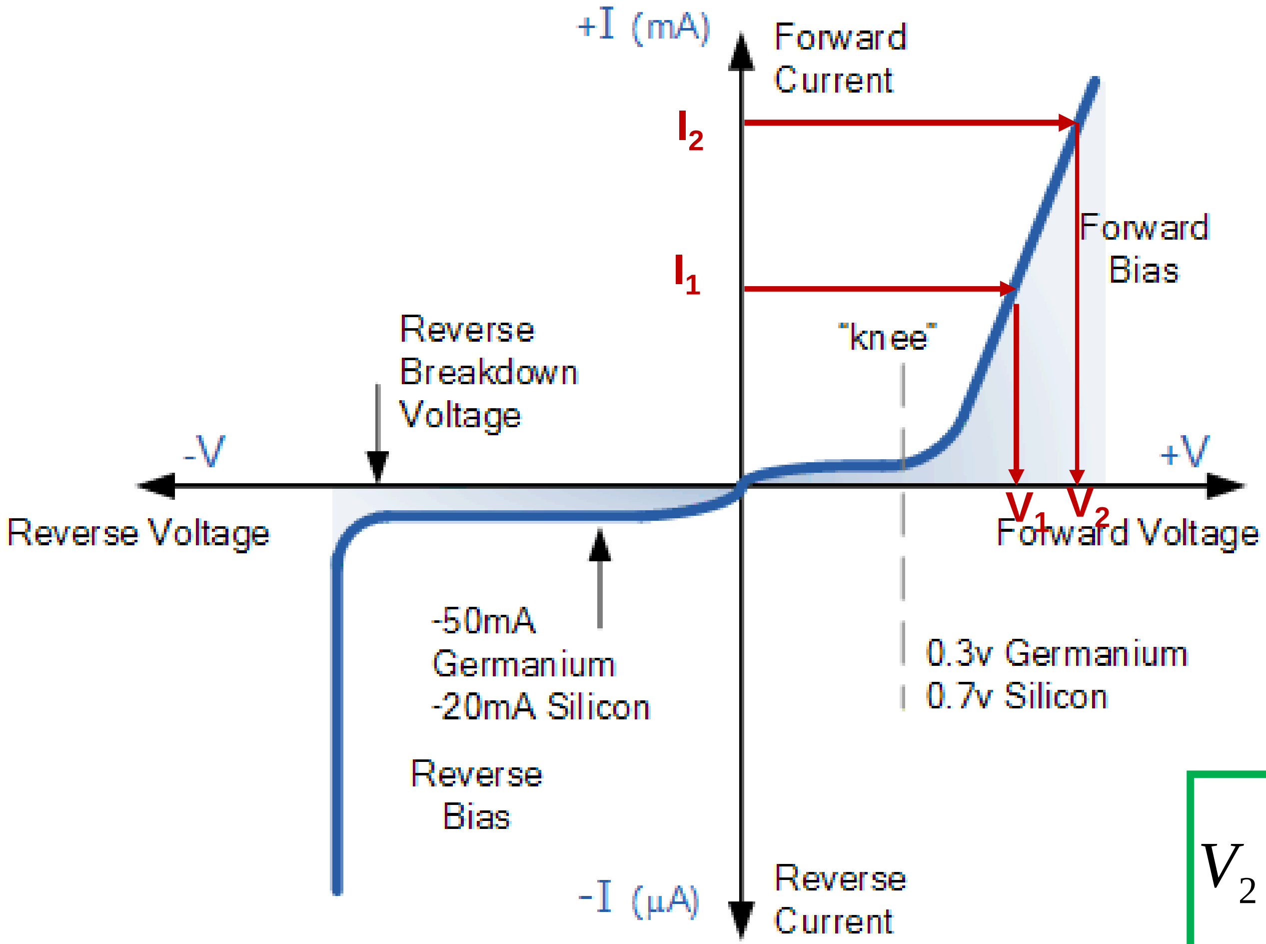
Example

Determine the current I_D and the diode voltage V_D for the circuit in Figure 5. With V = 5 V and R = 1 kΩ.



$$i = I_S\left(e^{V/nV_T}\right)$$

Assuming V_1 at I_1 and V_2 at I_2 then:



$$I_1 = I_S\left(e^{V_1/nV_T}\right)$$

$$I_2 = I_S\left(e^{V_2/nV_T}\right)$$

$$\frac{I_2}{I_1} = \frac{e^{V_2/nV_T}}{e^{V_1/nV_T}} = e^{(V_2-V_1)/nV_T}$$

$$V_2 - V_1 = nV_T \ln\frac{I_2}{I_1}$$

$$V_2 - V_1 = 2.3nV_T \log_{10}\frac{I_2}{I_1}$$

The *pn* Junction Under Forward-Bias Conditions

$$V_2 - V_1 = 2.3nV_T \log_{10} \frac{I_2}{I_1}$$

Let I_1 = 1 mA, and I_2 = 10 mA

$$V_2 - V_1 = 2.3nV_T \log_{10} \frac{10}{1} \equiv 2.3nV_T$$

Thus, for a decade (factor of 10) change in current, the diode voltage drop changes by $2.3nV_T$ which is approximately *60mv (for n=1) or 120mv (for n=2).*

The *pn* Junction Under Forward-Bias Conditions

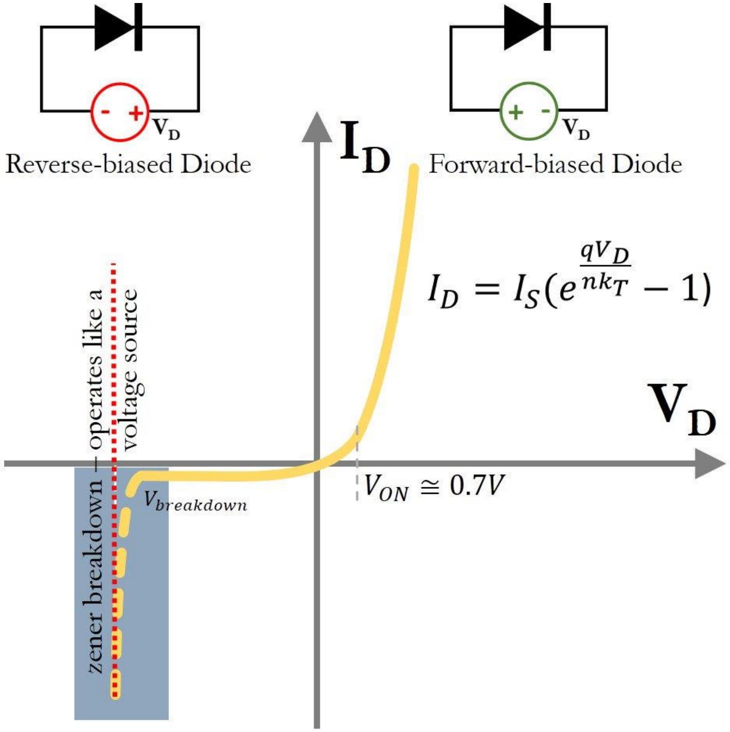
- **Turn-on voltage**

A conduction diode has approximately a constant voltage drop across it. It's called turn-on voltage.

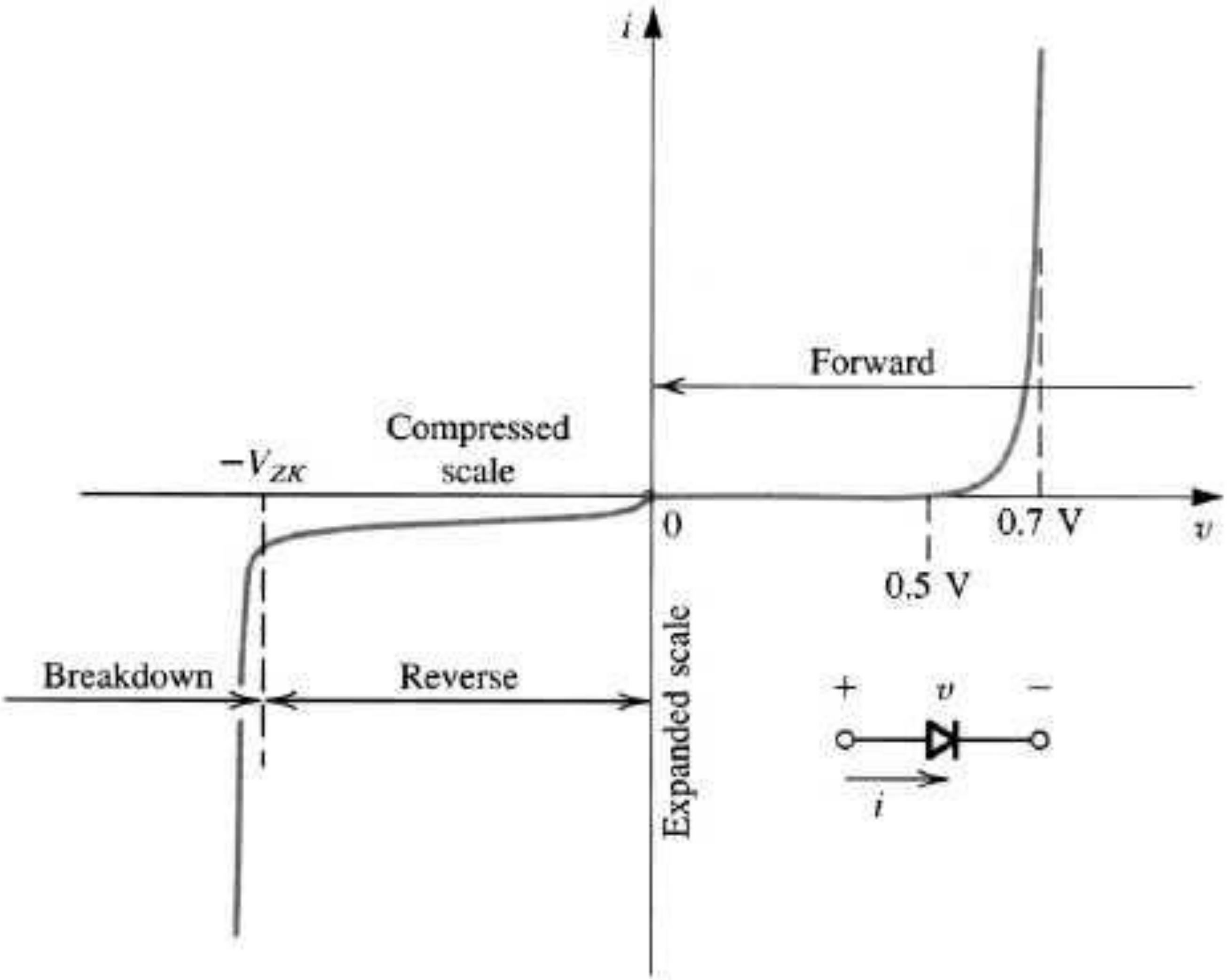
$$V_{D(on)} = 0.7V$$ For silicon

$$V_{D(on)} = 0.25V$$ For germanium

Diodes with different current rating will exhibit the turn-on voltage at different currents.



The experimental I-V characteristic of a Si diode



The diode i–v relationship with some scales expanded and others compressed in order to reveal details.

Diode Analyses: The Diode Models

Circuit Model

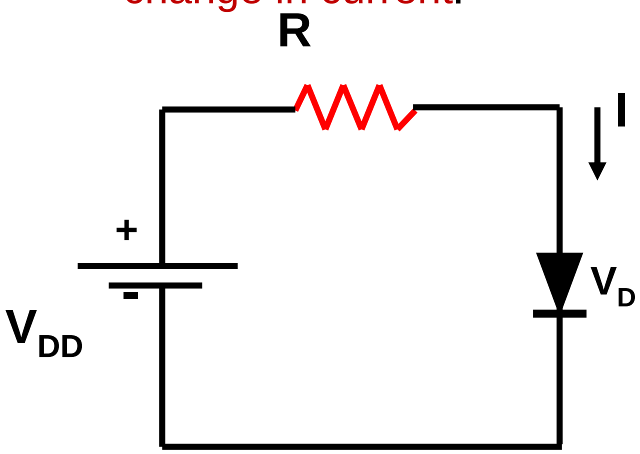
a) Piece wise linear model

b) The constant-voltage-drop model

c) Iterative analysis

Example

Determine the current I_D and the diode voltage V_D for the circuit in Figure 5. With V = 5 V and R = 1 kΩ. Assume that the diode has a current of 1 mA at a voltage of 0.7 V, and that its voltage drop changes by 0.1 V for every decade change in current.



voltage drop changes by 0.1 V for every decade change in current.
≡2.3 nV_T = 0.1 V

$$\boxed{V_{DD} = I_D R + V_D}$$

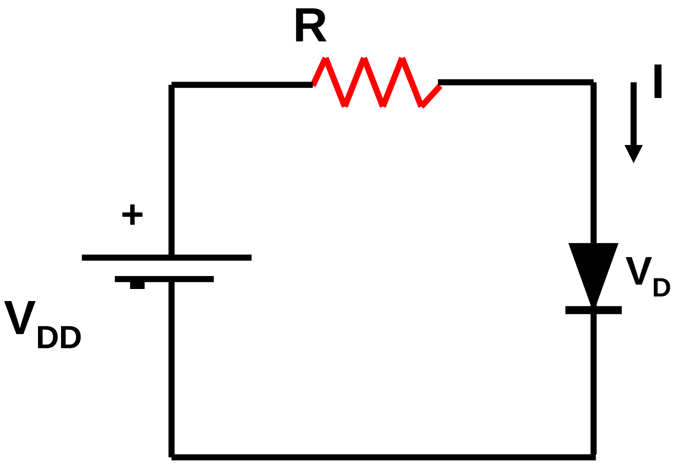
$$\boxed{I_D = \frac{(V_{DD} - V_D)}{R}}$$

$$\boxed{V_2 - V_1 = 2.3 n V_T \log_{10} \frac{I_2}{I_1}}$$

$$\boxed{V_2 = V_1 + 0.1 \log_{10} \frac{I_2}{I_1}}$$

First iteration

Determine the current I_D and the diode voltage V_D for the circuit in Figure 5. With V = 5 V and R = 1 kΩ. Assume that the diode has a current of 1 mA at a voltage of 0.7 V, and that its voltage drop changes by 0.1 V for every decade change in current.



To begin the iteration we assume that V_D = 0.7 V and use the equation below to determine the current.

I_1= 1 mA , V_1 = 0.7 V

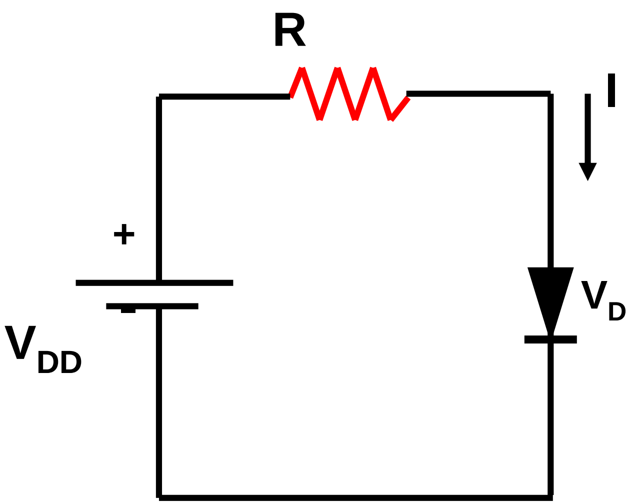
$$\boxed{I_D = \frac{(V_{DD} - V_D)}{R} = \frac{(5 - 0.7)}{1k\Omega} = 4.3mA \equiv I_2}$$

We then use the diode equation shown below to obtain a better estimate for V_D

$$\boxed{V_2 = V_1 + 0.1\log_{10}\frac{I_2}{I_1}}$$

Substituting V_1 = 0.7 V, I_1 = 1 mA, and I_2 = 4.3 mA results in V_2 = 0.763. Thus the results of the first iteration are I_D = 4.3 mA and V_D = 0.763 V

Second Iteration



Thus the results of the first iteration are I_D = 4.3 mA and V_D = 0.763 V. the second iteration proceeds in a similar manner: But this time I_1 = 4.3 mA and V_1 = 0.763 V.

$$I_D = \frac{(V_{DD} - V_D)}{R} = \frac{(5 - 0.763)}{1k\Omega} = 4.237mA$$

$$V_2 = 0.763 + 0.1\log_{10}\frac{4.237}{4.3} = 0.762$$

Thus, the second iteration yields I_D = 4.237 mA and V_D = 0.762V. Since these values are not much different from the values obtained after the first iteration, no further iterations are necessary, and the solution is I_D = 4.237 mA and V_D = 0.762V.

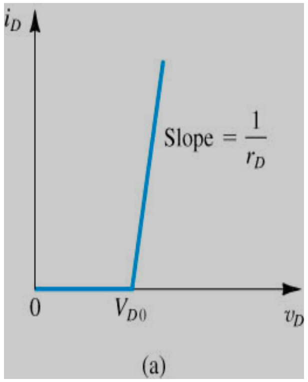
3.3.4 The need for Rapid Analysis

* ***In design process***, rapid circuit analysis is necessary, not in the final conformation process.
* In the final conformation process, SPICE is the best choice.

