Dr. Vishwanath Karad
MIT WORLD PEACE UNIVERSITY | PUNE
TECHNOLOGY, RESEARCH, SOCIAL INNOVATION & PARTNERSHIPS

Basics of Electrical and Electronics Engineering

Course Code: ECE1022A

Course Objectives and Outcomes

Course Objectives:

1. To impart knowledge of Electric, Magnetic, and Electronic circuits
2. To impart understanding of fundamentals of AC and DC circuits
3. To give comprehensive exposure to analyse circuits of semiconductor diodes, transistors and Operational Amplifiers.
4. To equip the students with ability to understand digital circuits.

Course outcomes: After completion of this course students will be able to

1. Predict the behaviour and characteristics of basic electrical and magnetic circuits. (CLII)
2. Classify Analog and Digital Circuits (CL-II)
3. Test basic electronic circuits based on diodes, transistors and Op-Amp.(CL-VI)
4. Identify components/equipment required for any particular application related to electrical and electronics engineering. (CL-II)
5. To design and test simple combinational logic circuits. (CL-VI)

Course Contents

- **Semiconductor Diodes:** PN Junction Diode characteristics, Diode Types: Zener and Light Emitting diodes (LED), Diode Applications: Rectifiers, half wave and full wave, Zener diode as a voltage regulator, regulated power supply (7L)
- **Bipolar Junction Transistor (BJT):** Working principle, operation, Common Emitter (CE), Common Base (CB), Common Collector (CC) Configurations, VI characteristics, biasing circuits, CE amplifier and its DC and AC Analysis with h parameter model. (8L)
- **Introduction to Integrated Circuits:** Analog Integrated circuits, Basics of OPAMP: - inverting and non-inverting mode, study of IC 741

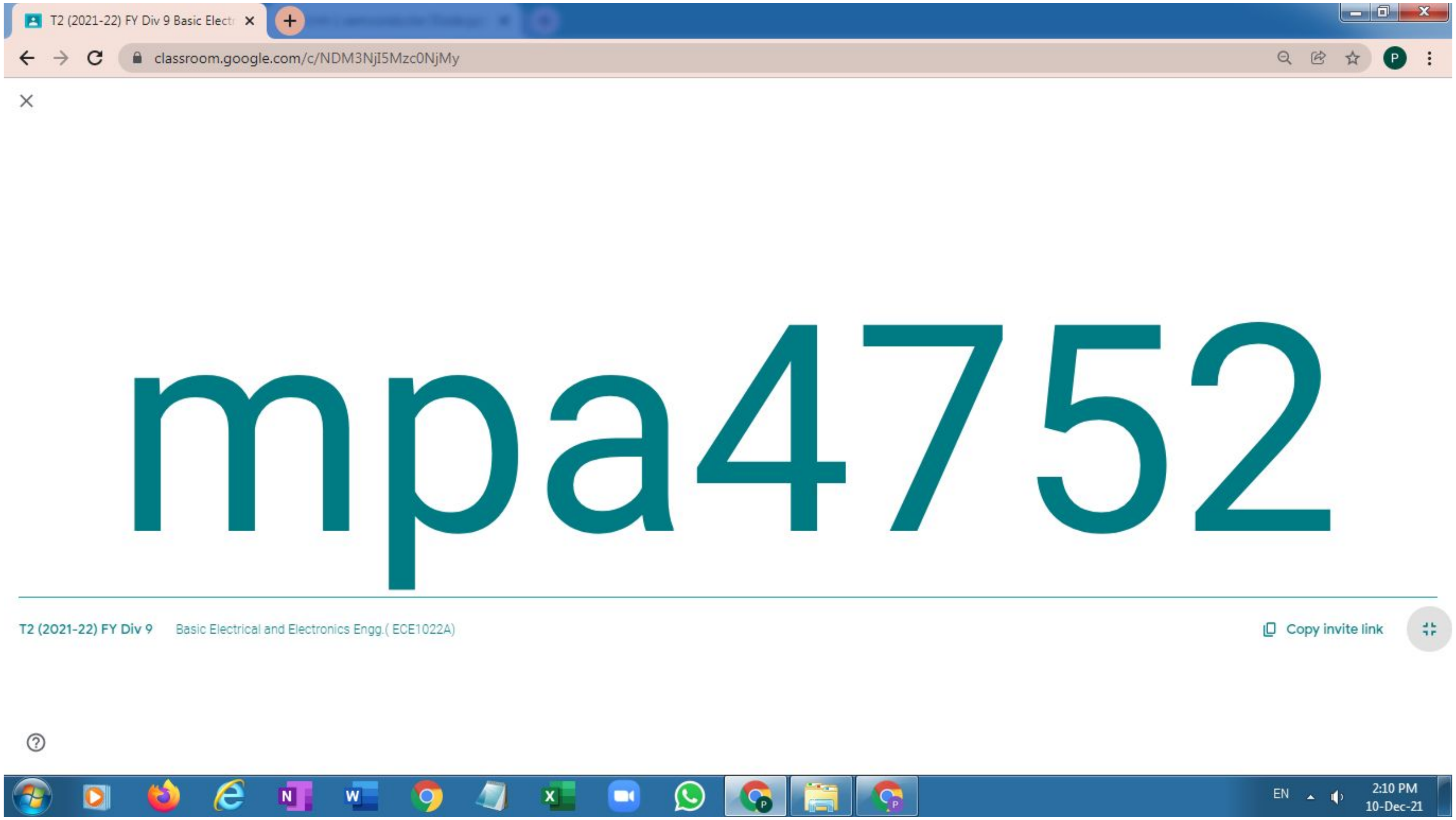
  Digital integrated circuits: Logic Gates, Boolean algebra, Combinational logic Circuits, De-Morgan's theorems, SOP, POS, K- map, Half Adder, Full Adder, flip-flops: RS flipflop, JK flip flop, D flip flop, shift registers, Introduction to Microcontroller (8L)

Course Contents contd…

- **Single Phase Transformer:** Working principle, Construction, Types, Equivalent circuit, Losses, Efficiency, Regulation (6L)
- **D.C. Circuits:** Basic active and passive circuit elements, dependent and independent sources, series, parallel, star to delta and delta to star conversion, KCL, KVL, Thevenin's Theorem, Superposition Theorem (8L)
- **A.C. Circuits:** Generation of alternating EMF, Equation of alternating quantity, waveforms, phasor representation, Concept of impedance, admittance and power triangle, series RL, RC, RLC circuits, Series resonance, parallel circuits, Generation of three phase EMF(8L)

Google Classroom – Class code

Pls visit classroom.google.com to join the BEEE classroom using the code given below.



List of Laboratory Exercises / Practical:

After completion of the laboratory course students will be able to handle basic Laboratory Exercises like-

1.**Introduction to instruments and electronic components, Build and test Light Emitting diode Circuit on Bread- Board**

2. Design of rectifier using PN junction diode.

3. Design of voltage regulator using Zener diode.

4. Measurement of transistor amplifier gain in CE configuration.

5. Design and implementation of Full Adder using basic and universal gates.

6. Design of inverting and non-inverting amplifier using OPAMP.

7 **Verification of KVL, KCL**

8. Finding Resonant Frequency of series R-L-C circuit

9. Finding efficiency and regulation of Single-phase Transformer using Direct Loading method.

Books

Reference Books:

1. Hughes , “Electrical and Electronic Technology”, 10th Edition, Pearson
2. Cotton H., “Electrical Technology”, 7th Ed., C.B.S. Publication.
3. Theraja B.L., “Electrical Technology”, Vol. I and II, 2005, S. Chand
4. R.P. Jain, Modern Digital Electronics. New Delhi: Tata McGraw-Hill, 4th Edition, 2009

Supplementary Reading:

1. Nagrath I.J. and Kothari D.P., “Theory and Problems of Basic Electrical Engineering”, 2005, PHI Learning Pvt. Ltd
2. Floyd Thomas, “Electronic Devices”, Prentice Hall, 9th Edition 2012

Links:

https://legacy-uploads.ul.com/wp-content/uploads/sites/40/2016/02/Internet-of-Things-white-paper_final.pdf.pdf

Assessment Scheme

Class Continuous Assessment (CCA) (100 Marks)

Assignments	Mid term Test	MCQ test
50	20	30

Laboratory Continuous Assessment (LCA) (50 Marks)