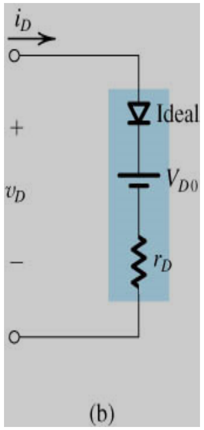
3.3.5 The Piecewise-Linear model

$$i_D = 0, \quad \upsilon_D \le V_{D0}$$

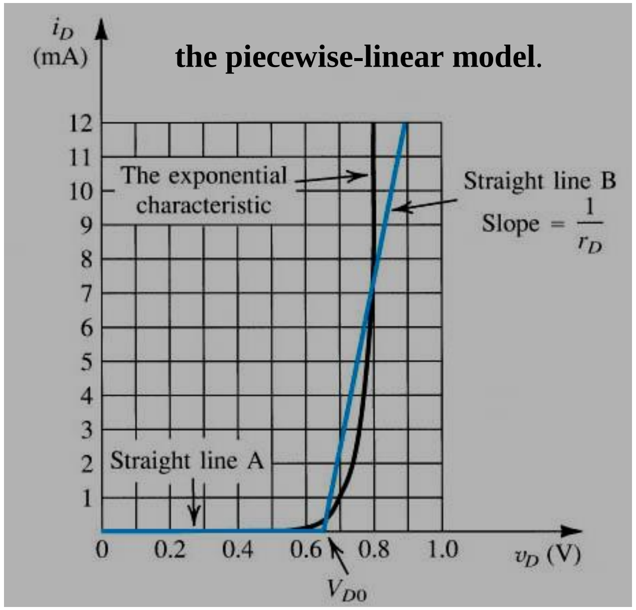
$$i_D = (\upsilon_D - V_{D0})/r_D, \quad \upsilon_D \ge V_{D0} \qquad (3.8)$$



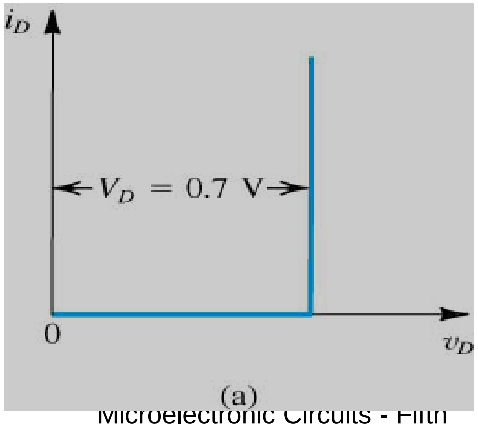
(a)



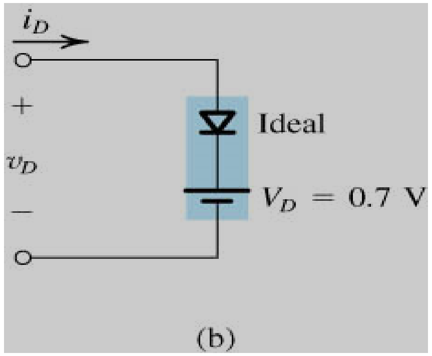
(b)



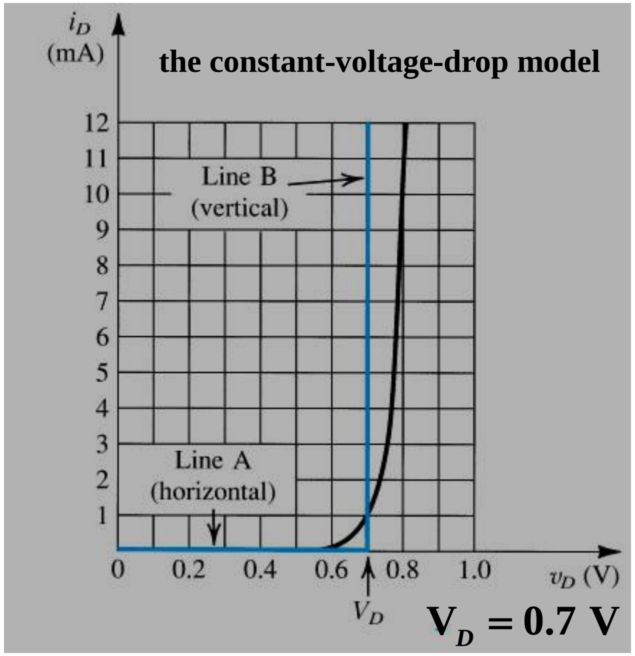
3.3.6 The Constant-Voltage-Drop model



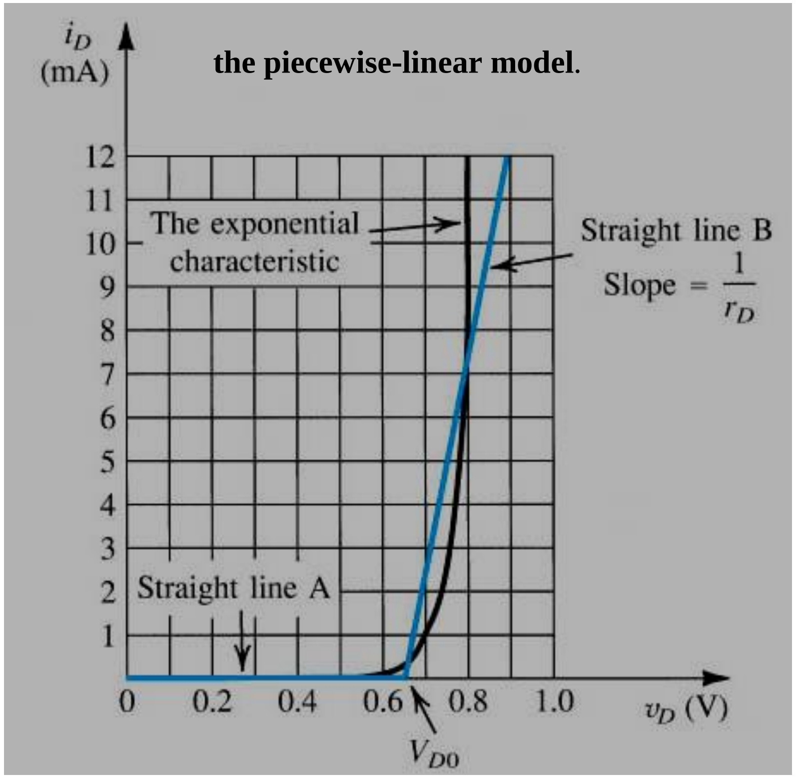
(a)

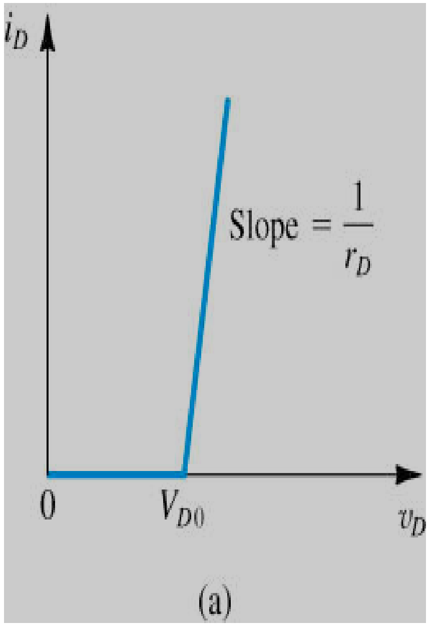


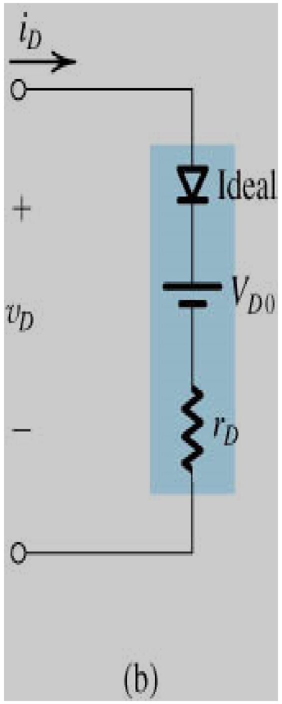
(b)



Piecewise linear model



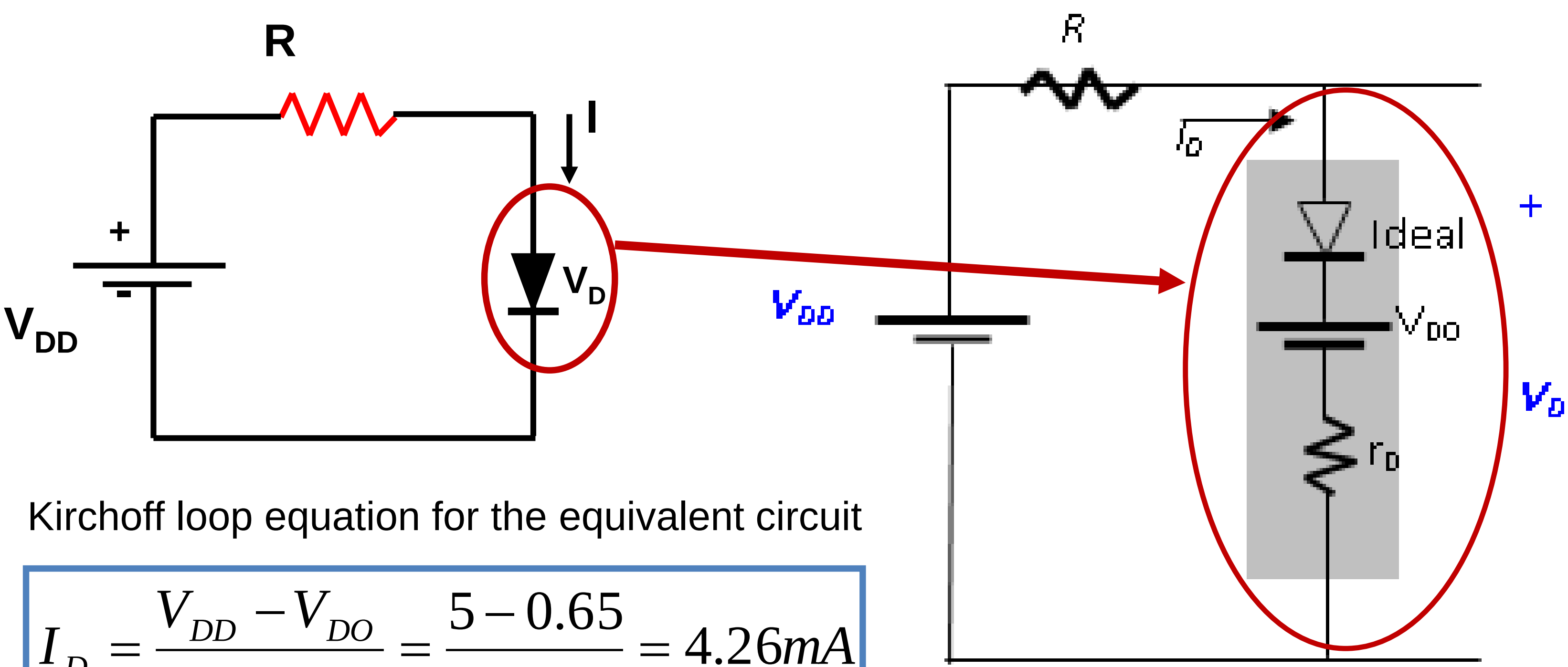




Where V_{DO} is the intercept of line B on the voltage axis and r_D is the inverse of the slope of line B. For the particular example shown, V_{DO} = 0.65 V and r_D = 20 Ω.

Example 2

Repeat the problem solved earlier with iterative analysis, utilizing the piecewise-linear model. (Take V_{DO} = 0.65 V and r_D = 20 Ω)



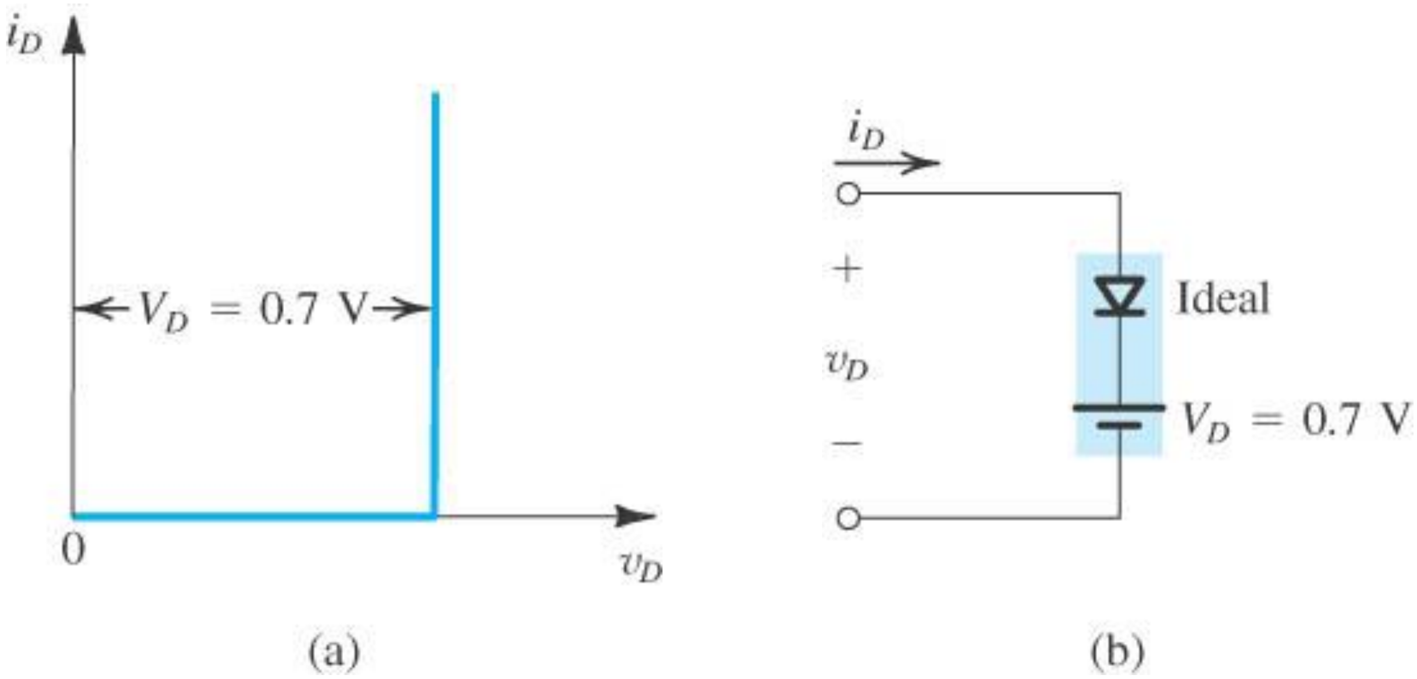
Kirchoff loop equation for the equivalent circuit

$$I_D = \frac{V_{DD} - V_{DO}}{R + r_D} = \frac{5 - 0.65}{1 + 0.02} = 4.26mA$$

The diode voltage can now be:

$$V_D = V_{DO} + I_D r_D = 0.65 + 4.26 \times 0.02 = 0.735V$$

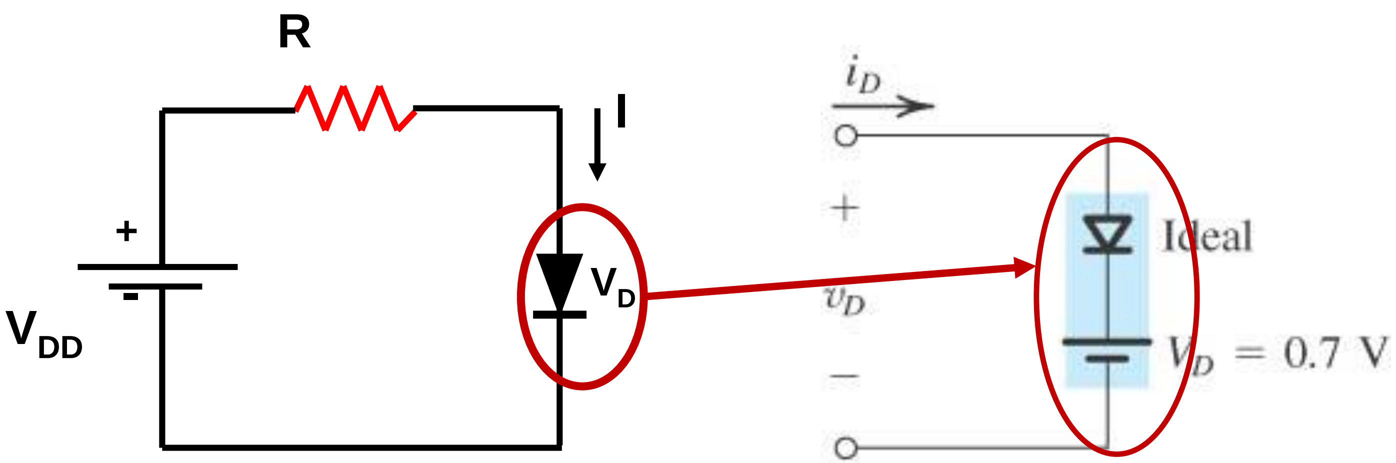
The Constant-Voltage-Drop Model



The constant-voltage-drop model of the diode forward characteristics and its equivalent-circuit representation.

Example 3

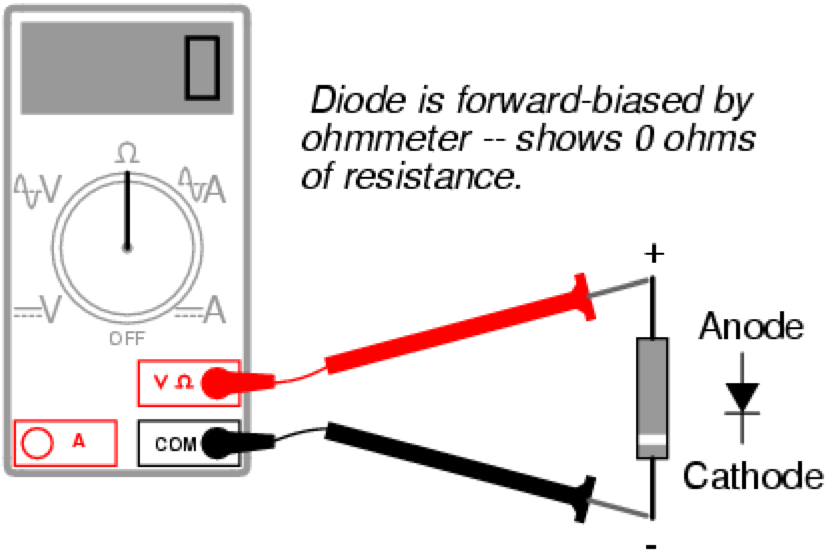
Determine the current I_D and the diode voltage V_D for the circuit in Figure 5. With V = 5 V and R = 1 kΩ.



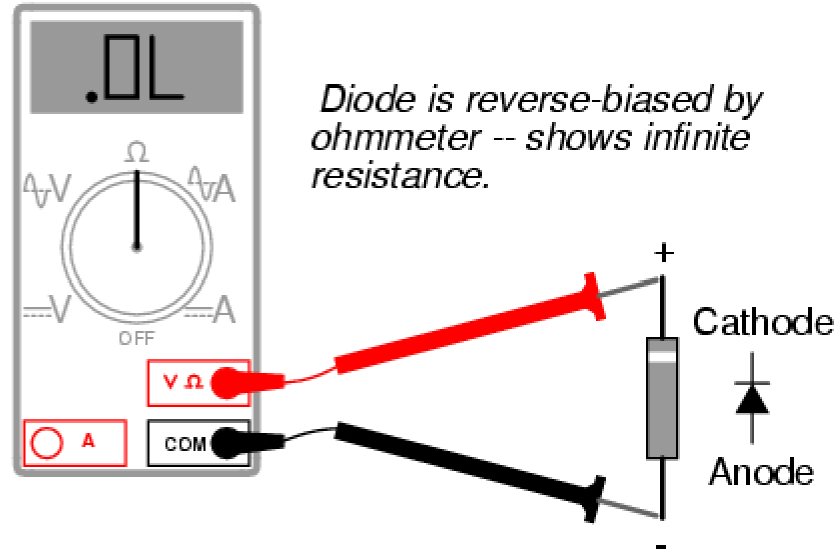
Let's solve the same problem using the constant-drop-voltage model. We obtain;

$$\boxed{I_D = \frac{V_{DD} - 0.7}{R} = \frac{5 - 0.7}{1} = 4.3mA}$$

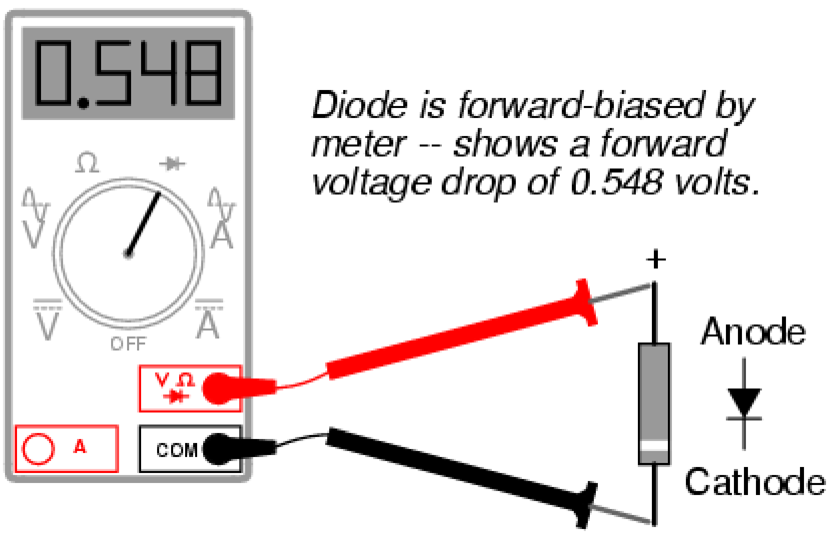
Testing a diode



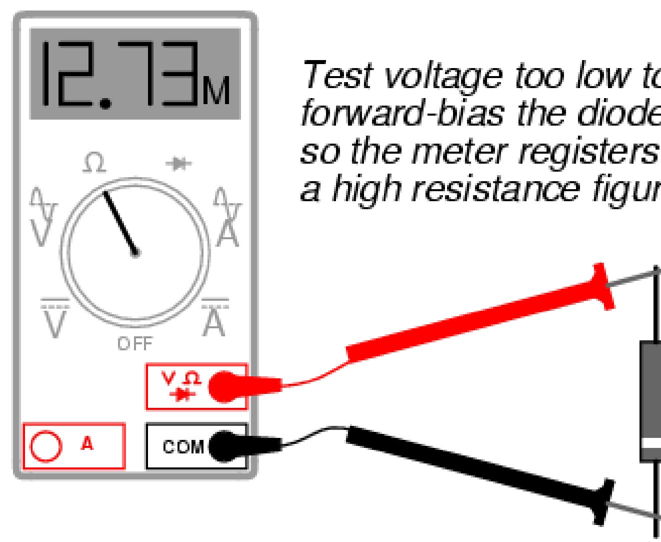
Diode is forward-biased by ohmmeter -- shows 0 ohms of resistance.



Diode is reverse-biased by ohmmeter -- shows infinite resistance.



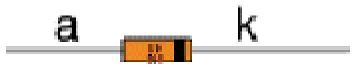
Diode is forward-biased by meter -- shows a forward voltage drop of 0.548 volts.

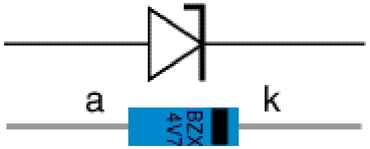


Test voltage too low to forward-bias the diode, so the meter registers a high resistance figure.

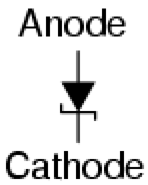
Types of diodes

- **<u>Rectifier diodes</u>**
- Designed to carry high current necessary in power supplies.
- **<u>Signal diodes</u>**
- Optimized for speed, they are used in low current and switching applications.
- **<u>Zener diode</u>**
- Designed to conduct in the reverse direction with a precise breakdown voltage, they are used in power supply regulation.

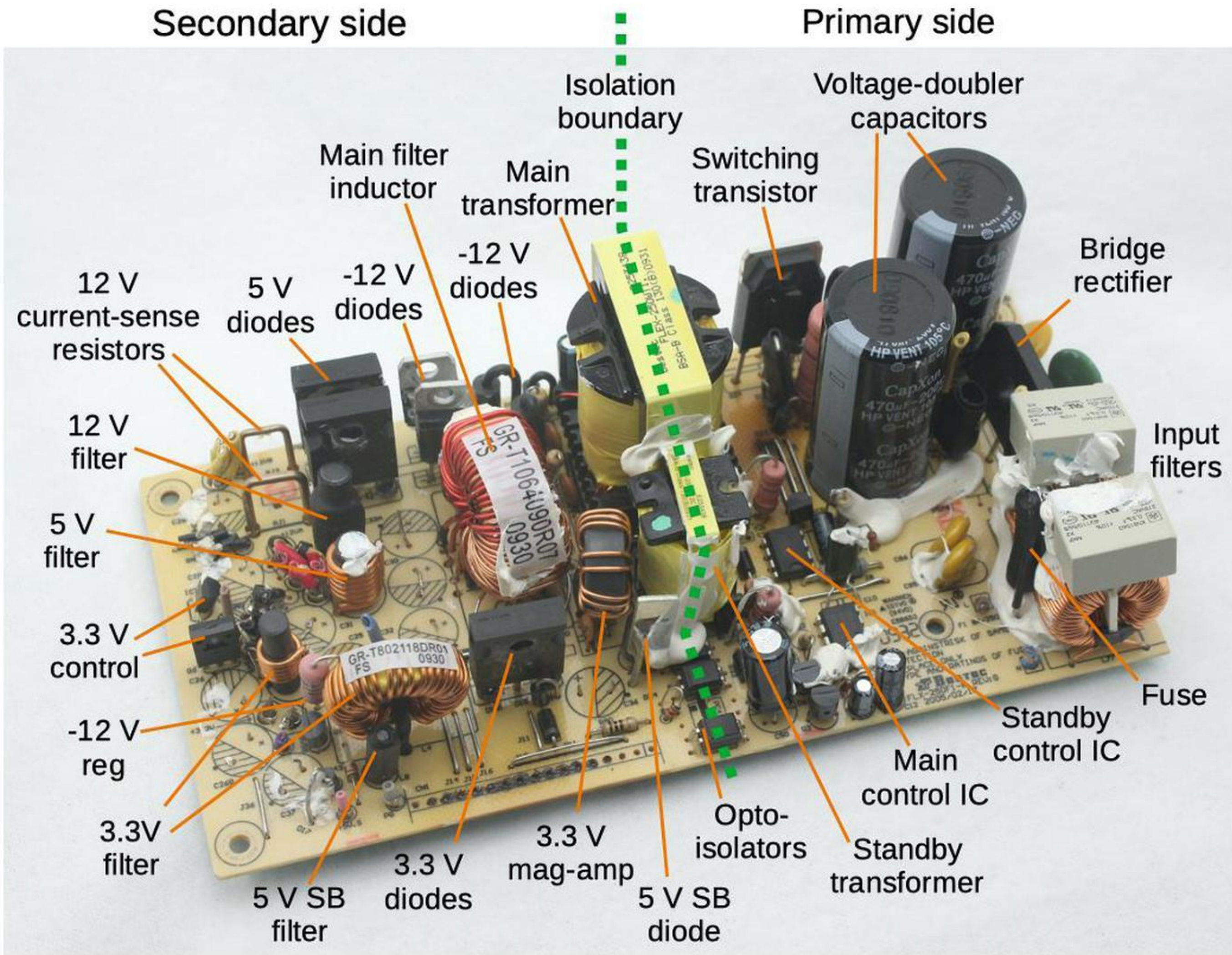




Zener diode

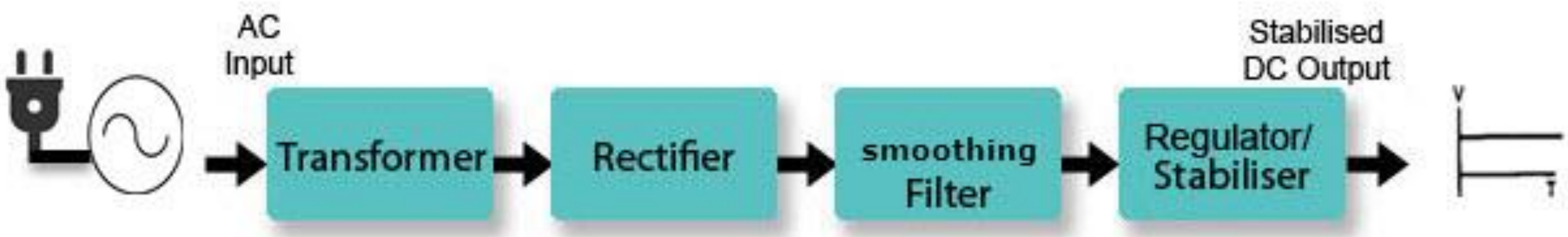


A simple application of the diode



DC Power Supply Unit

Rectification: converting AC to DC

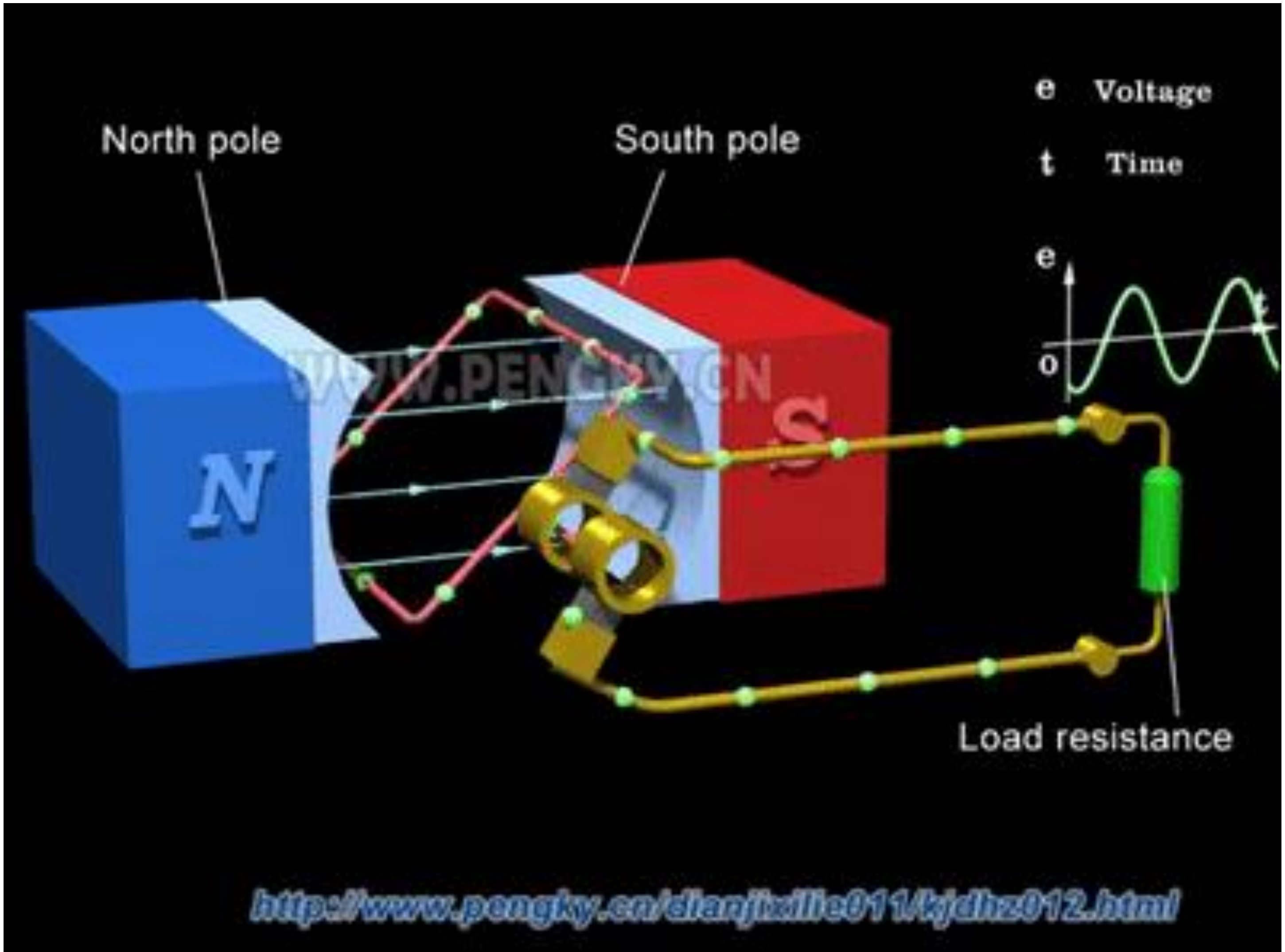


Power Supply Block Diagram

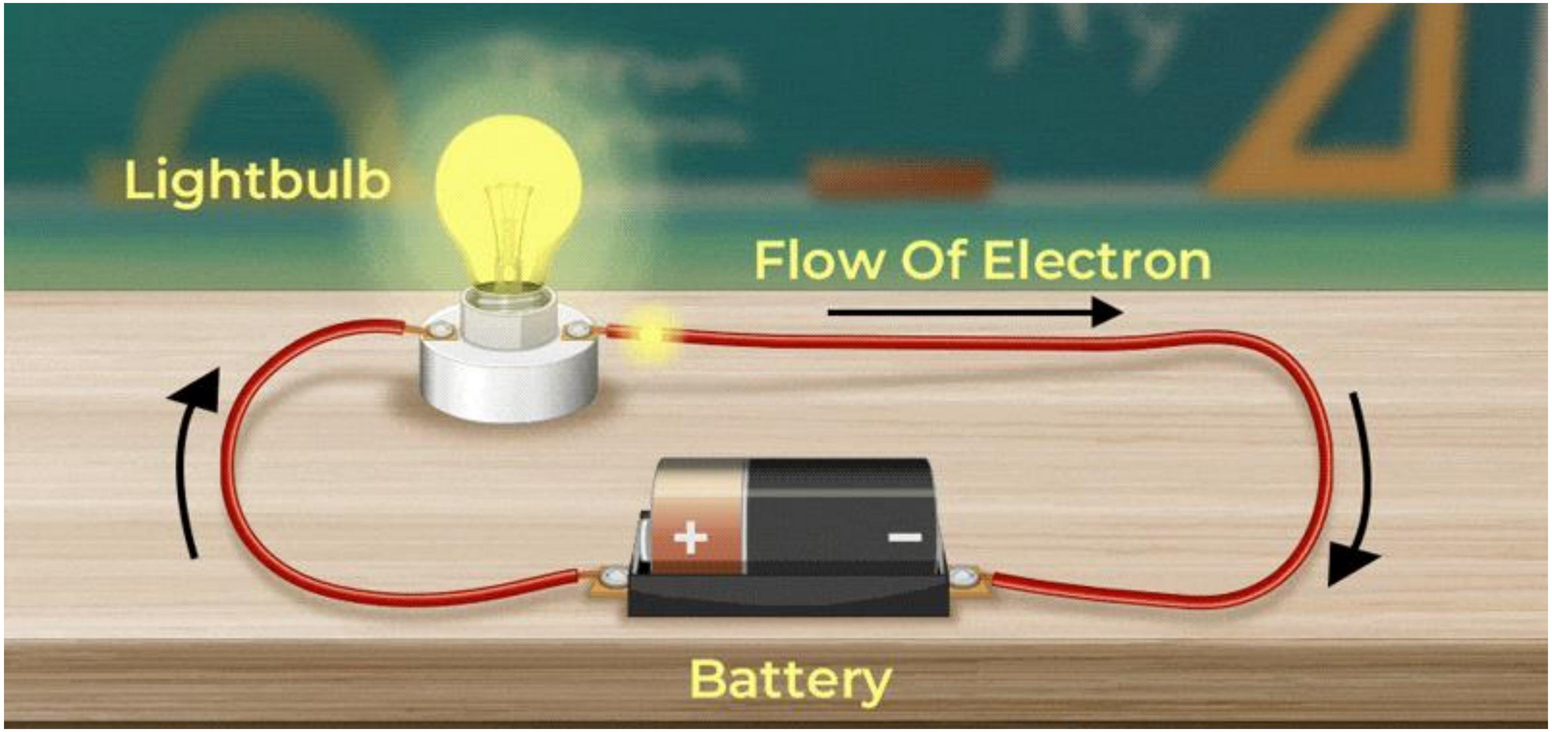
Getting DC back out of AC

- AC provides a means for us to distribute electrical power, but most devices actually *want* DC
  - bulbs, toasters, heaters, fans don't care: plug straight in
  - sophisticated devices care because they have diodes and transistors that require a certain polarity
    - rather than oscillating polarity derived from AC
    - this is why battery orientation matters in most electronics
- Use diodes to "rectify" AC signal
- Simplest (half-wave) rectifier uses one diode:

Alternating Current



Direct Current



Direct current and alternating current

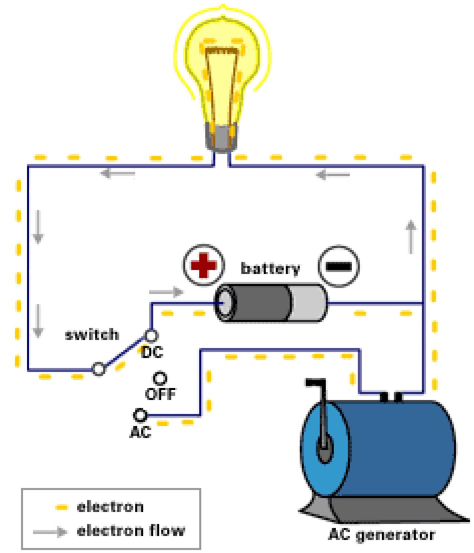
Direct Current (DC)

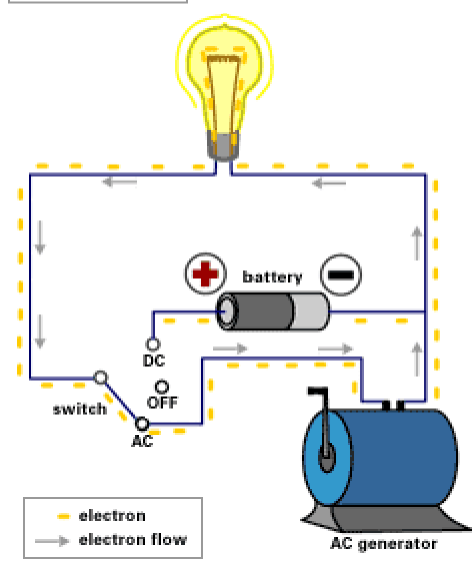
Unidirectional flow of charge

- Battery
- Dynamo
- Rectification from Alternating Current (AC)

Usually has a constant value

Used for low voltages





Alternating Current (AC)