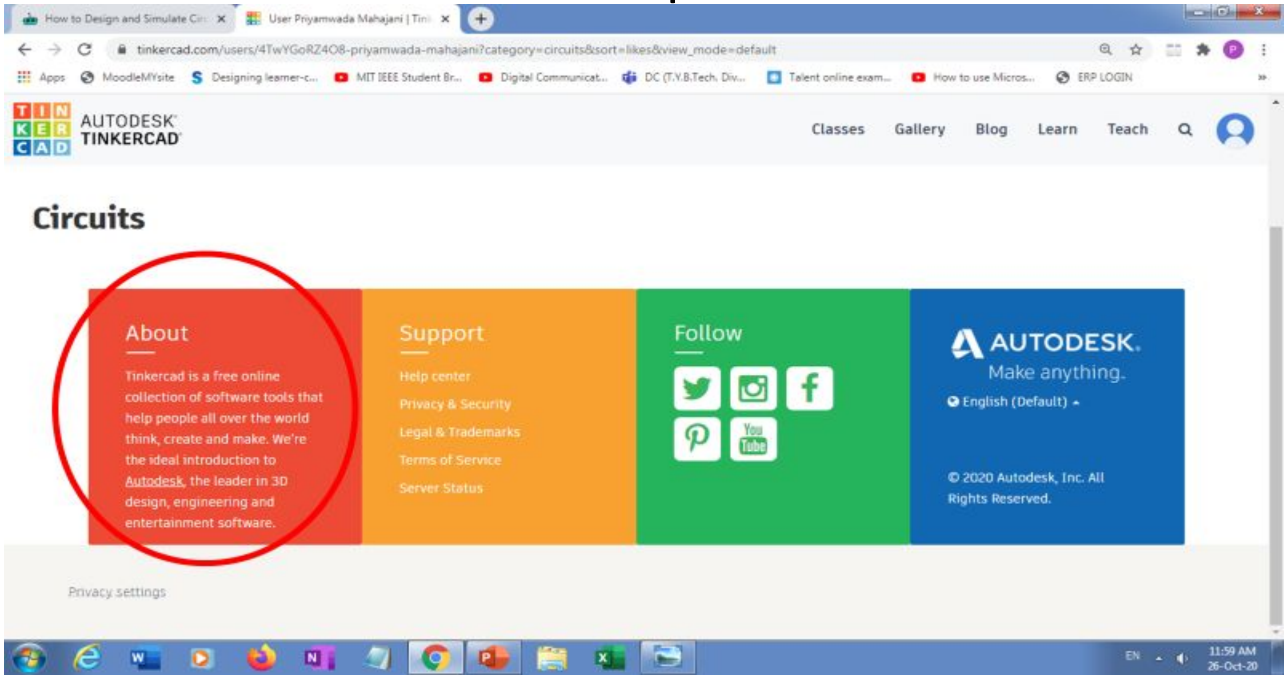
Labwork + Submission	Project
30	20

Term End Examination:

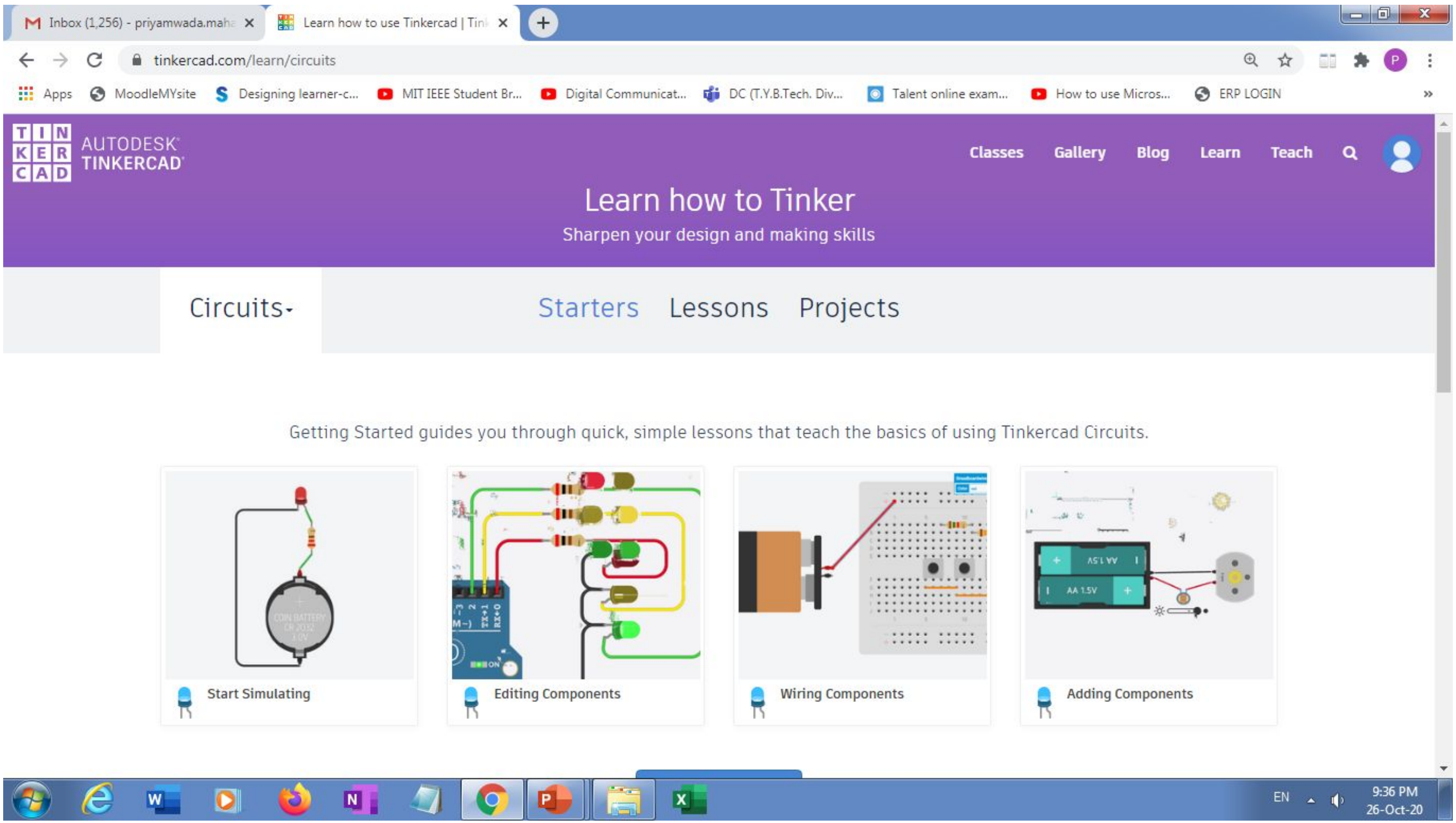
Term end exam of 50 Marks will be based on entire syllabus.

Lab Experiments / Simulations

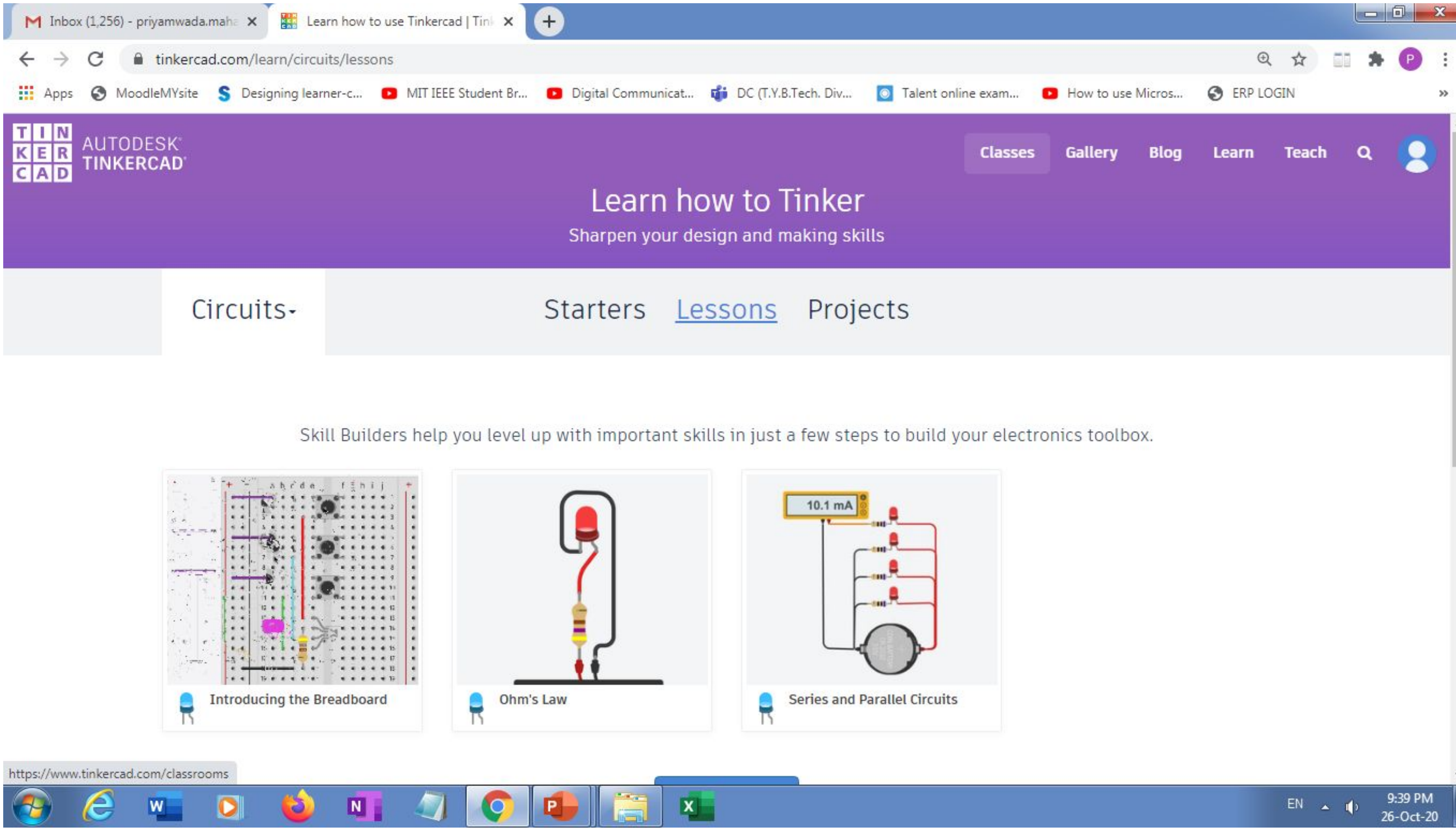
- Tinkarcad software – Circuits section
- Pls visit : https://www.tinkercad.com/dashboard
- Create your account/register using gmail id forTinkercad software use
- Simple tutorials are available for practice