Electric flow of charge that changes cyclic

- Alternators
- Houses

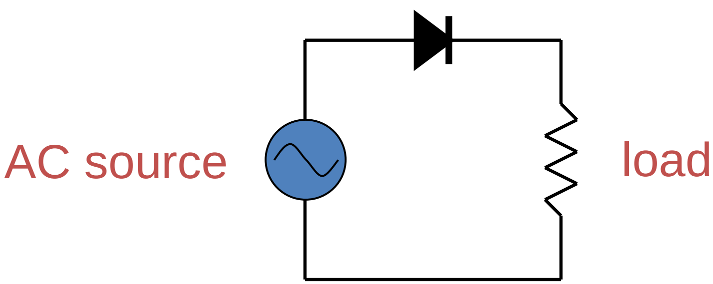
Usually is a sine wave

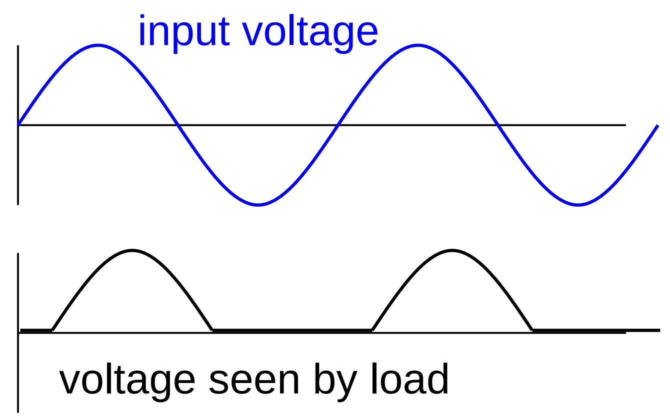
$$V_{RMS} = \frac{V}{\sqrt{2}}$$

High voltages

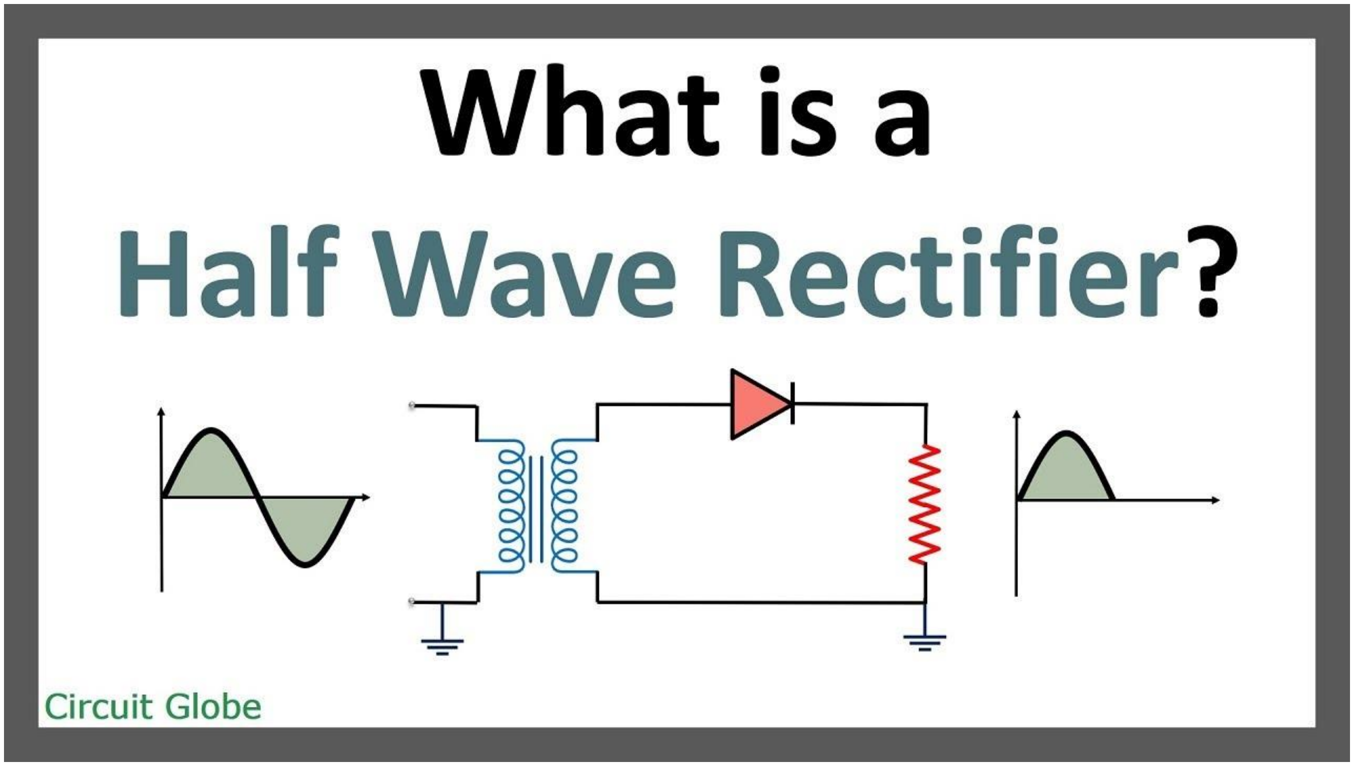
Getting DC back out of AC

- Use diodes to “rectify” AC signal
- Simplest (half-wave) rectifier uses one diode:

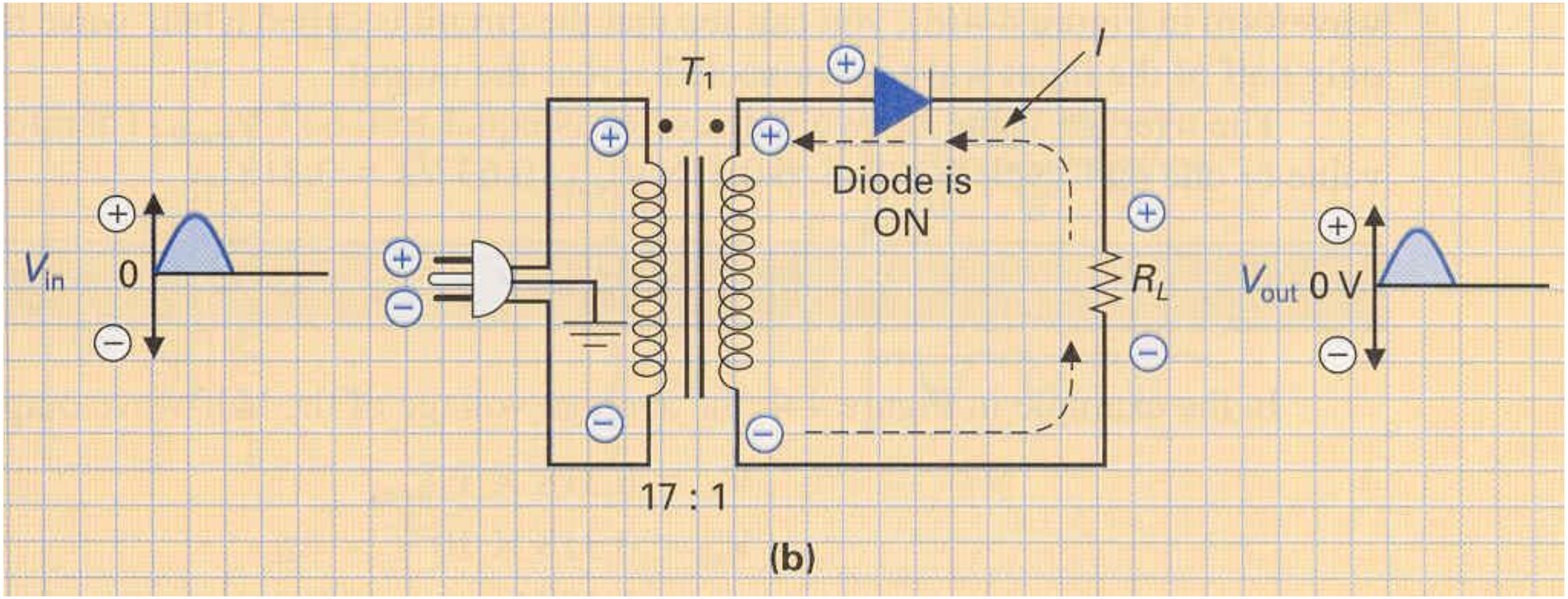




diode only conducts
when input voltage is positive

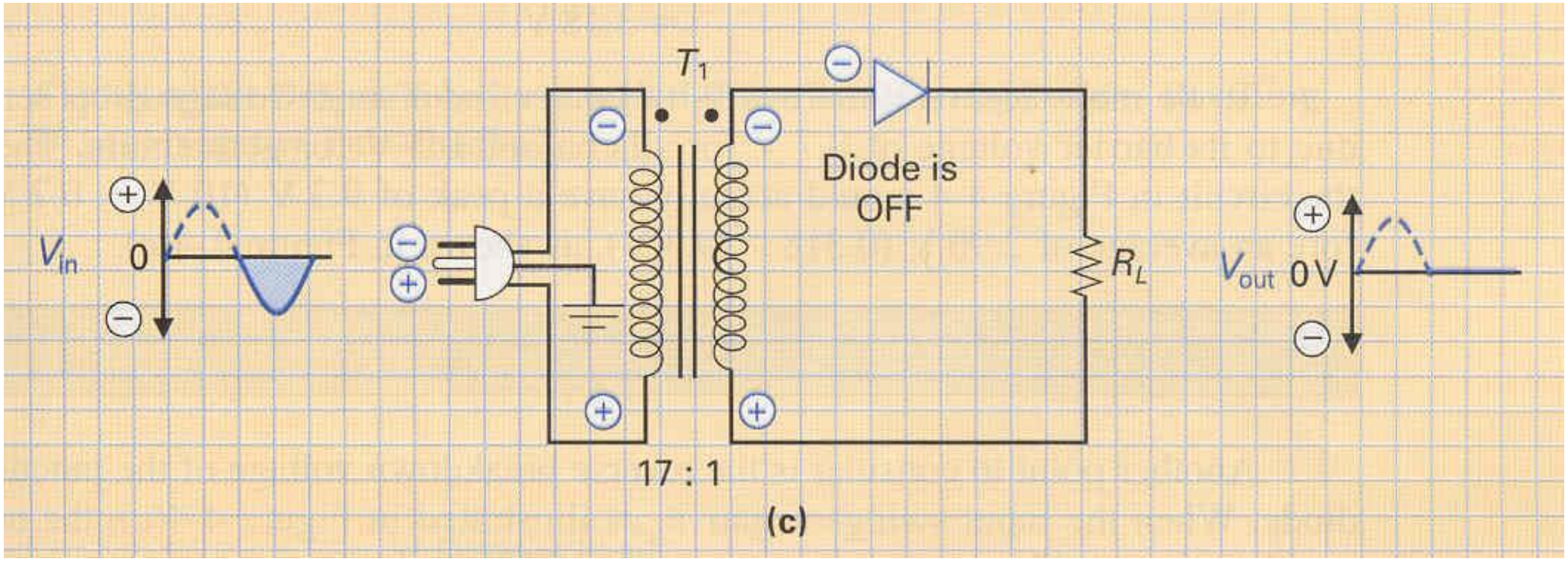

What is a
Half Wave Rectifier?
Circuit Globe

Half-wave rectifier

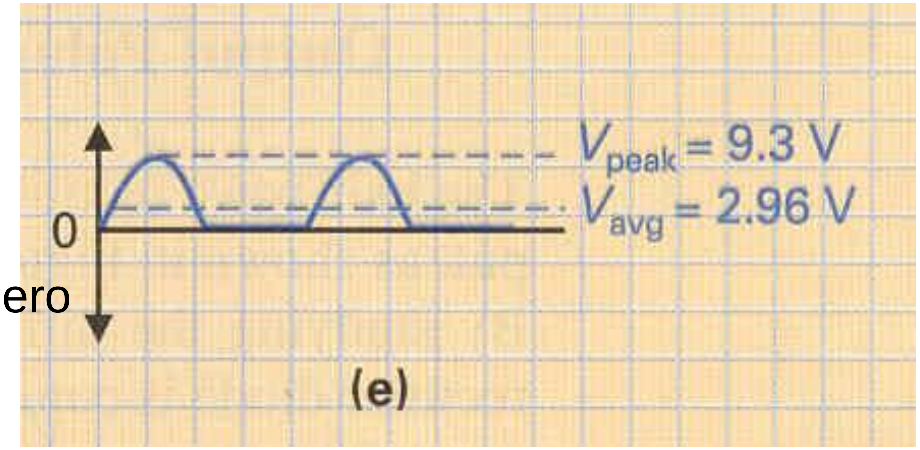


When the sinusoidal input voltage goes positive, the diode is forward-biased and conducts current to the load resistor

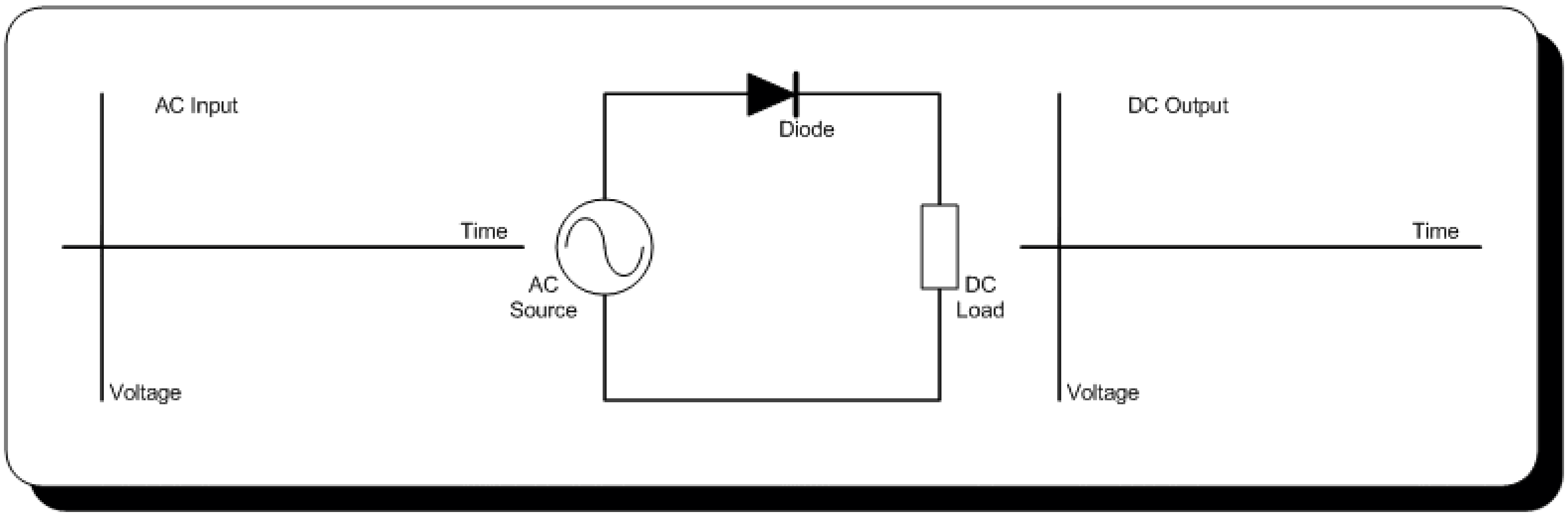
Half-Wave Rectifier



When the input voltage goes negative during the second half of its cycle, the diode is reverse-bias. There is no current, so the voltage across the load resistor is zero



Half-Wave Rectifier

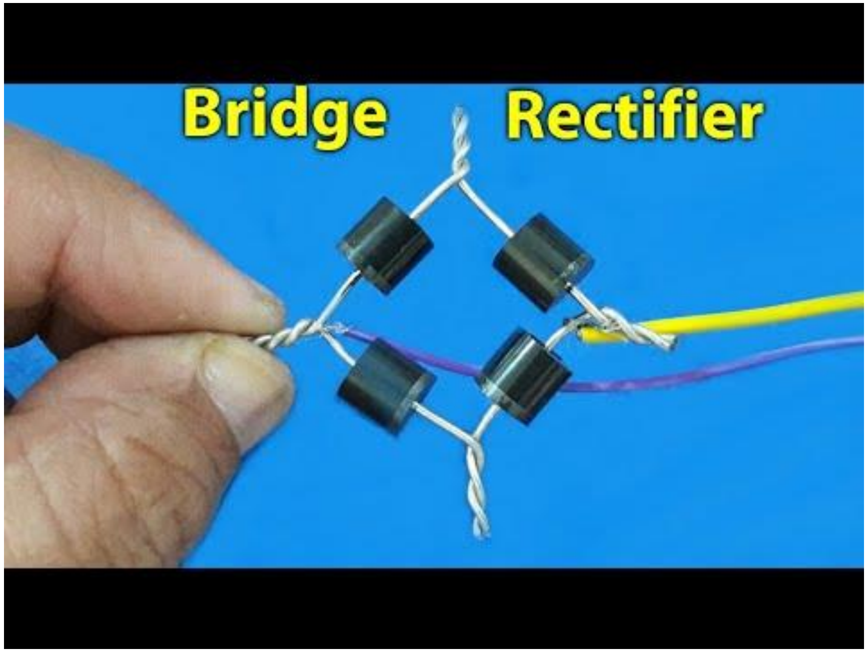


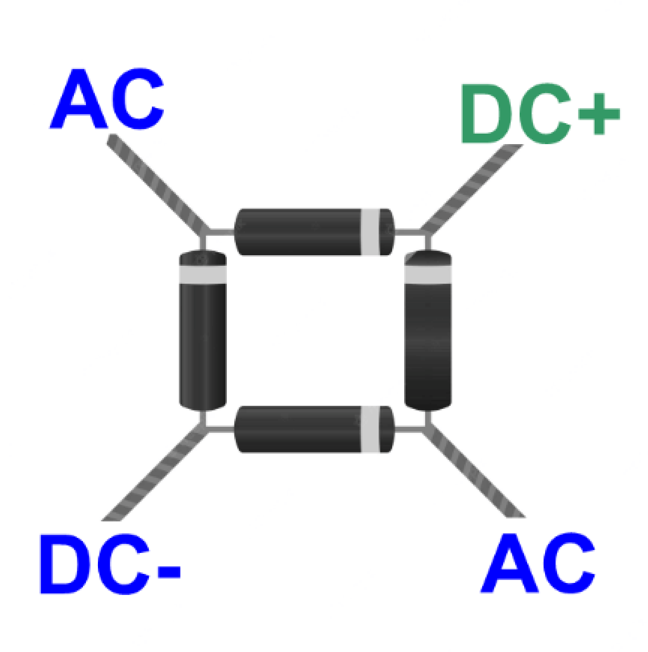
Precautions

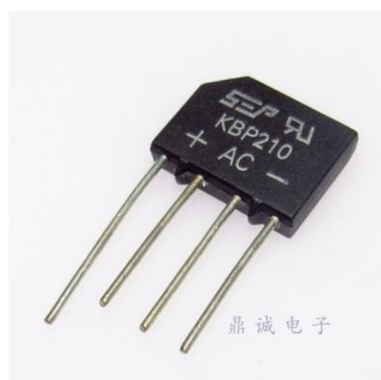
- In selecting diodes for rectifier design, two important parameters must be specified: the current handling capability required of the diode, determined by the largest current the diode is expected to conduct,
- The peak inverse voltage (PIV) that the diode must be able to withstand without breakdown, determined by the largest reverse voltage that is expected to appear across the diode.
- It is usually prudent, however to select a diode that has a reverse breakdown voltage at last 50 % greater than the expected PIV.