Basics of Tinkercad circuits



Lessons in Tinkercad



Simple circuit simulation designed in Tinkercad

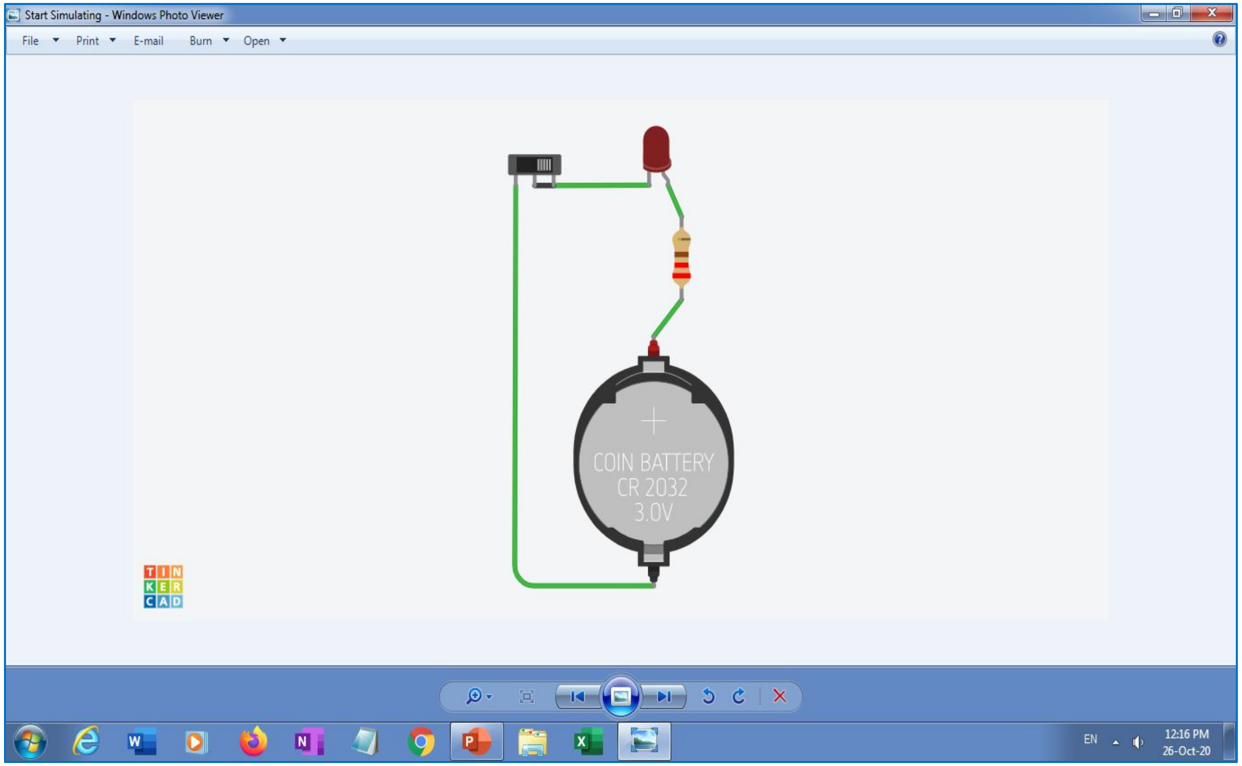
Components:

1. Red LED
2. Coin Battery 3V
3. Slide-switch
4. Resistor 220 Ohms
5. Connecting wires

Operation:

Switch position will decide whether LED in ON or OFF.

In simulation, LED turning ON/OFF can be seen by sliding the switch.



Topic1: Semiconductor Diodes

- Semiconductor Diode Characteristics
- Rectifiers : Half wave Rectifiers, Full wave Rectifiers
- Rectifier with Capacitor filters
- Zener diode & its applications
- LEDs and applications

https://www.khanacademy.org/science/electrical-engineering/ee-semiconductor-devices/ee-diode/v/ee-diode

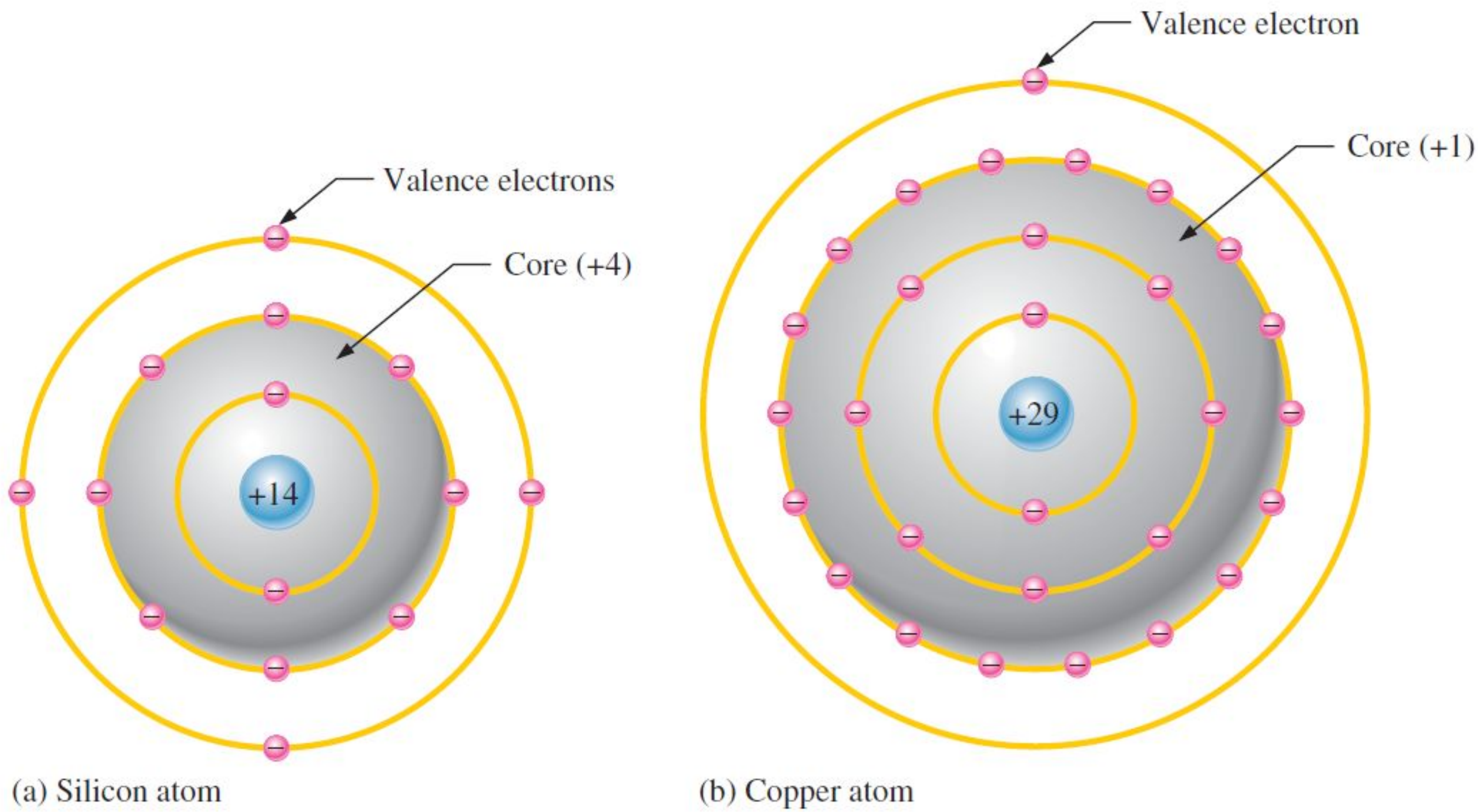
Introduction to Semiconductor Material

- Two types of semiconducting materials Silicon and Germanium are used in electronic devices
- Both have four valance electrons- tetravalent
- When Silicon and Germanium atoms combine into molecules to form a solid material they arrange themselves in fixed pattern called a crystal/lattice
- Atoms within the crystal structure are held together by covalent bonds
- An intrinsic crystal is one that has no impurities

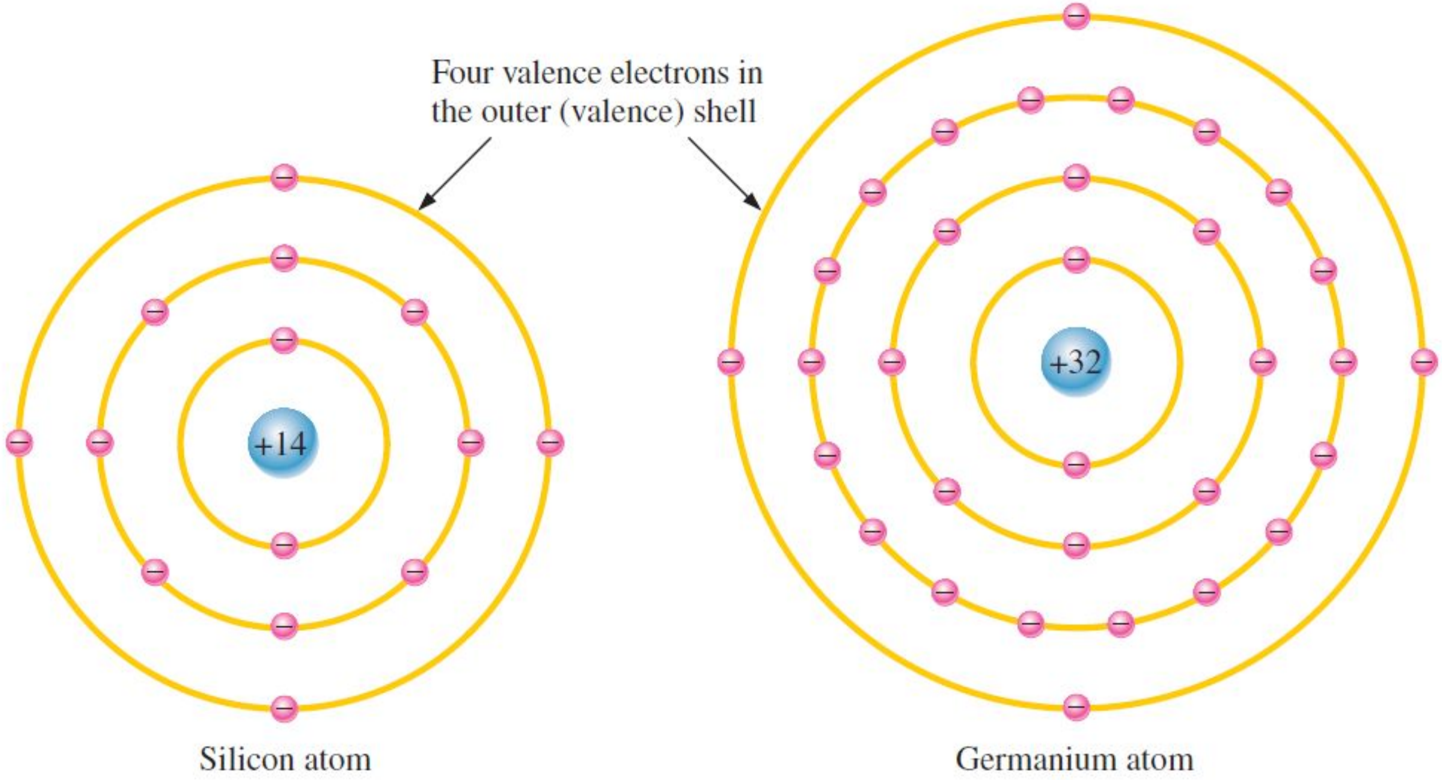
Introduction to Semiconductor Material

- In an intrinsic semiconductor there are very few free electrons
- Pure semiconductor materials are neither good conductor nor good insulators
- Intrinsic semiconductor material must be modified by increasing the free electrons and holes to increase its conductivity and make it useful for electronic devices
- By adding impurities, n-type and p-type extrinsic semiconductor material can be produced

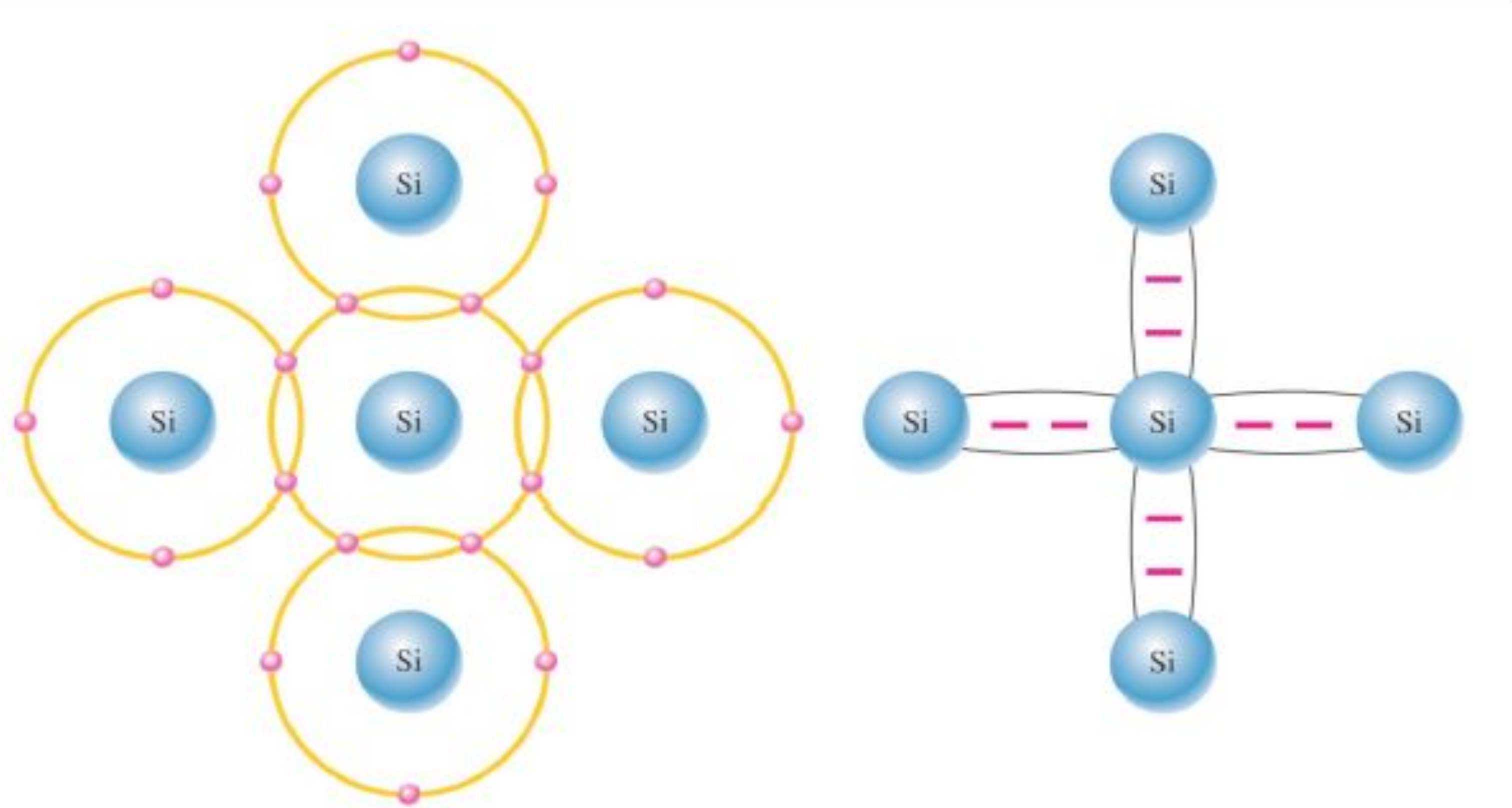
Bohr diagrams of the silicon and copper atoms