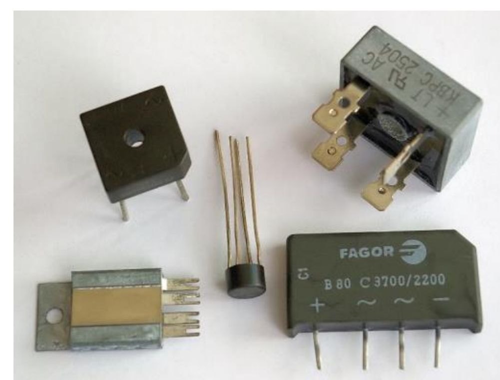
Doing Better: Full-wave Diode Bridge

- The diode in the rectifying circuit simply prevented the negative swing of voltage from conducting
  - but this wastes half the available cycle
  - also very irregular (bumpy): far from a “good” DC source
- By using four diodes, you can recover the negative swing:

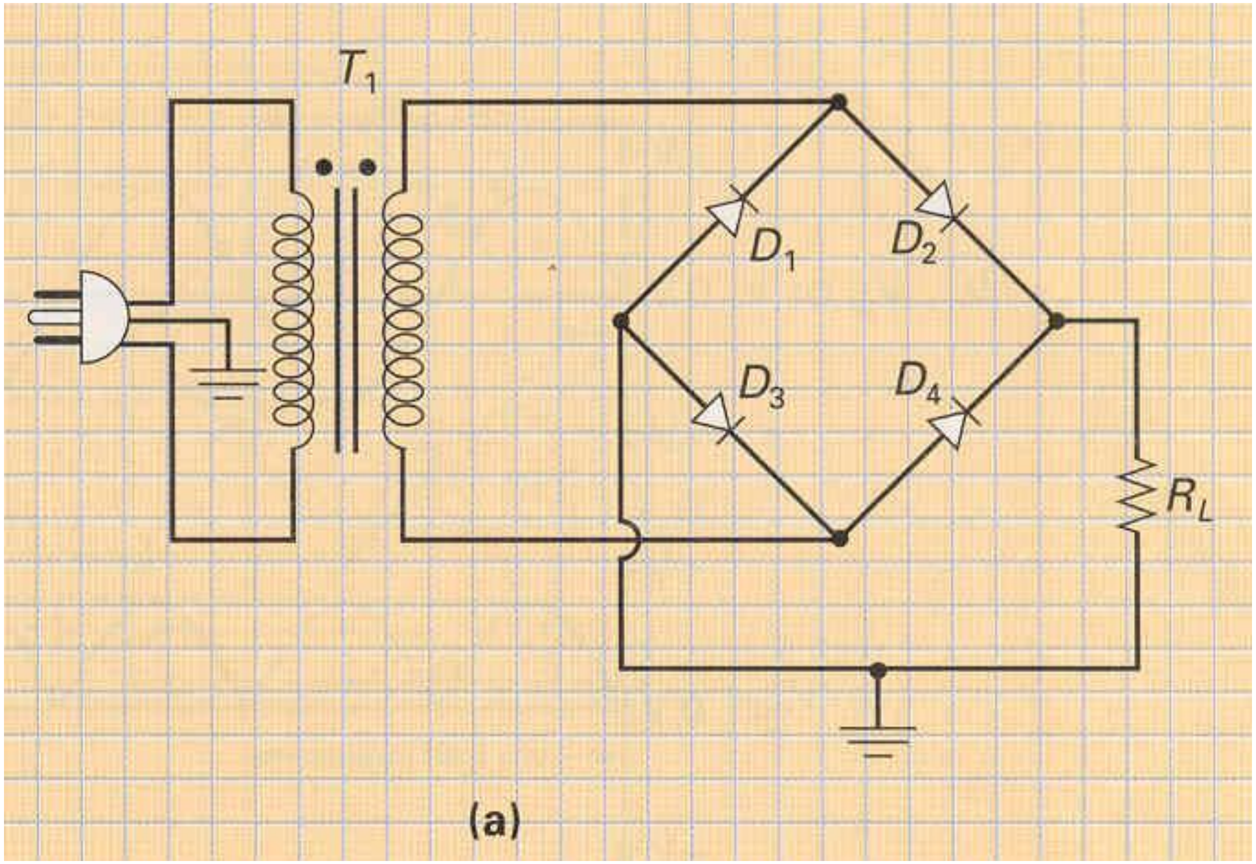

Bridge Rectifier


AC
DC+
DC-
AC

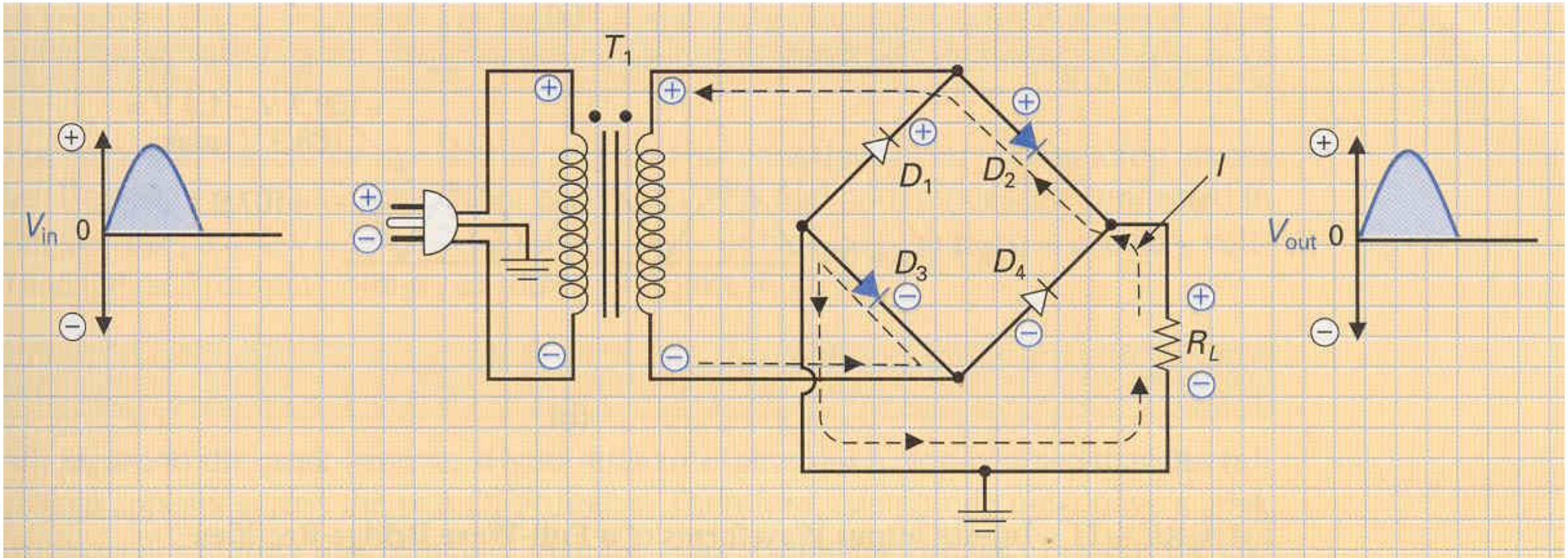

KBP210
+ AC −
鼎诚电子


FAGOR
B 80 C3700/2200
+ ~ ~ −

Bridge (Full wave rectifier)

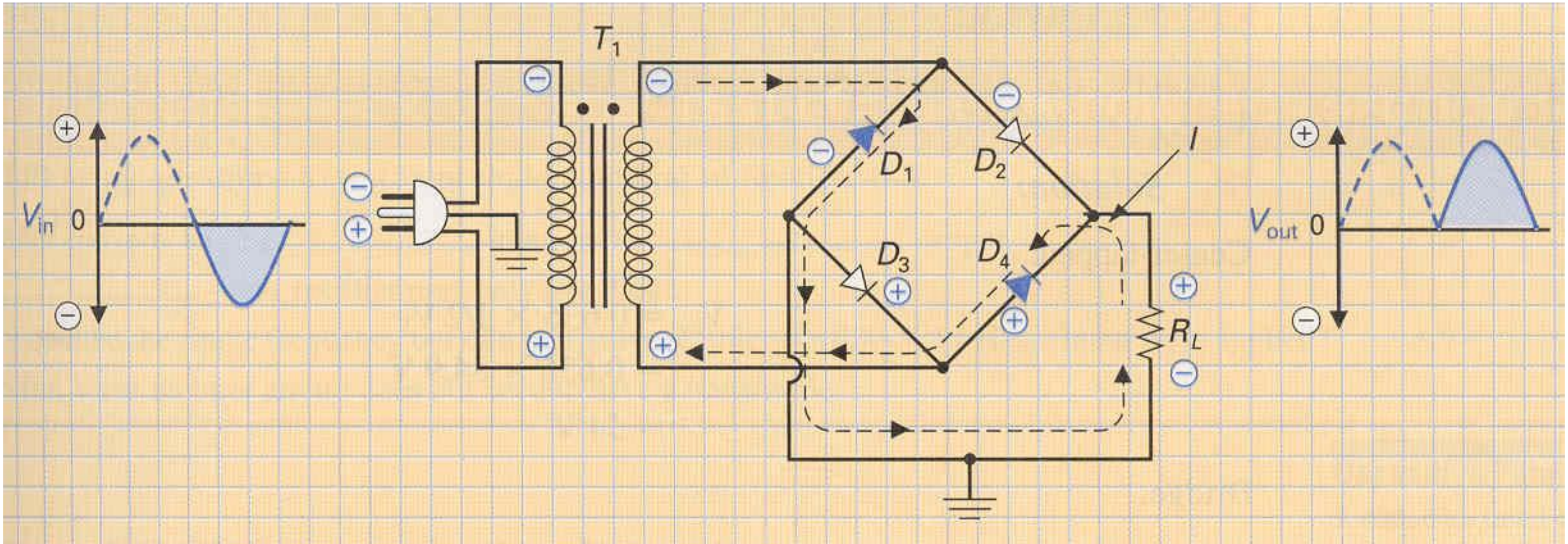


Bridge (Full wave rectifier)

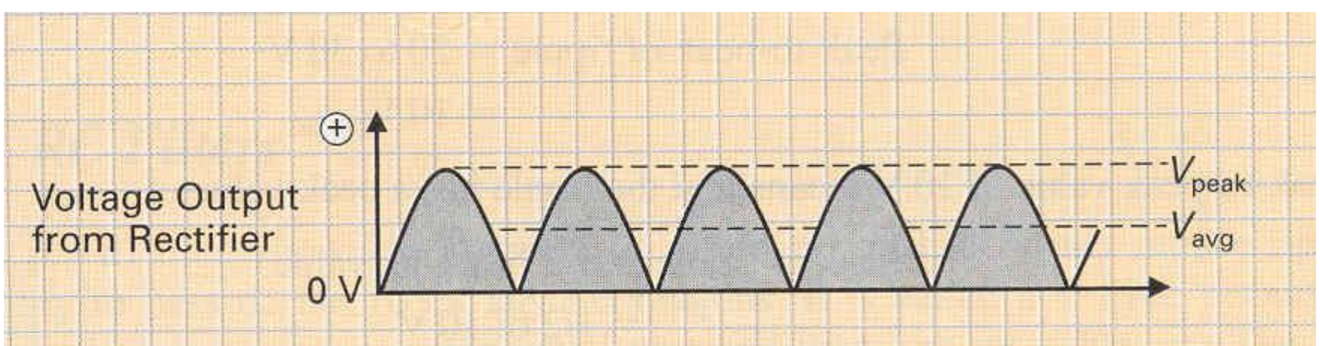


(b)

Bridge (Full wave rectifier)

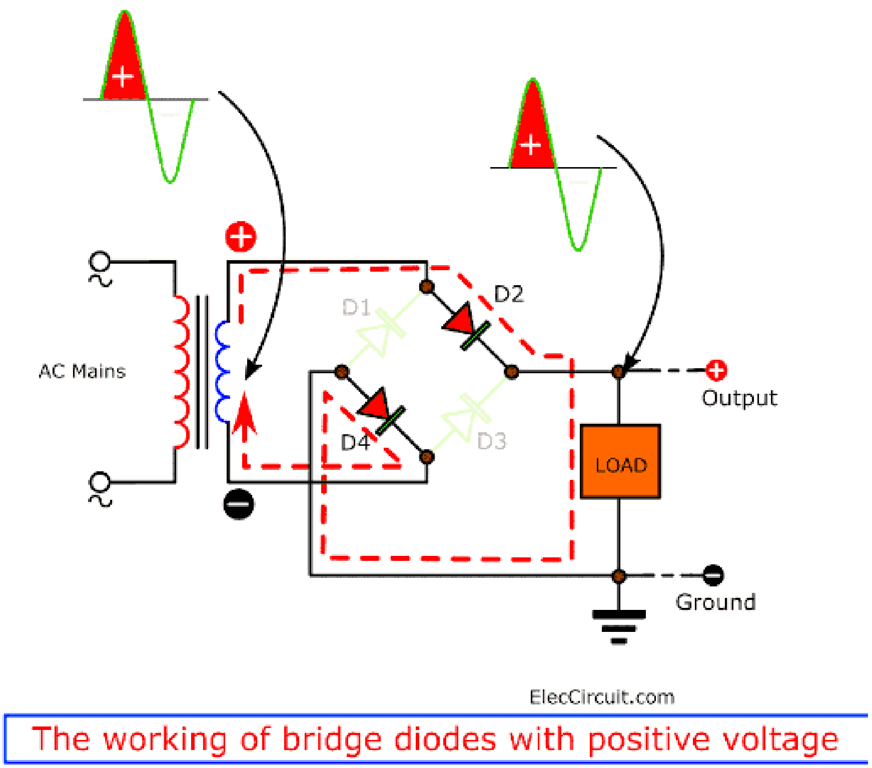


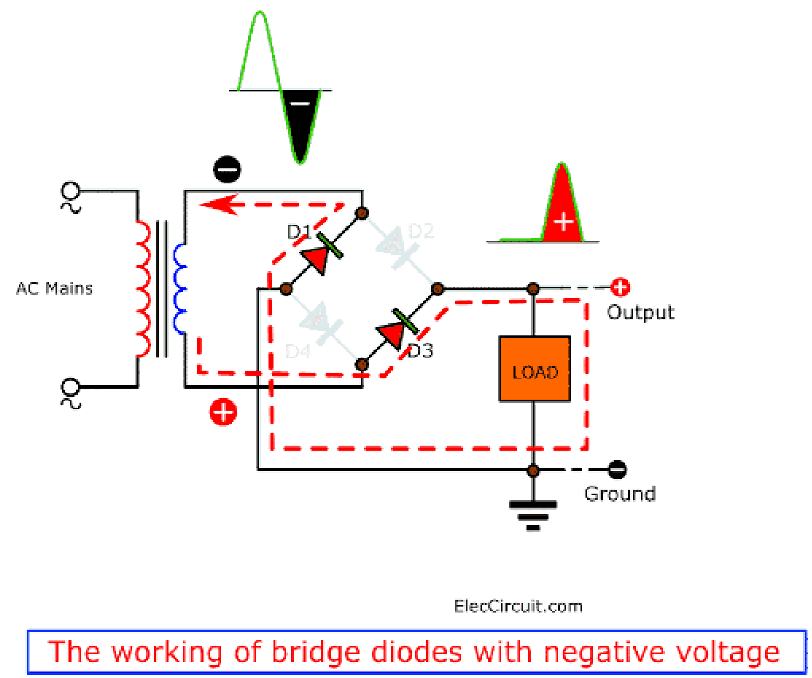
(c)



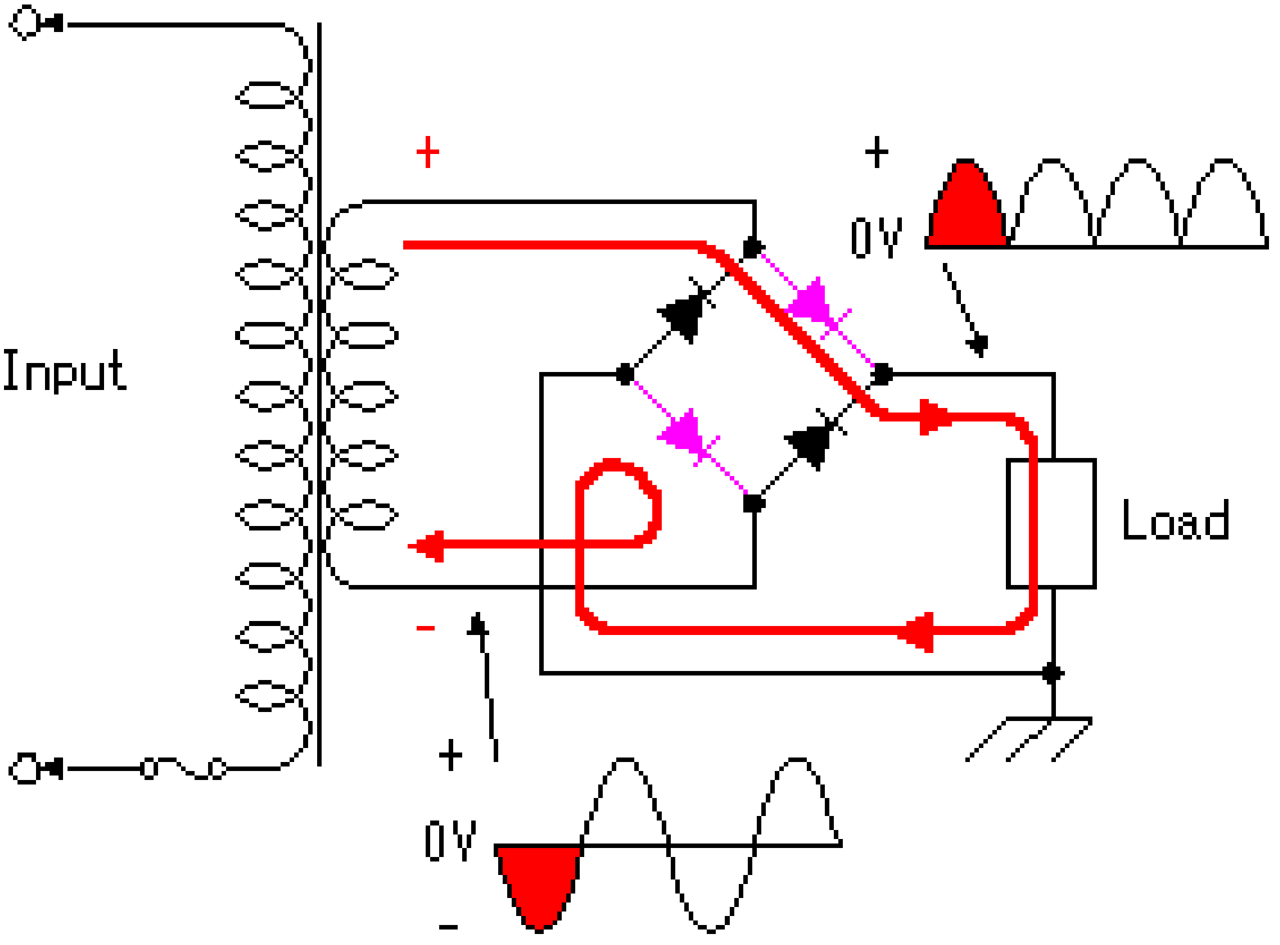
(b)