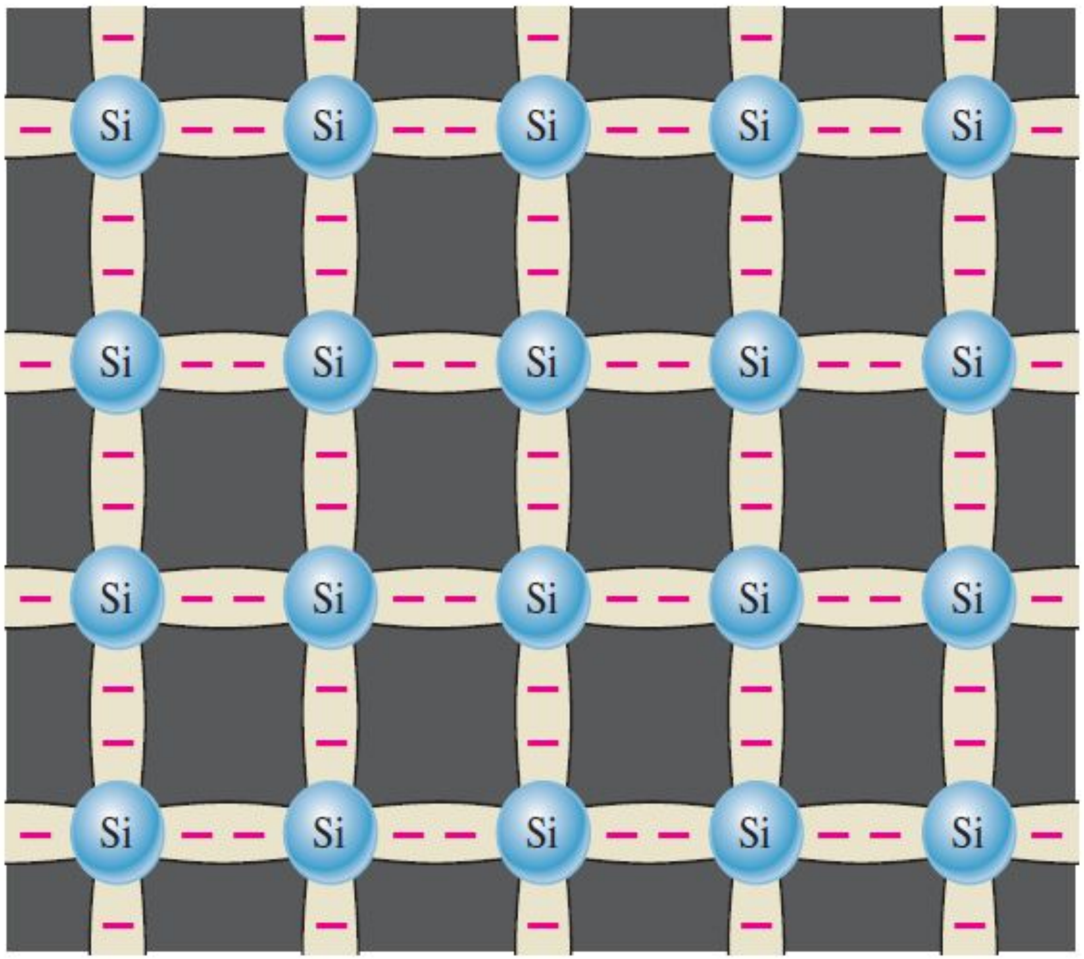
Silicon and Germanium atoms



Covalent bonds in silicon

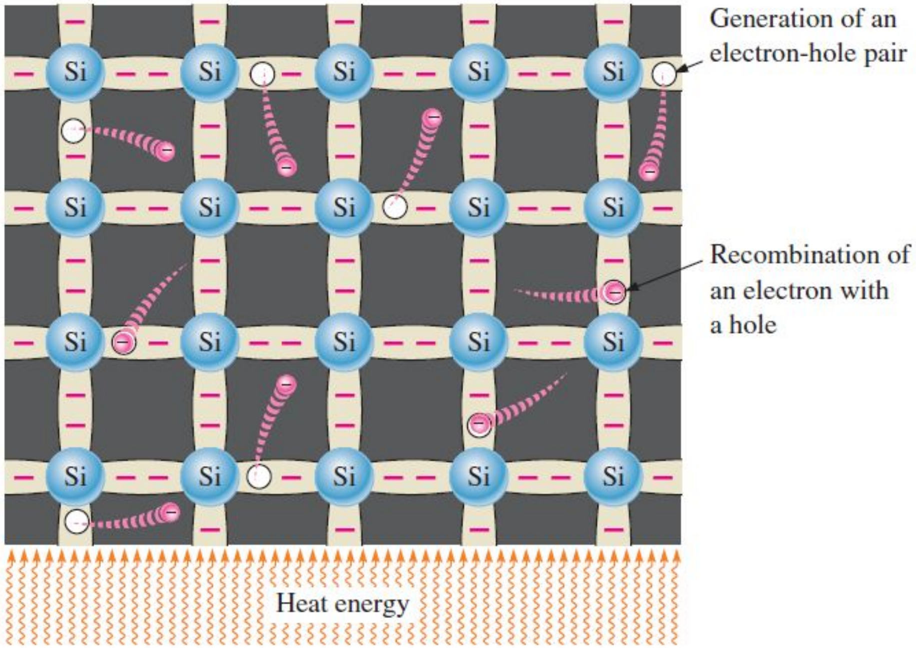


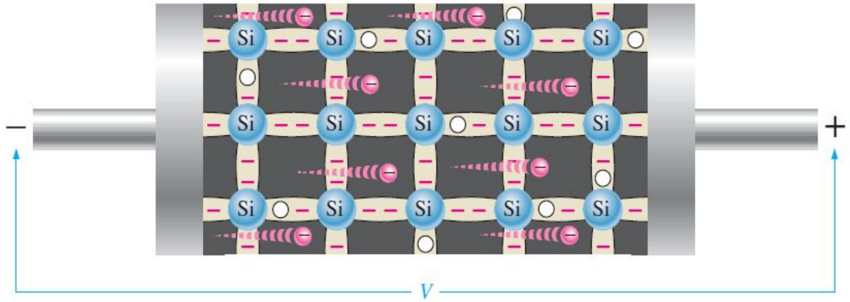
Covalent bonds in a silicon crystal



An intrinsic Silicon crystal

Electron and Hole Current





Electron current in intrinsic silicon is produced by the movement of thermally generated free electrons

Modified Semiconductor material

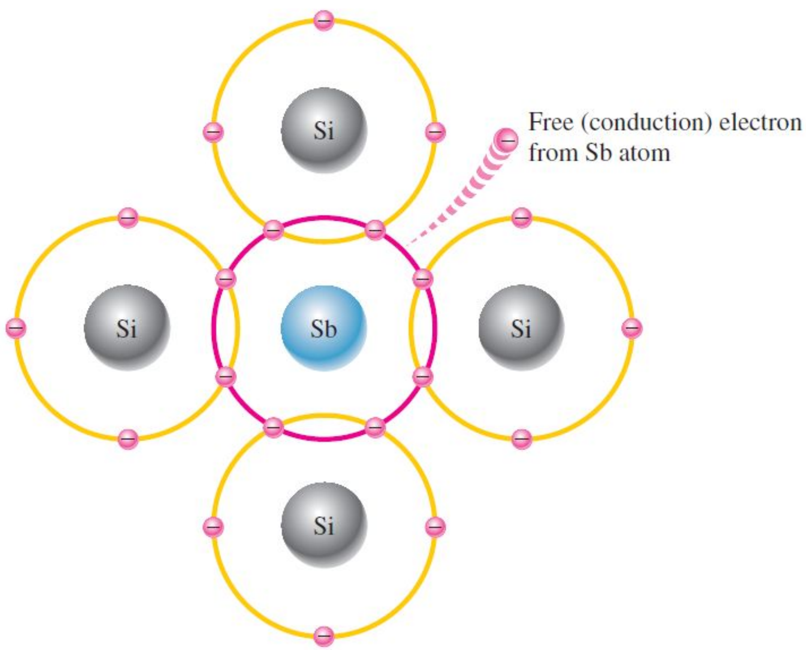
- Doping is the process of adding impurities to intrinsic semiconducting materials to increase and control conductivity within the material

✔ **N-type material** is formed by adding **pentavalent** (5 valance electrons) impurity atoms such as arsenic (As), phosphorus (P), and antimony (Sb).
  - electrons are called majority carriers in n-type material
  - holes are called minority carrier in n-type material

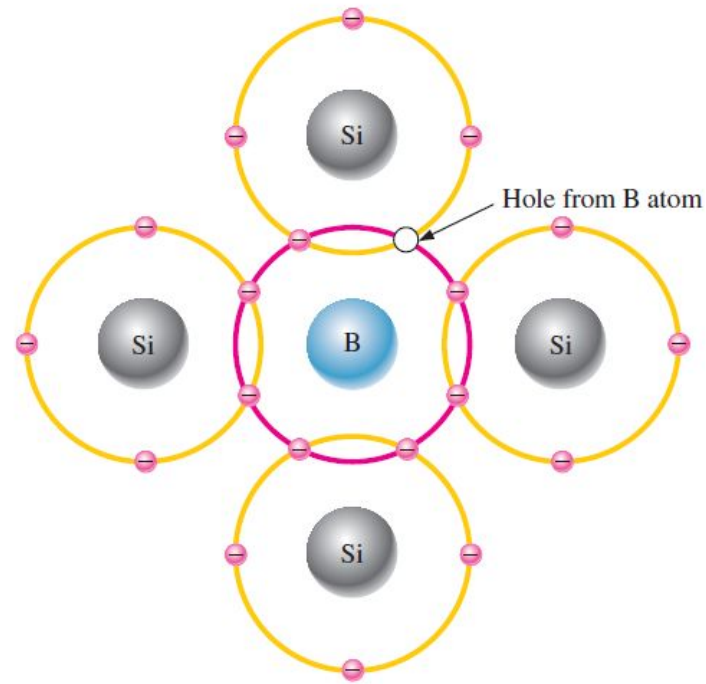
✔ **P-type material** is formed by adding **trivalent** (3 valance electrons) impurity atoms such as boron (B), indium (In), and gallium(Ga)
  - holes are called majority carriers in p-type material
  - electrons are called minority carrier in p-type material

N-type and P-type Semiconductors

***N*-Type Semiconductor Semiconductor**

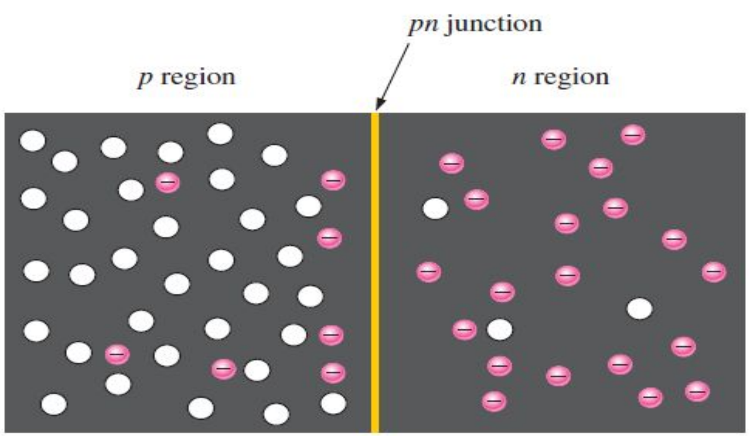


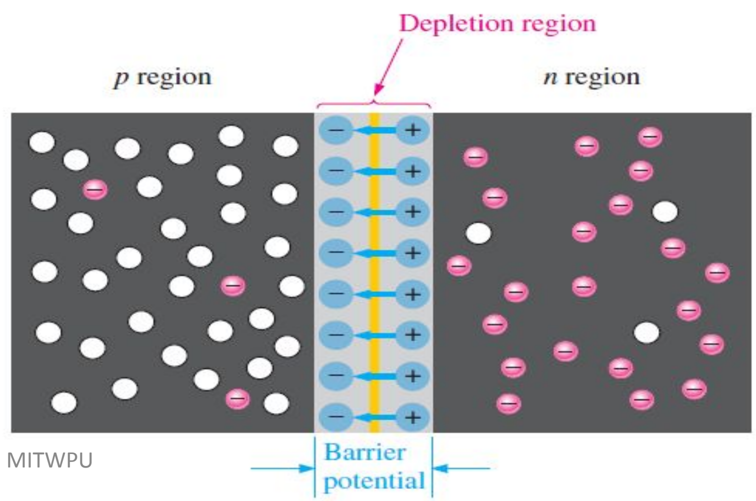
***P*-Type**



PN Junction

- A block of Si is doped with a trivalent impurity in half part and the other half part doped with pentavalent impurity, a boundary called PN junction is formed.
  - ✔ Yellow line shows PN junction
  - ✔ Electrons near PN junction diffuses across the junction and combines with holes, a positive charge is left in the n region and a negative charge is created in the p region, forming a **Depletion Region**.
  - ✔ Region near the pn junction is depleted of charge carriers (electrons and holes) due to diffusion across the junction.
  - ✔ Depletion region is formed very quickly and is very thin compared to the n region and p region.
  - ✔ This action continues until the voltage of the barrier repels further diffusion.





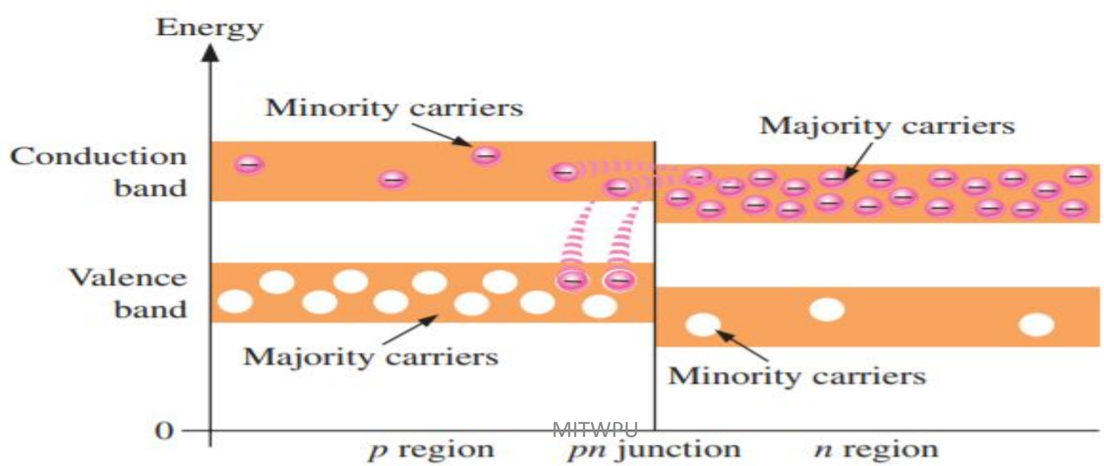
PN Junction

- Forces between the opposite charges form an electric field (blue arrows)
- The potential difference of the electric field across the depletion region is the amount of voltage required to move electrons through the electric field.
- This potential difference is called the **barrier potential** and is expressed in volts.
- To overcome the barrier potential, a certain amount of voltage equal to the barrier potential and with the proper polarity must be applied across a PN junction before electrons will begin to flow across the junction.

Energy Diagrams of PN Junction

An energy diagram for a pn junction at the instant of formation

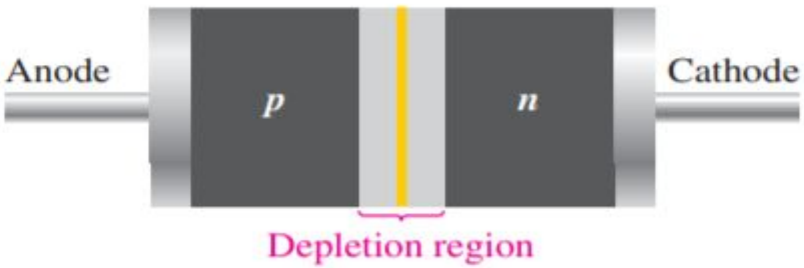
- Valence and conduction bands in the n region are at lower energy levels than those in the p region (trivalent impurities exert lower forces on the outer shell electrons than the pentavalent)
- Lower forces in P-type means, electron orbits are slightly larger hence have greater energy than electrons in n-type.
- There is a significant amount of overlapping also.
- Free electrons in the n region occupy the upper part of the conduction band in terms of their energy can easily diffuse across the junction (they do not have to gain additional energy)
- These electrons temporarily become free electrons in the lower part of the p-region conduction band.
- After crossing the junction, the electrons quickly lose energy and fall into the holes in the p-region valence band as indicated in the figure



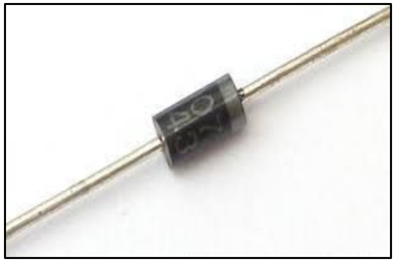
The PN Junction Diode

- A **diode** is made from a small piece of semiconductor material, usually silicon, in which half is doped as a *p* region and half is doped as an *n* region with a *pn* junction and depletion region in between.

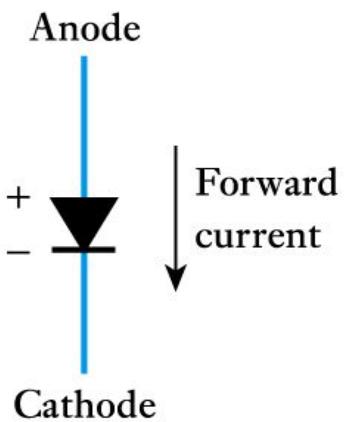
- Two terminal device: Anode and Cathode