FULL WAVE BRIDGE RECTIFIER

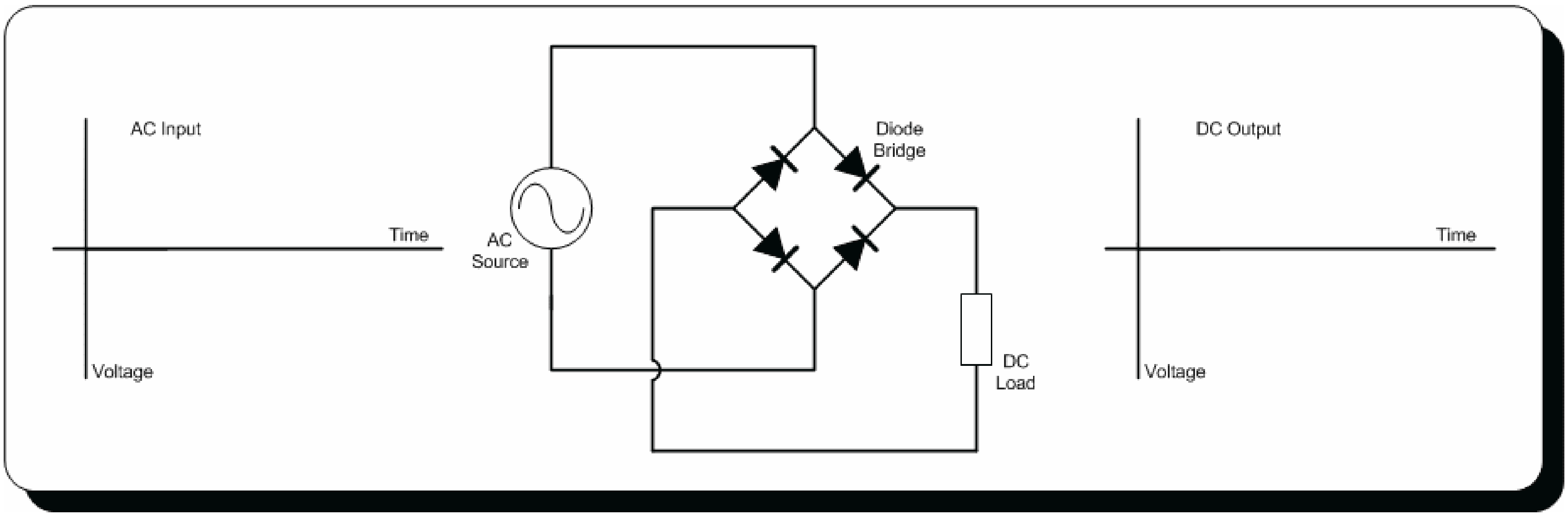




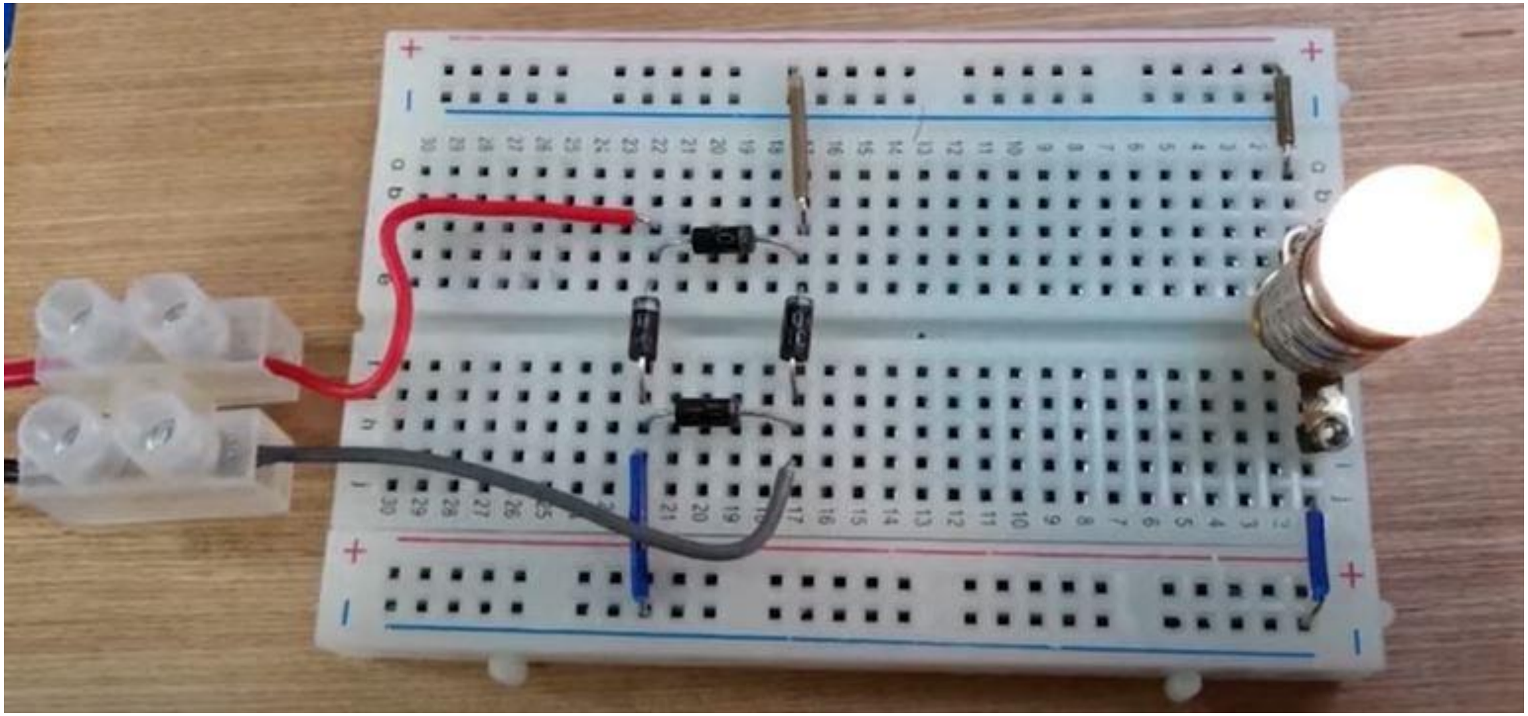
FULL WAVE BRIDGE RECTIFIER



FULL WAVE BRIDGE RECTIFIER

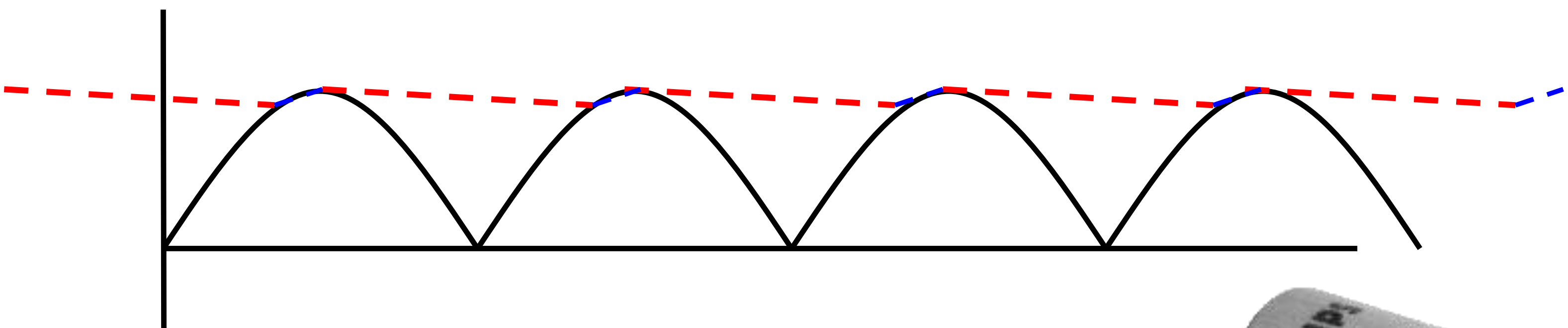


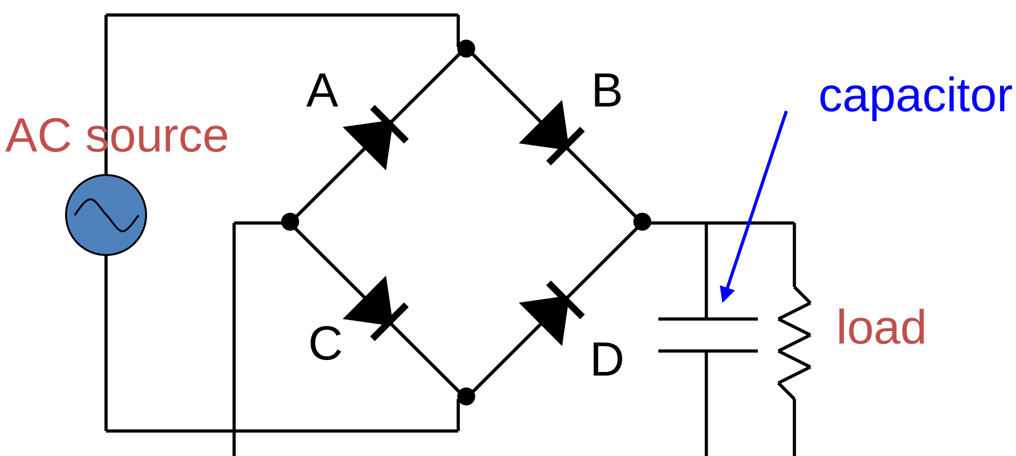

Vin
t
Full Wave
Rectifier
Vout
t

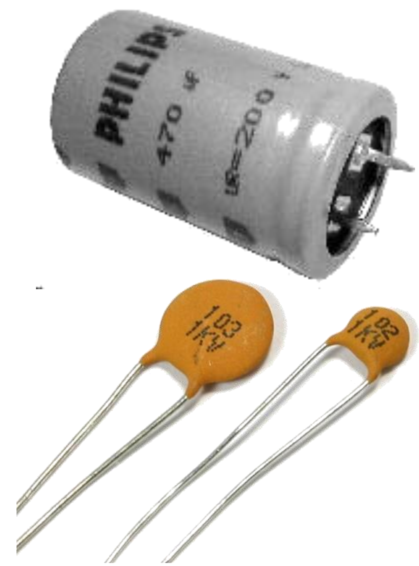


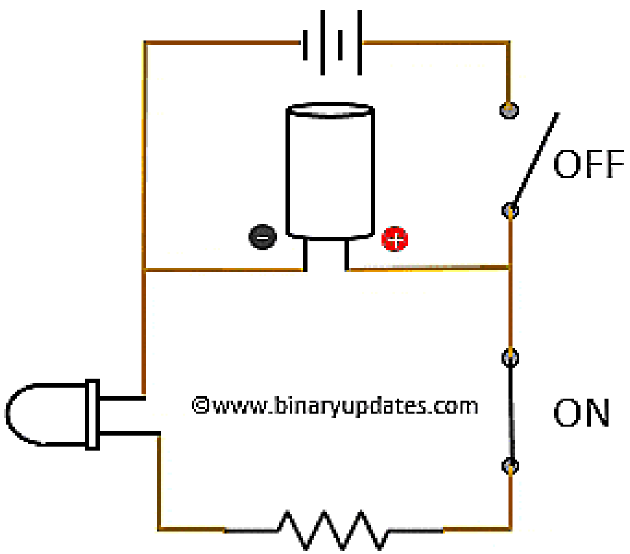
Smoothing out the Bumps

- Still a bumpy ride, but we can smooth this out with a capacitor
  - capacitors have capacity for storing charge
  - acts like a reservoir to supply current during low spots
  - voltage regulator smoothes out remaining ripple



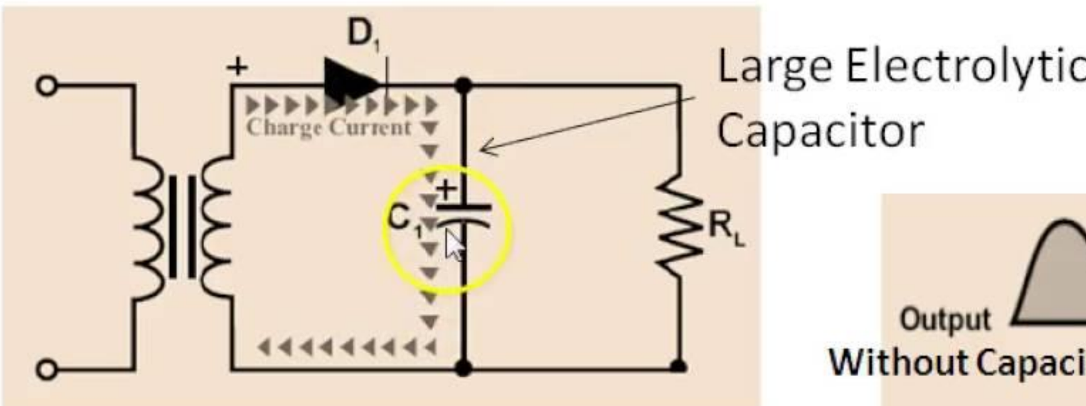




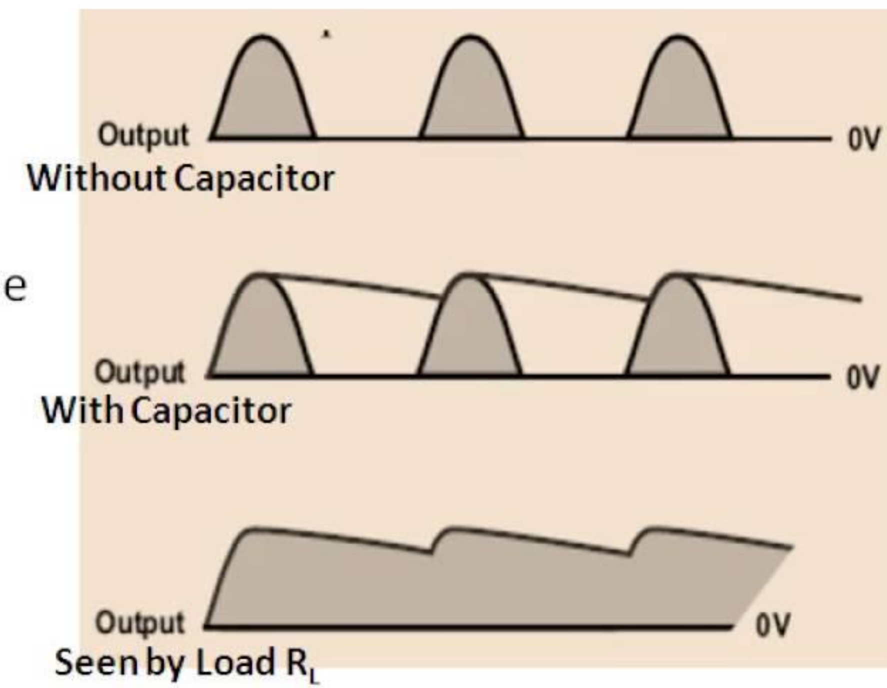

OFF
©www.binaryupdates.com
ON

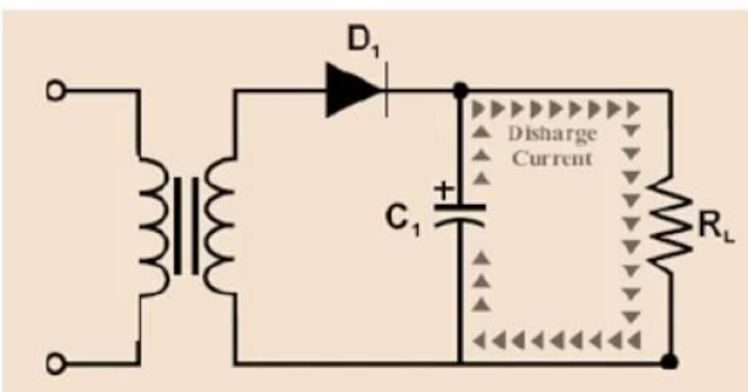

nichicon
4700μF 35v
CAPACITOR
189-505-5
193-10 8216
103K
500V
151
15
10
224K
100V

Half-wave rectifier with capacitor input filter



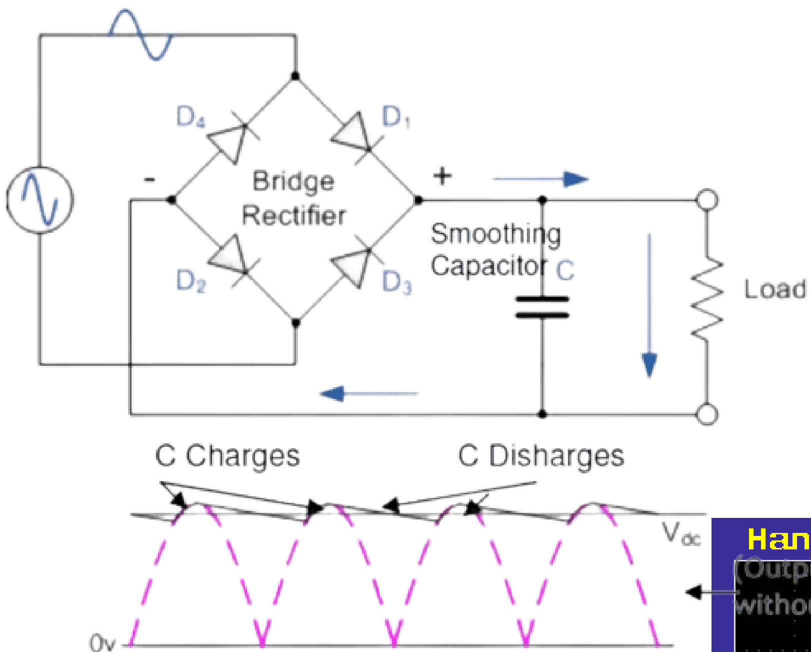
Half Wave Rectifier : Positive Half Cycle



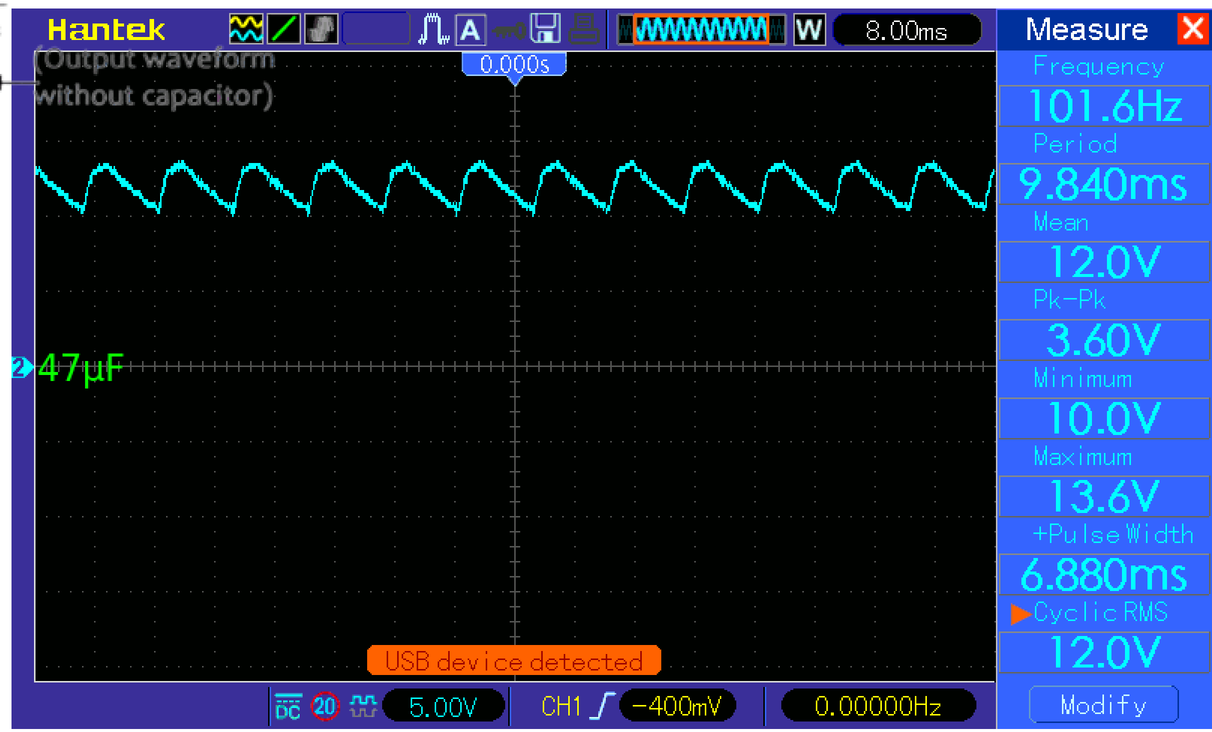


Half Wave Rectifier : Negative Half Cycle

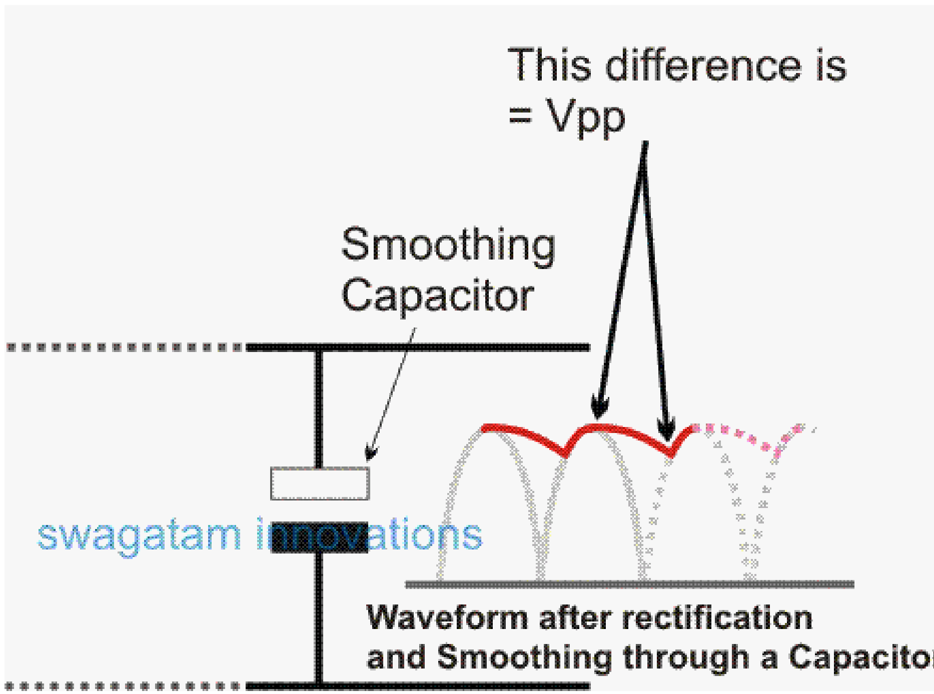
$V \approx V$

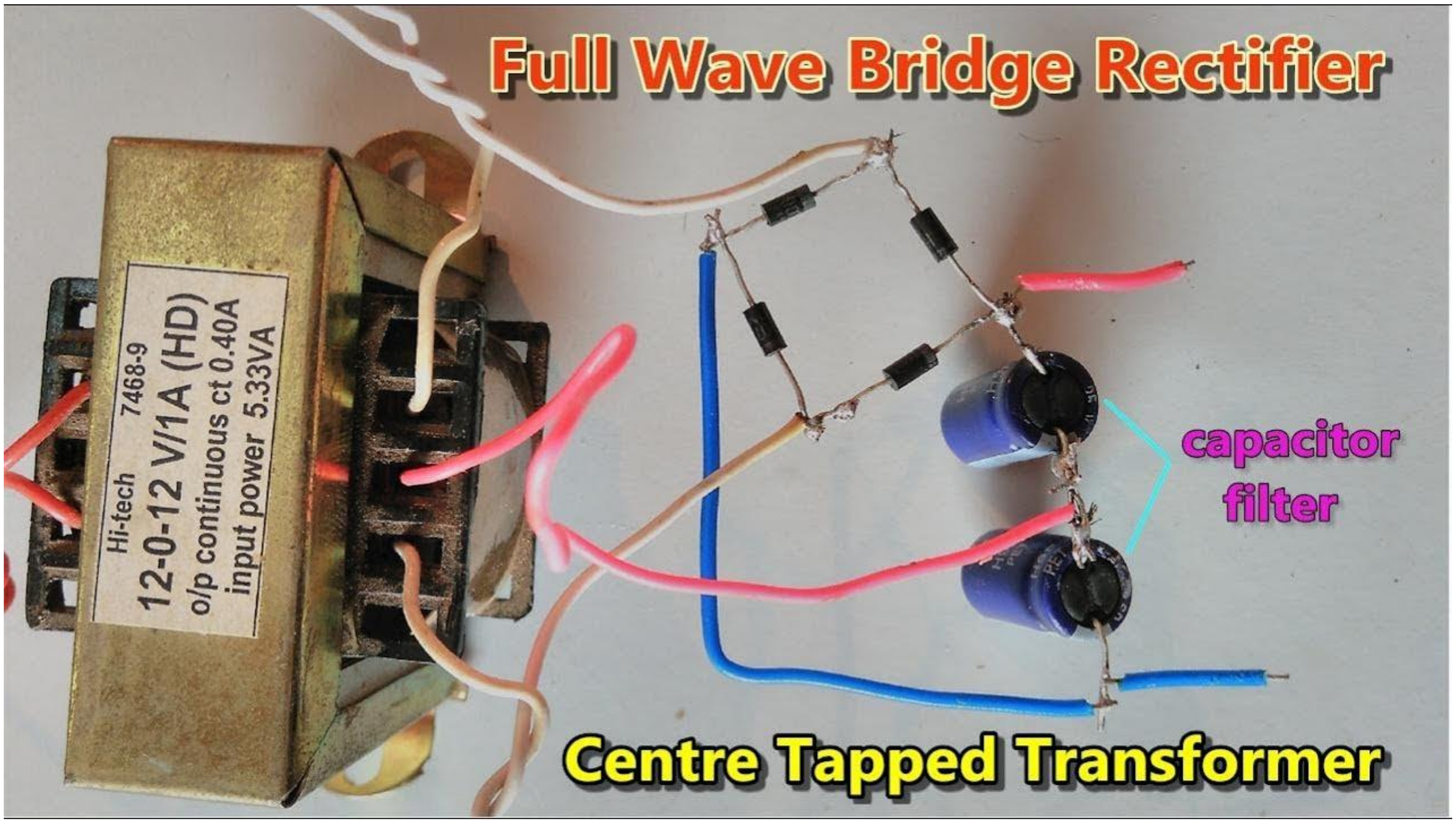


D4
D1
D2
D3
-
+
Bridge
Rectifier
Smoothing
Capacitor C
Load
C Charges
C Disharges
Vdc
0v

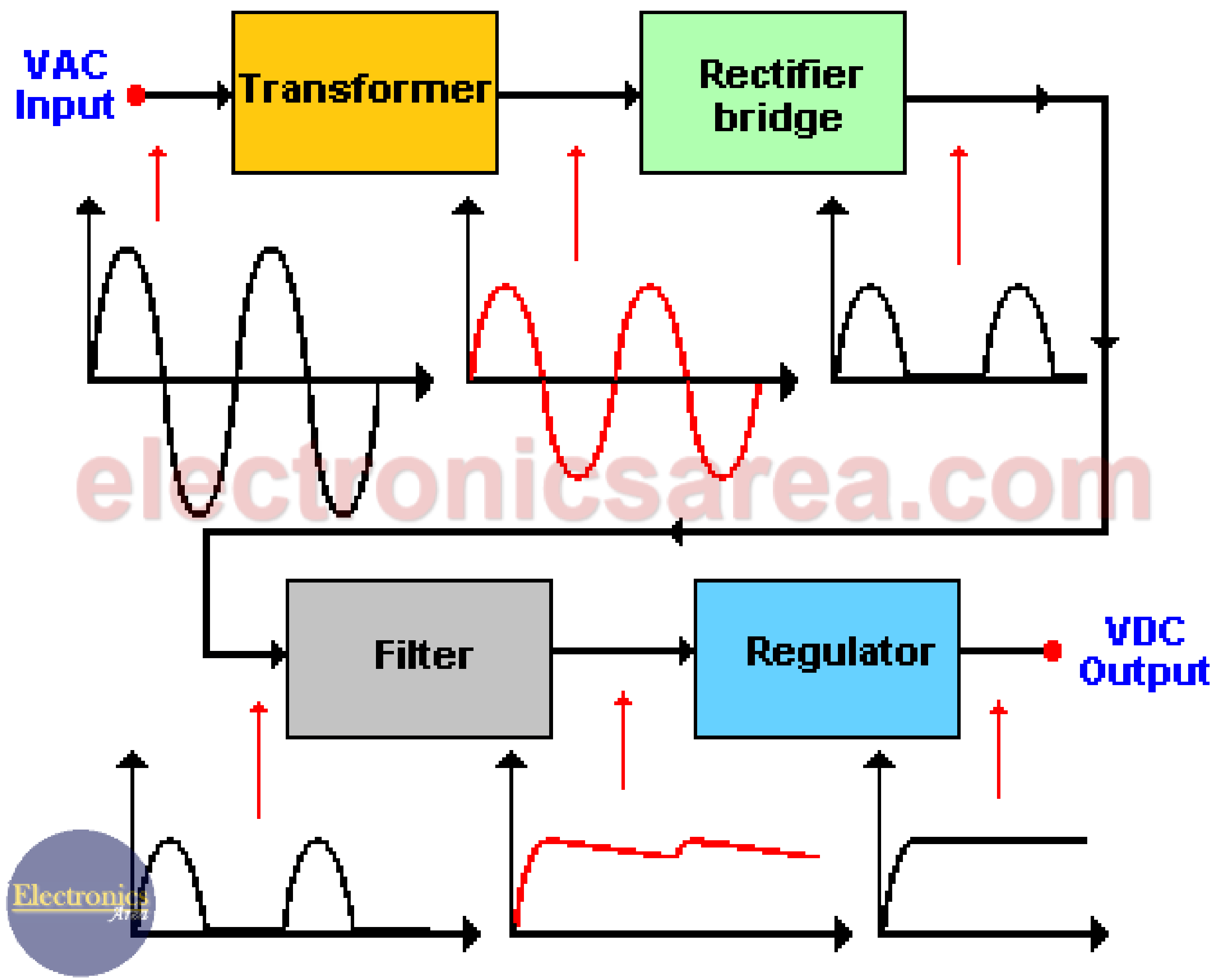


(Output waveform
without capacitor)
Hantek
8.00ms
0.000s
47µF
USB device detected
5.00V
CH1
-400mV
0.00000Hz
Measure
Frequency
101.6Hz
Period
9.840ms
Mean
12.0V
Pk-Pk
3.60V
Minimum
10.0V
Maximum
13.6V
+Pulse Width
6.880ms
Cyclic RMS
12.0V
Modify

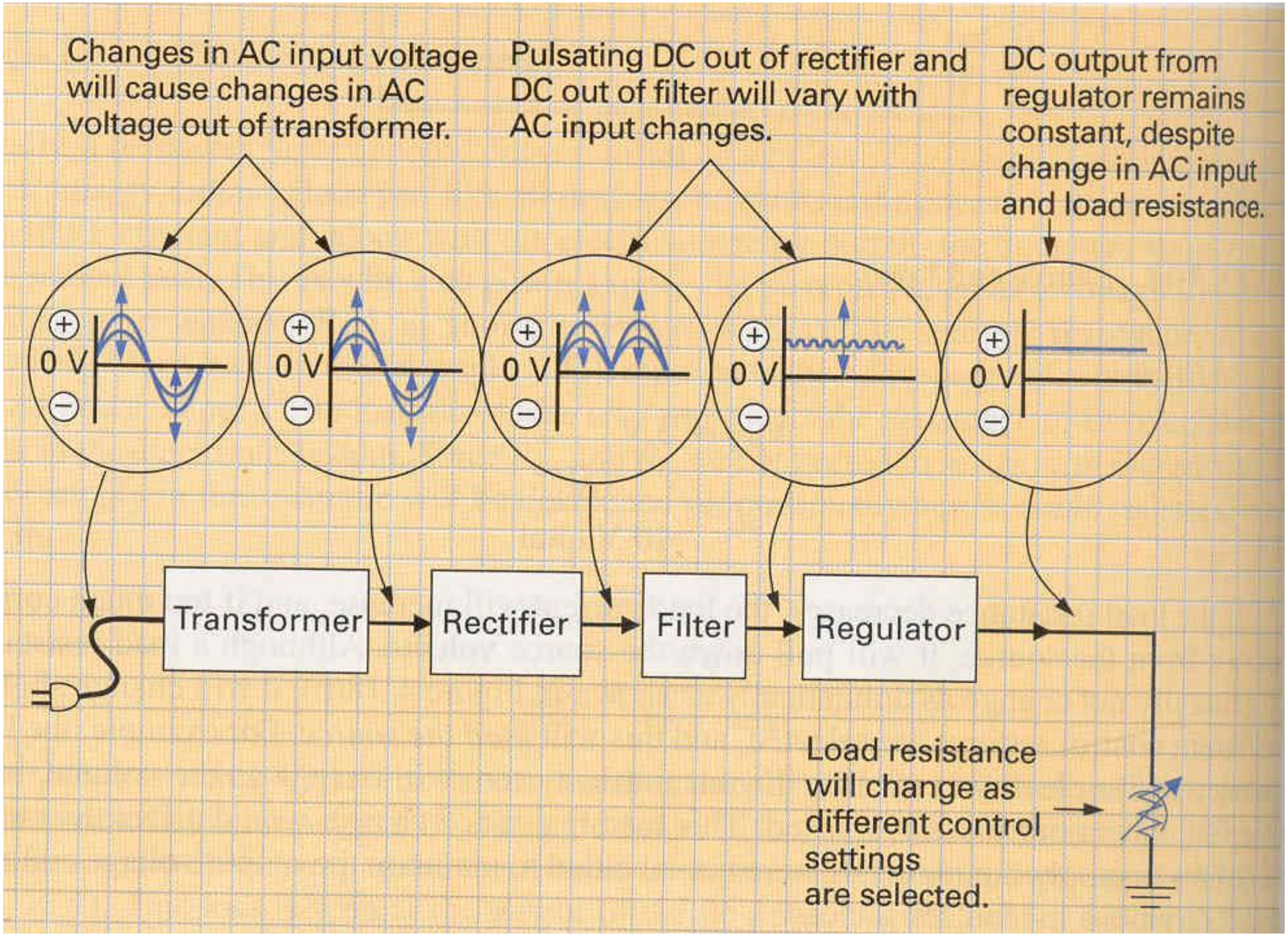

This difference is
= Vpp
Smoothing
Capacitor
swagatam innovations
Waveform after rectification
and Smoothing through a Capacitor


Full Wave Bridge Rectifier
Hi-tech 7468-9
12-0-12 V/1A (HD)
o/p continuous ct 0.40A
input power 5.33VA
capacitor
filter
Centre Tapped Transformer

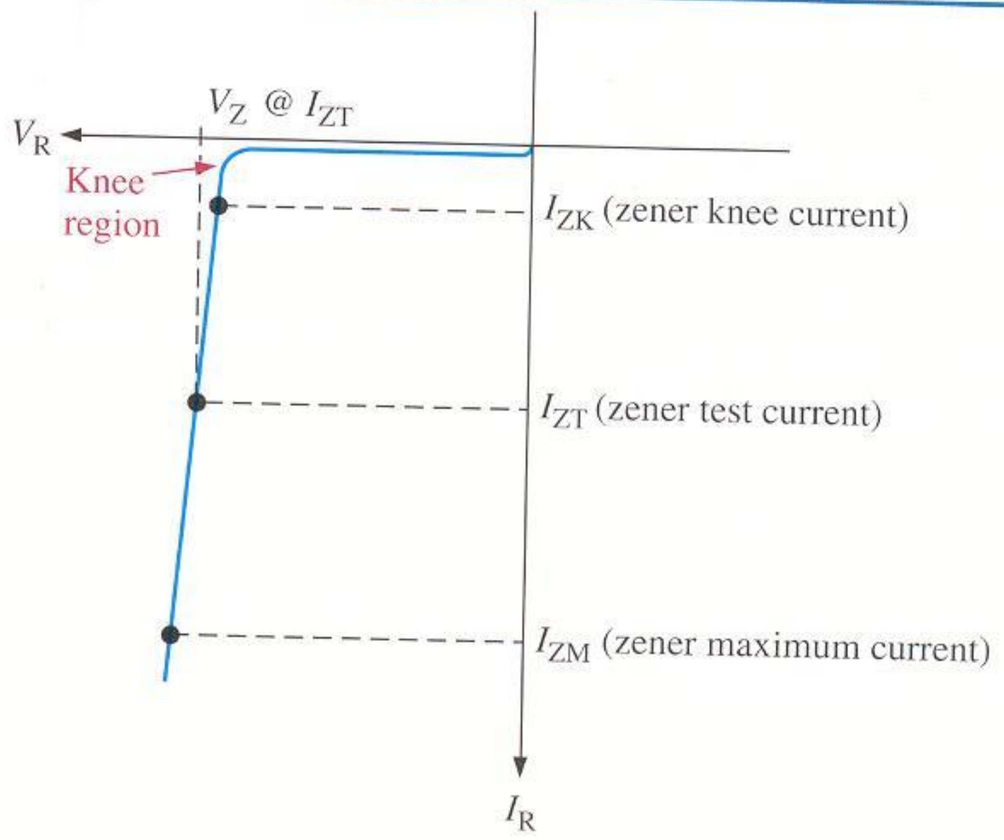
SCIENCE PROJECT


VAC
Input
Transformer
Rectifier
bridge
Filter
Regulator
VDC
Output
electronicsarea.com
Electronics
Area

The need for voltage regulators



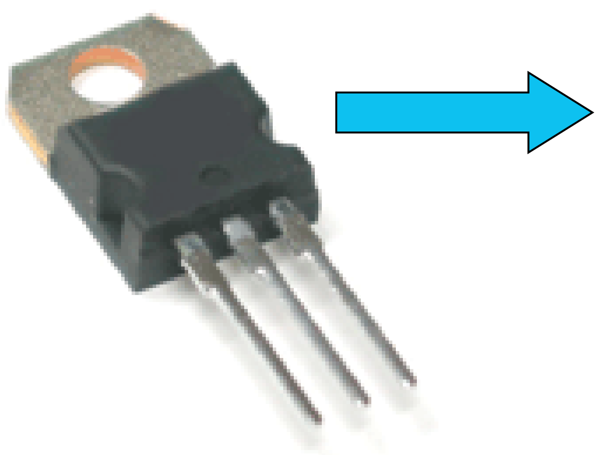
Zener diode (I-V characteristics)

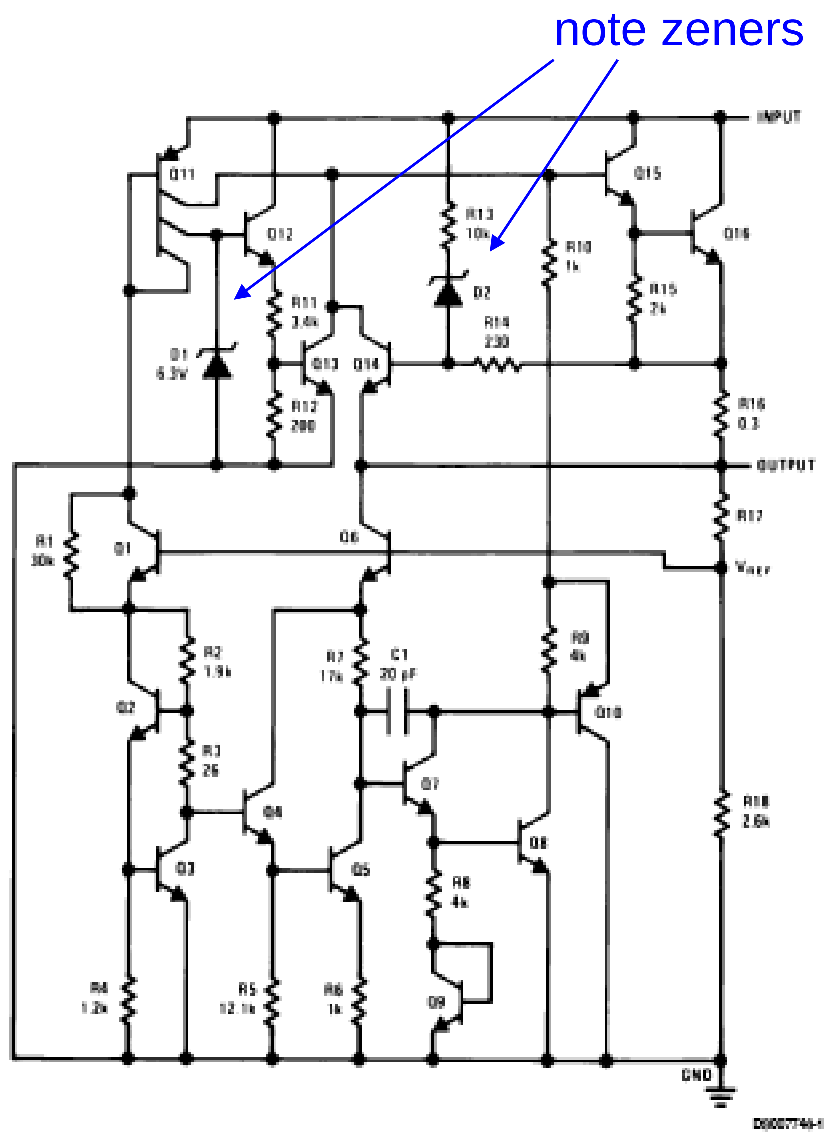


Zener diodes can be used for voltage regulation in non critical applications.