(a) Basic structure

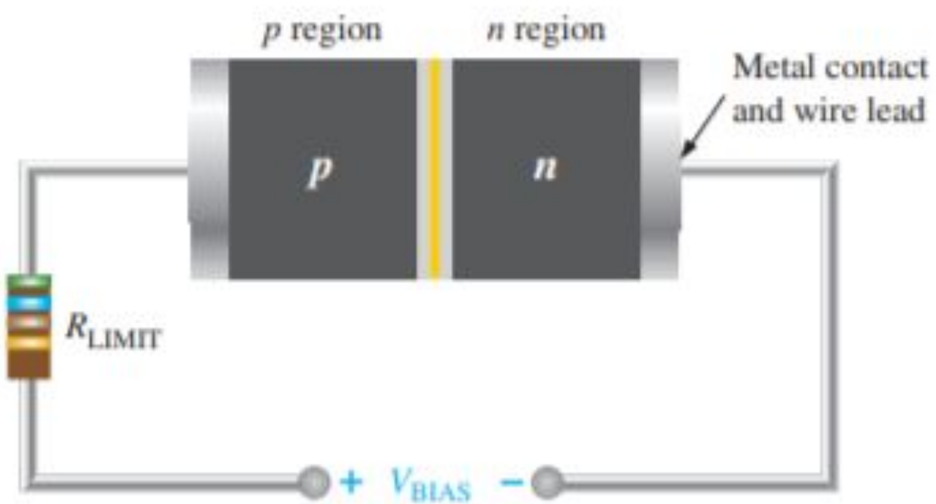


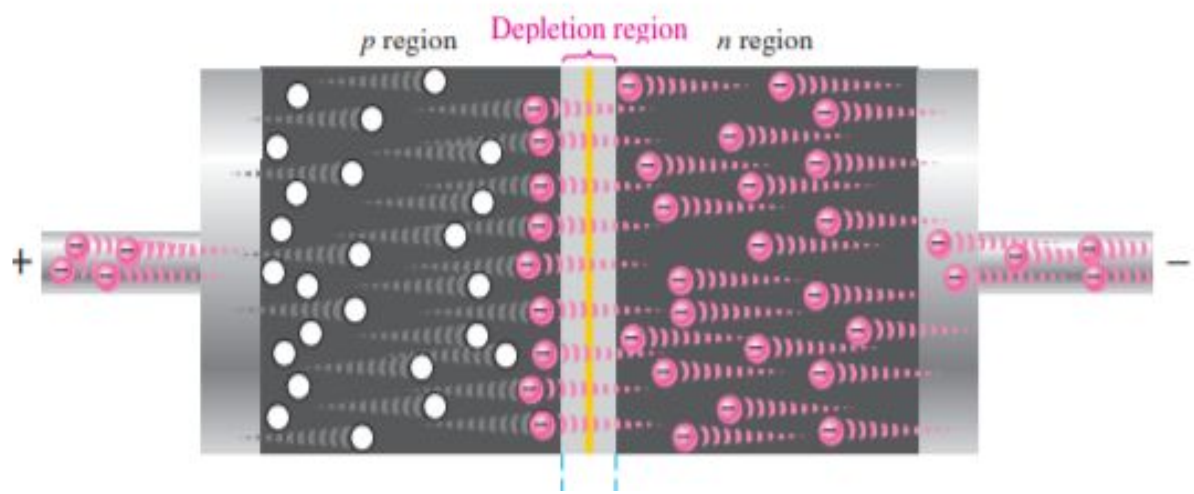
Diode Image



(b) Diode circuit symbol

Forward Biased Diode Requirements

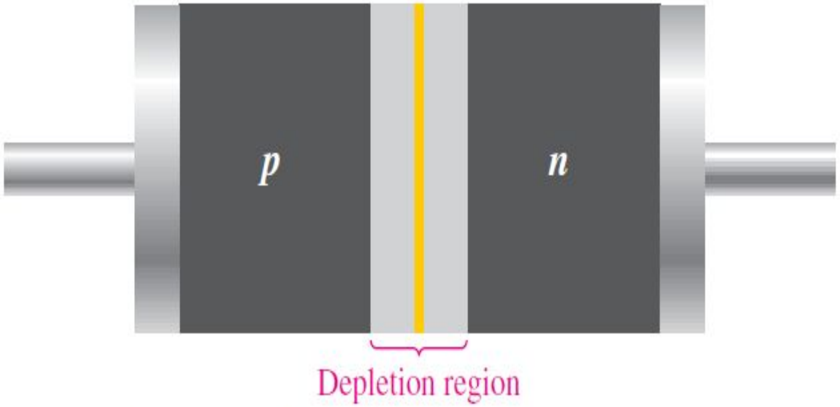




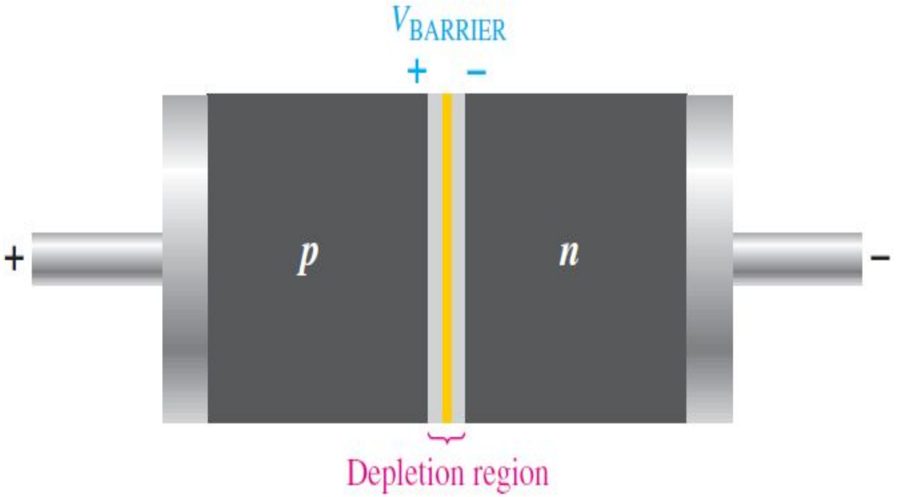
Forward Biased Diode Requirements

- R_{limit} – current limiting resistance, V_{BIAS} – must be greater than barrier potential
- Effect of Forward Bias : Depletion Region becomes narrow
- Effect of Barrier Potential During FB: Free electrons overcome the barrier potential and give up an amount of energy equivalent to barrier potential.
- Voltage drop across PN junction is for Si=0.7 V and Ge=0.3 V
- An additional small voltage drop occurs across p and n regions due to internal resistance of the material (dynamic resistance)

The Effect of Forward Bias on the Depletion Region

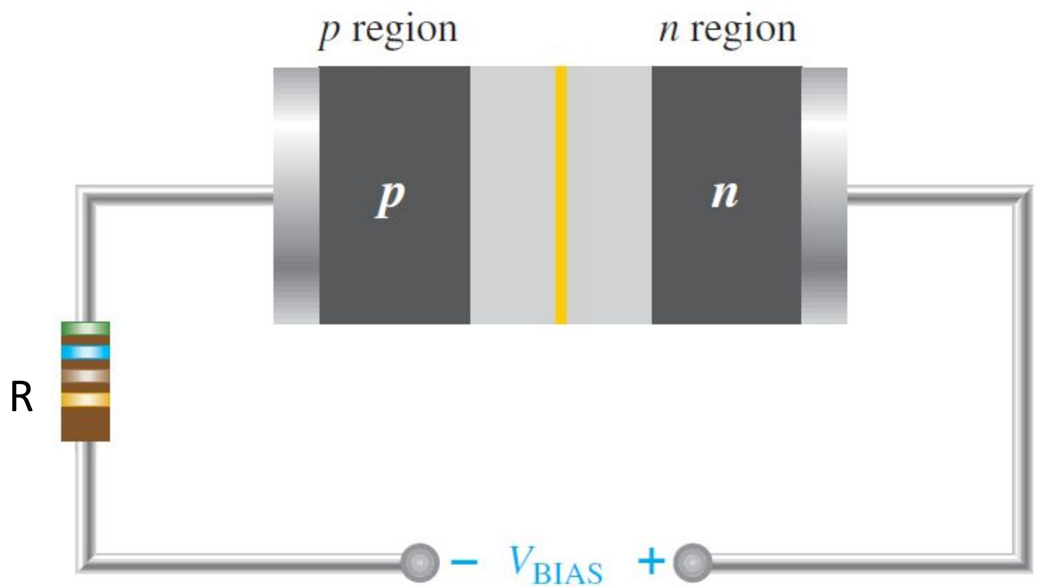


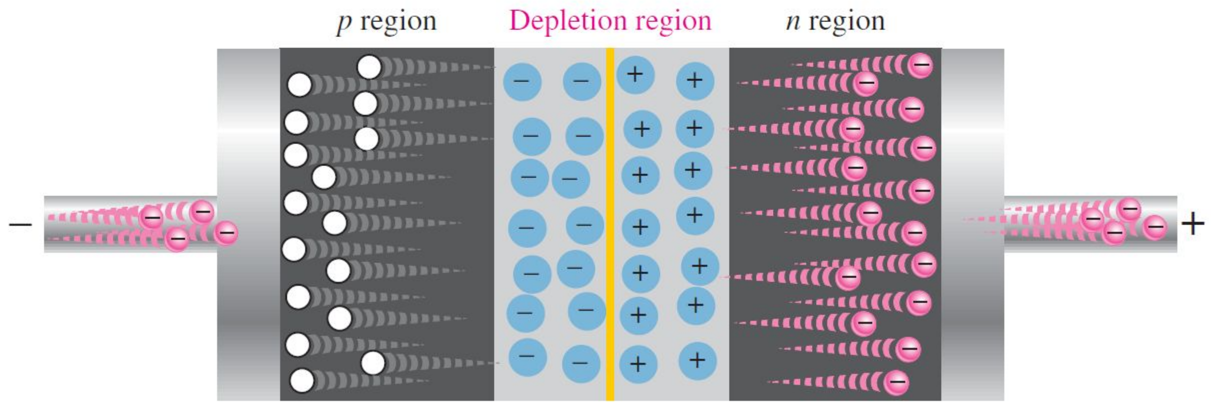
(a) At equilibrium (no bias)



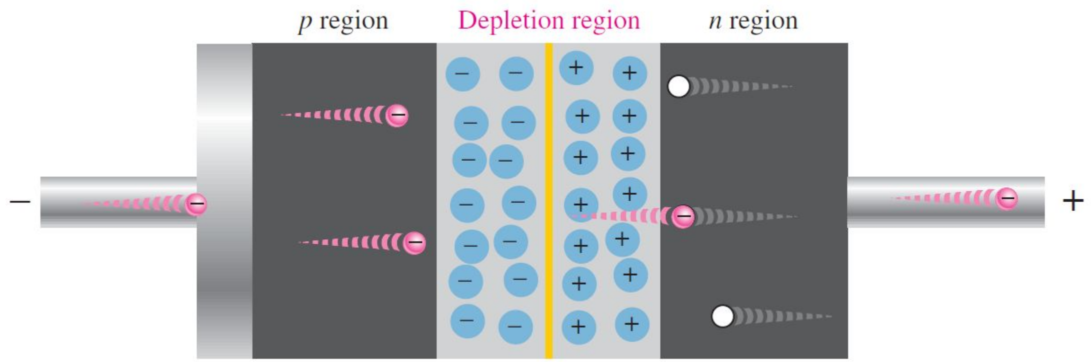
(b) Forward bias narrows the depletion region and produces a voltage drop across the *pn* junction equal to the barrier potential.

Reverse Bias



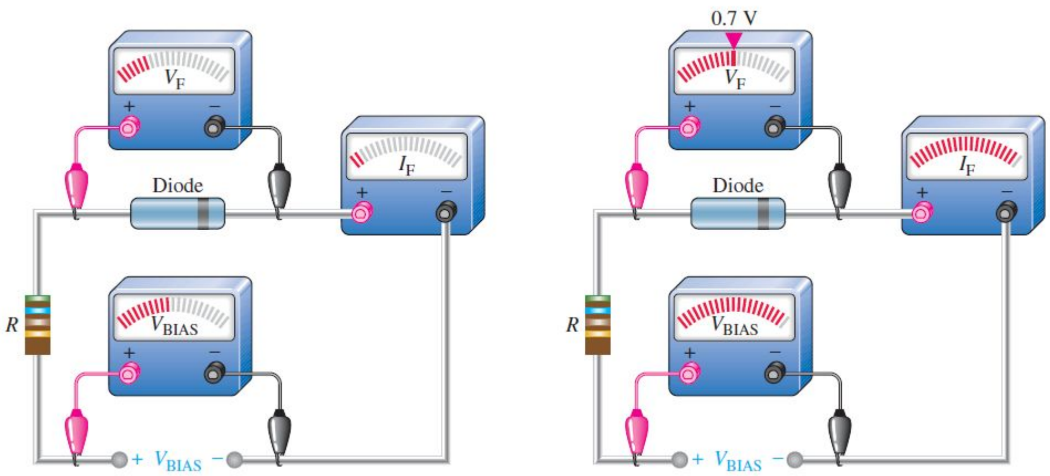


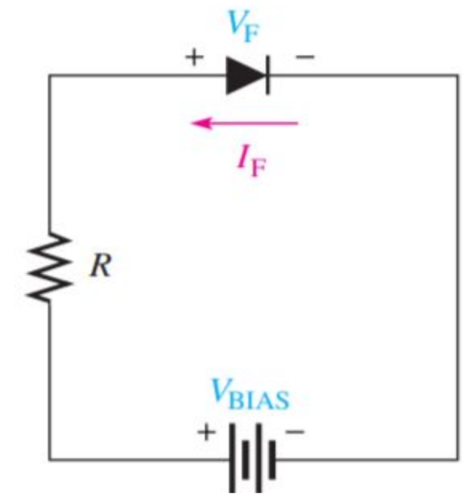
Reverse Bias

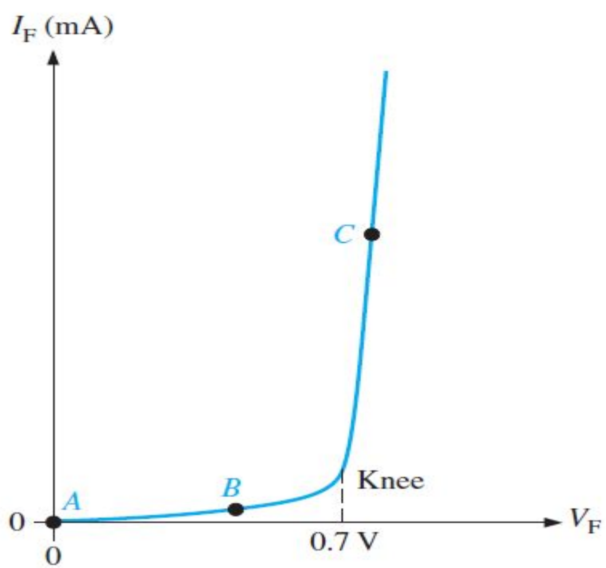


- The extremely small reverse current in a reverse-biased diode is due to the minority carriers from thermally generated electron-hole pairs.
- If the external reverse-bias voltage is increased to a value called the breakdown voltage, the reverse current will drastically increase.
- The multiplication of conduction electrons is known as the **avalanche effect.**