Voltage Regulator IC

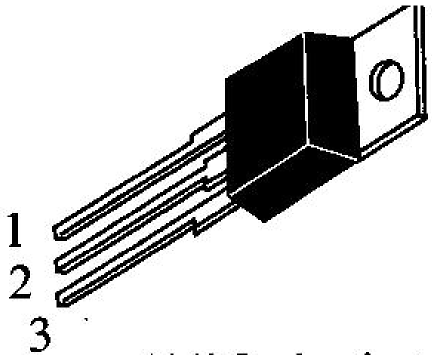
- Can trim down ripply voltage to precise, rock-steady value
- Now things get complicated!
  - We are now in the realm of integrated circuits (ICs)
- ICs are whole circuits in small packages
- ICs contain resistors, capacitors, diodes, transistors, etc.





IC regulators

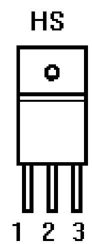
Type number	Output voltage
7805	+5.0 V
7806	+6.0 V
7808	+8.0 V
7809	+9.0 V
7812	+12.0 V
7815	+15.0 V



(All 3 plastic types)
Pin 1. Input
2. Ground
3. Output
(Heatsink surface connected to

Voltage Regulators

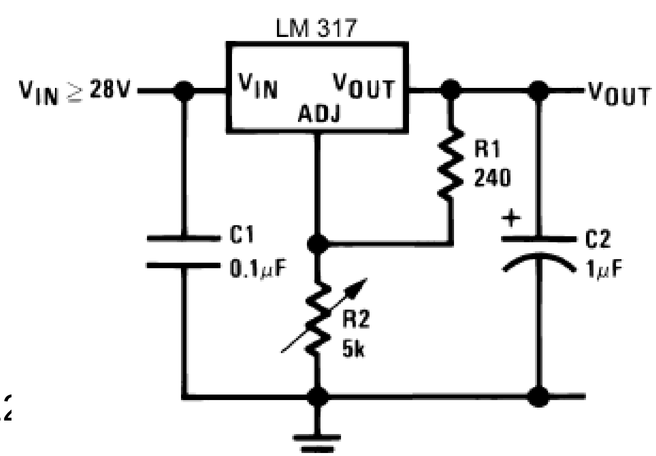
- The most common voltage regulators are the LM78XX (+ voltages) and LM79XX (– voltages)
  - XX represents the voltage
    - 7815 is +15; 7915 is –15; 7805 is +5, etc
  - typically needs input > 3 volts above output (reg.) voltage



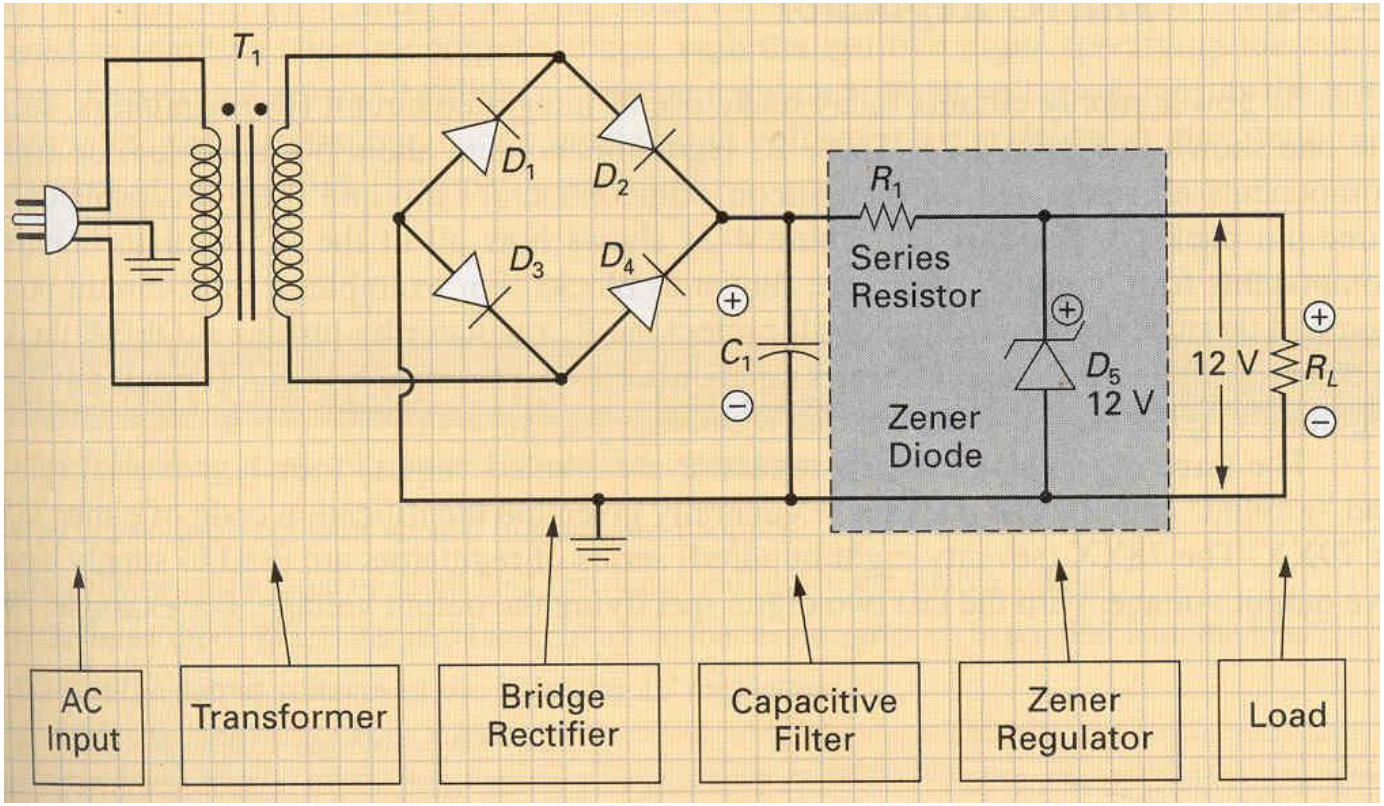
PIN	7915	7815	LM317
1	GND	IN	ADJ.
2	IN	GND	OUT
3	OUT	OUT	IN
HS	IN	GND	OUT

beware that housing is not always ground

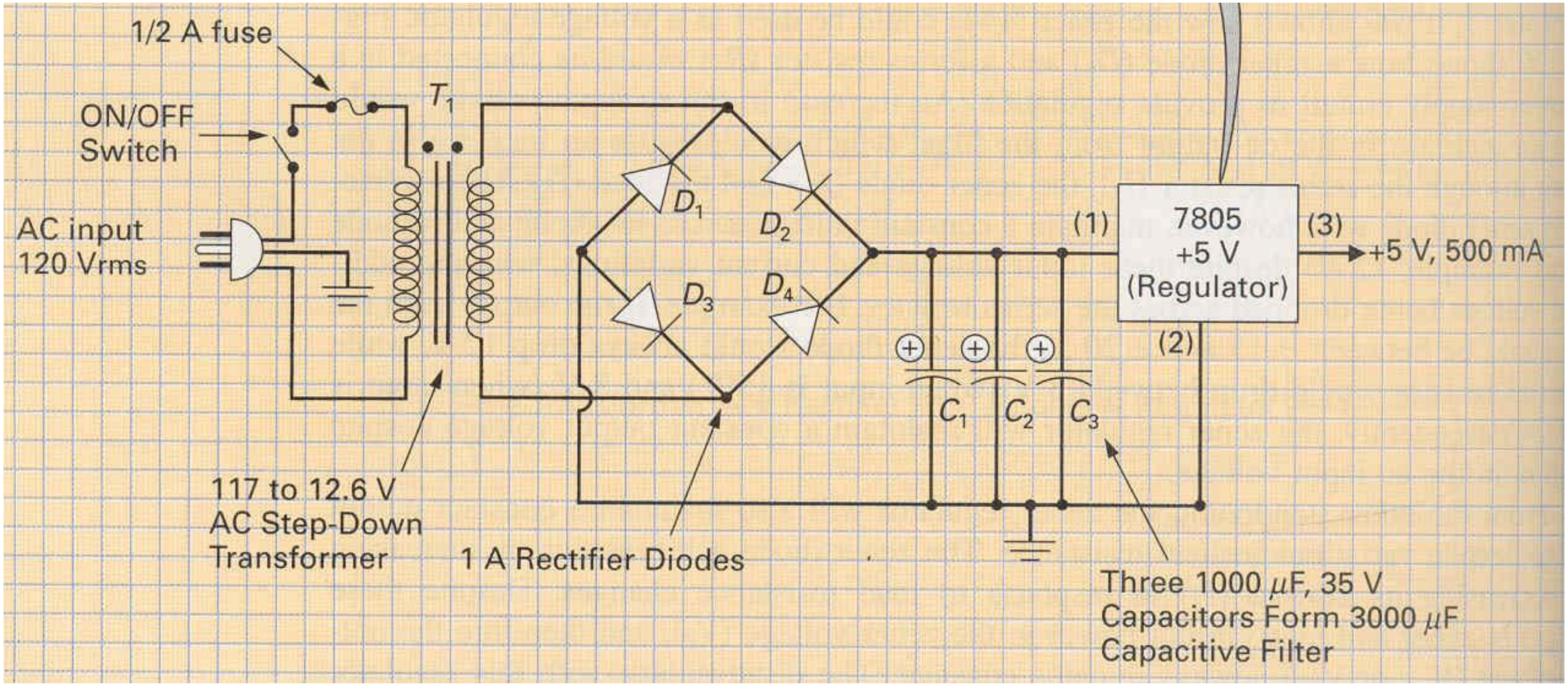
- A versatile regulator is the LM317 (+) or LM337 (–)
  - 1.2–37 V output
  - $V_{out} = 1.25(1+R_2/R_1) + I_{adj}R_2$
  - Up to 1.5 A
  - picture at right can go to 25 V
  - datasheetcatalog.com for details



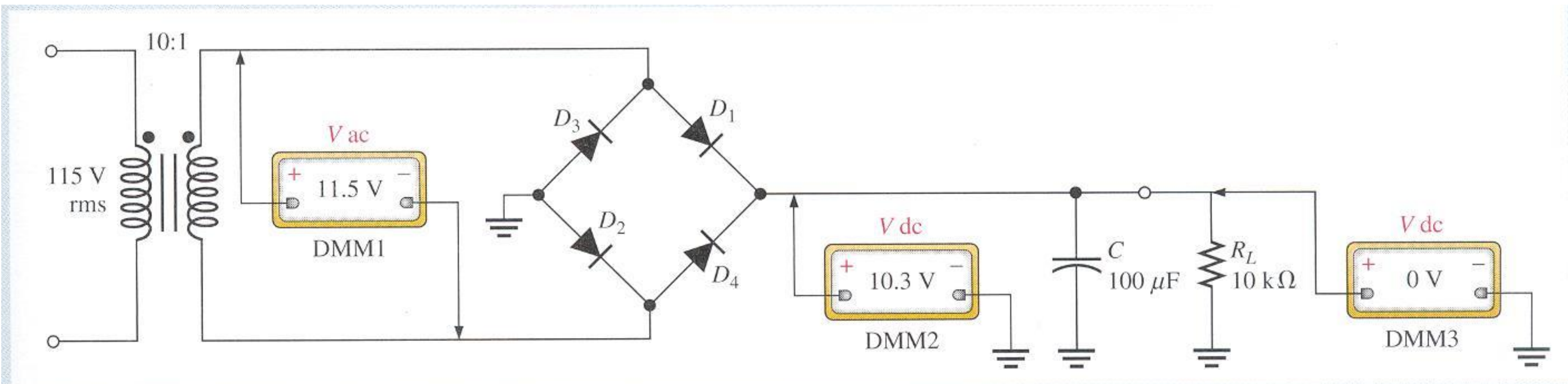
Zener regulator



IC regulator

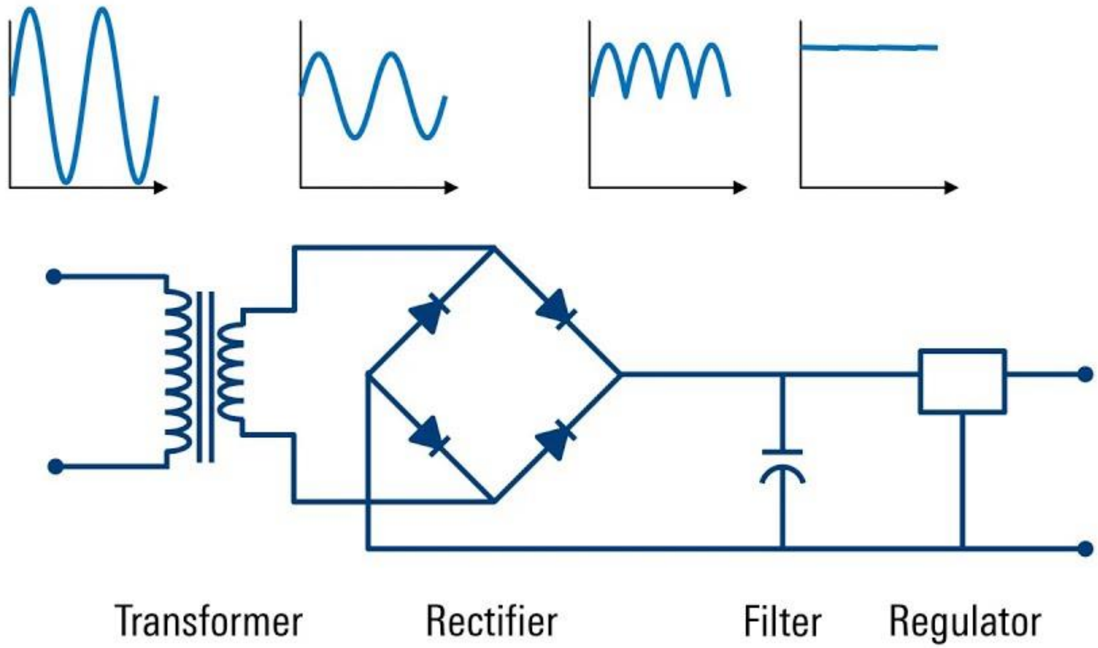


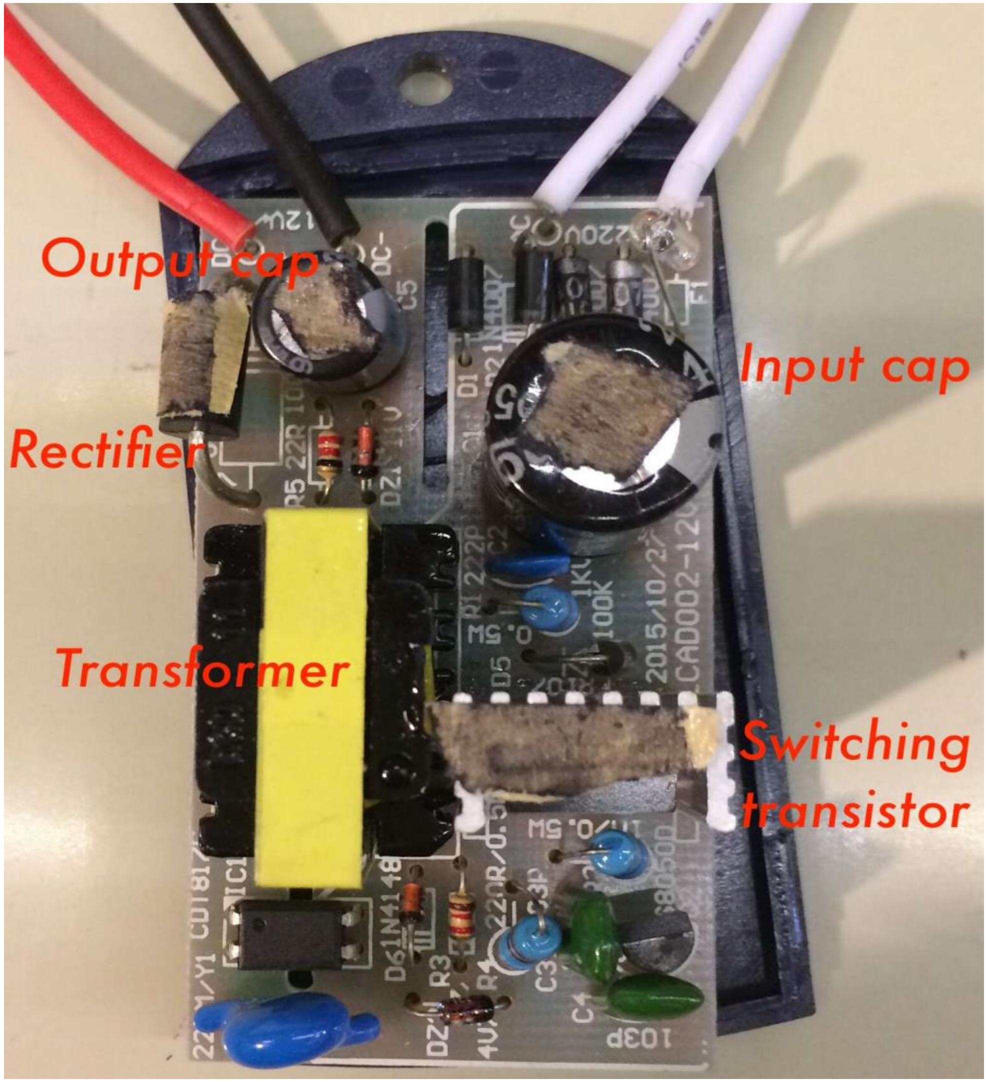
Question



What could be wrong with this circuit ?

Review




Output cap
Rectifier
Transformer
Input cap
Switching transistor


CX650M