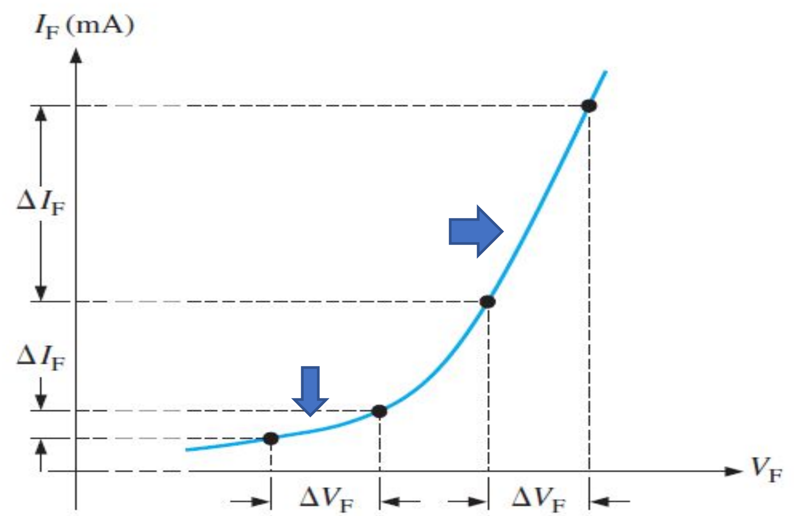
V-I characteristics of a diode in Forward Bias







(a) *V-I* characteristic curve for forward bias.



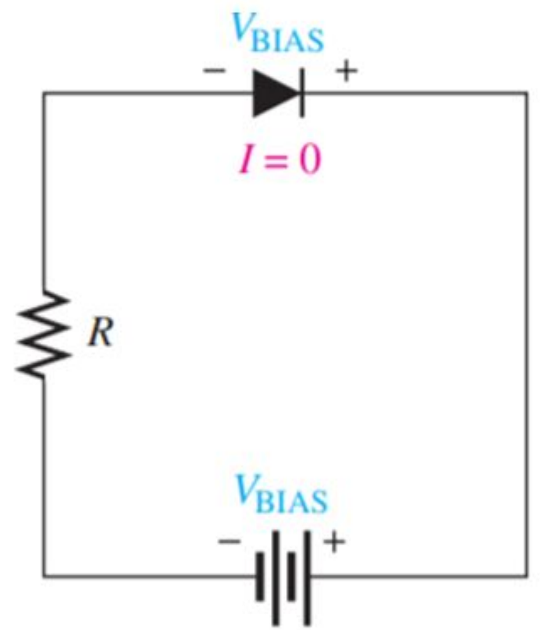
(b) Expanded view of a portion of the curve in part (a). The dynamic resistance r'_d decreases as you move up the curve, as indicated by the decrease in the value of $\Delta V_F / \Delta I_F$.

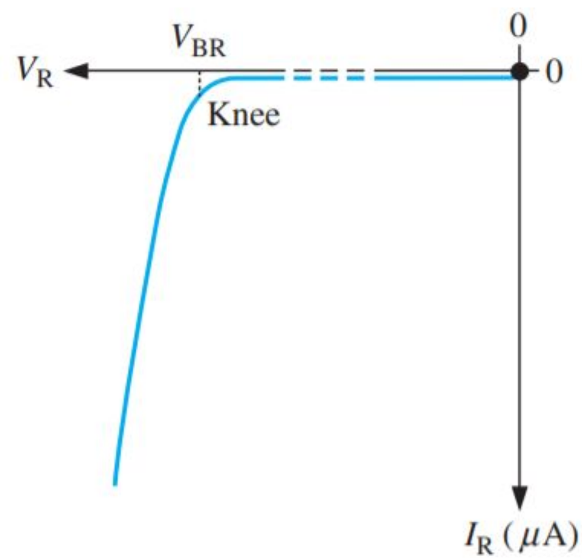
V-I characteristics of a diode in Forward Bias

- Forward current (I_F) - cathode to anode (flow of electrons).
- Conventional current flow (due to holes) - high potential to low potential (opposite of I_F).
- Forward voltage drop (V_F) due to the barrier potential
- R limits forward current, so that overheating and damage of diode is avoided.
- $V_{BIAS} = 0$, $I_F = 0$
- Gradual increase in V_{BIAS} : I_F and voltage across the diode V_F start increasing gradually
- A portion of forward-bias voltage is dropped across R
- V_{BIAS} increased: V_F = approximately 0.7 V (barrier potential), the forward current begins to increase rapidly.
- Further increase in V_{BIAS} : I_F increases very rapidly, but the voltage across the diode increases only gradually above 0.7 V.
- Voltage drop across diode is above 0.7 V due to the voltage drop across the internal dynamic resistance of the semiconducting material.
- $rd = \Delta V_F / \Delta I_F$

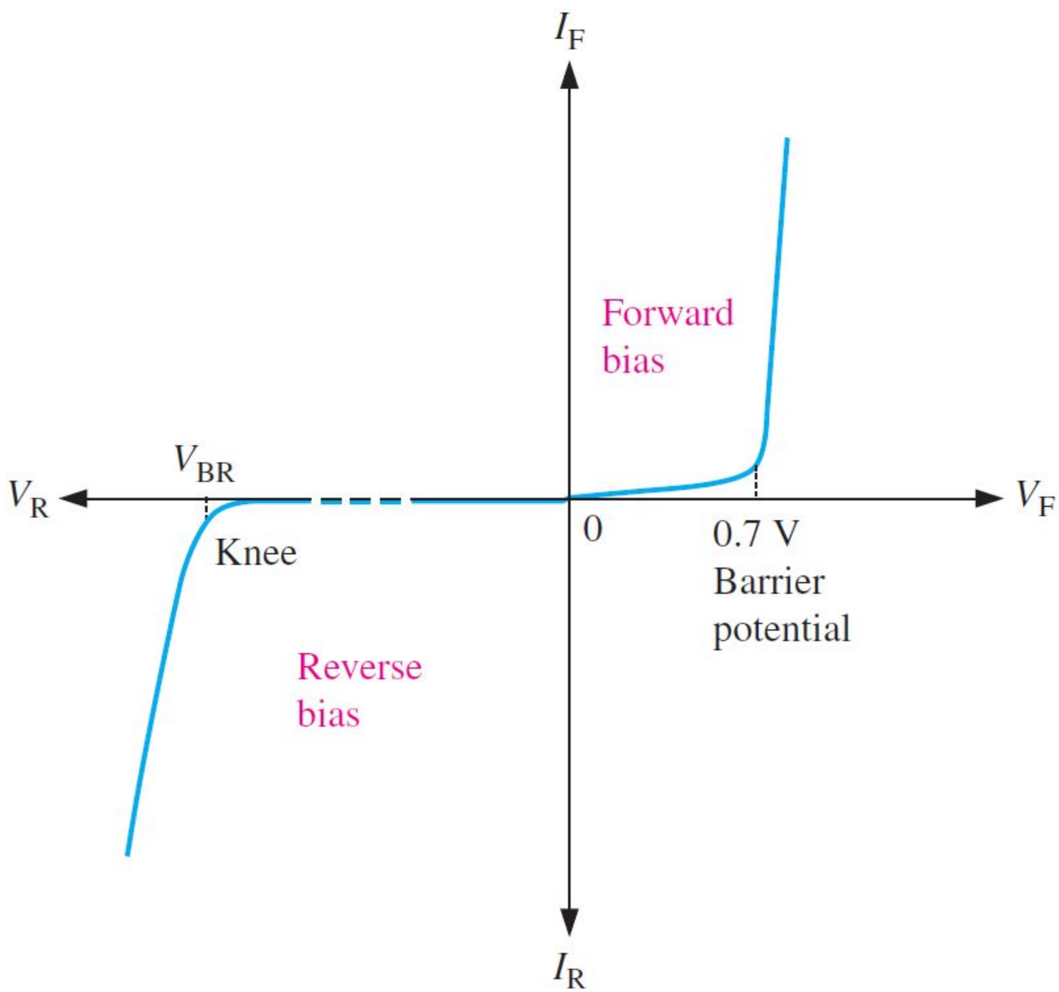
V-I Characteristic for Reverse Bias

- Extremely small reverse current (I_R) flow through the pn junction.
- V_{BIAS}=0,I_R=0
- Gradual increase in V_{BIAS} - very small reverse current flow and the voltage across the diode increases.
- When V_{BIAS} is increased: V_R = breakdown value (V_{BR}), the reverse current increases rapidly.
- Further increase in V_{BIAS}- current increases very rapidly, but the voltage across the diode increases very little above V_{BR}.
- Breakdown, with exceptions, is not a normal mode of operation for most pn junction devices.



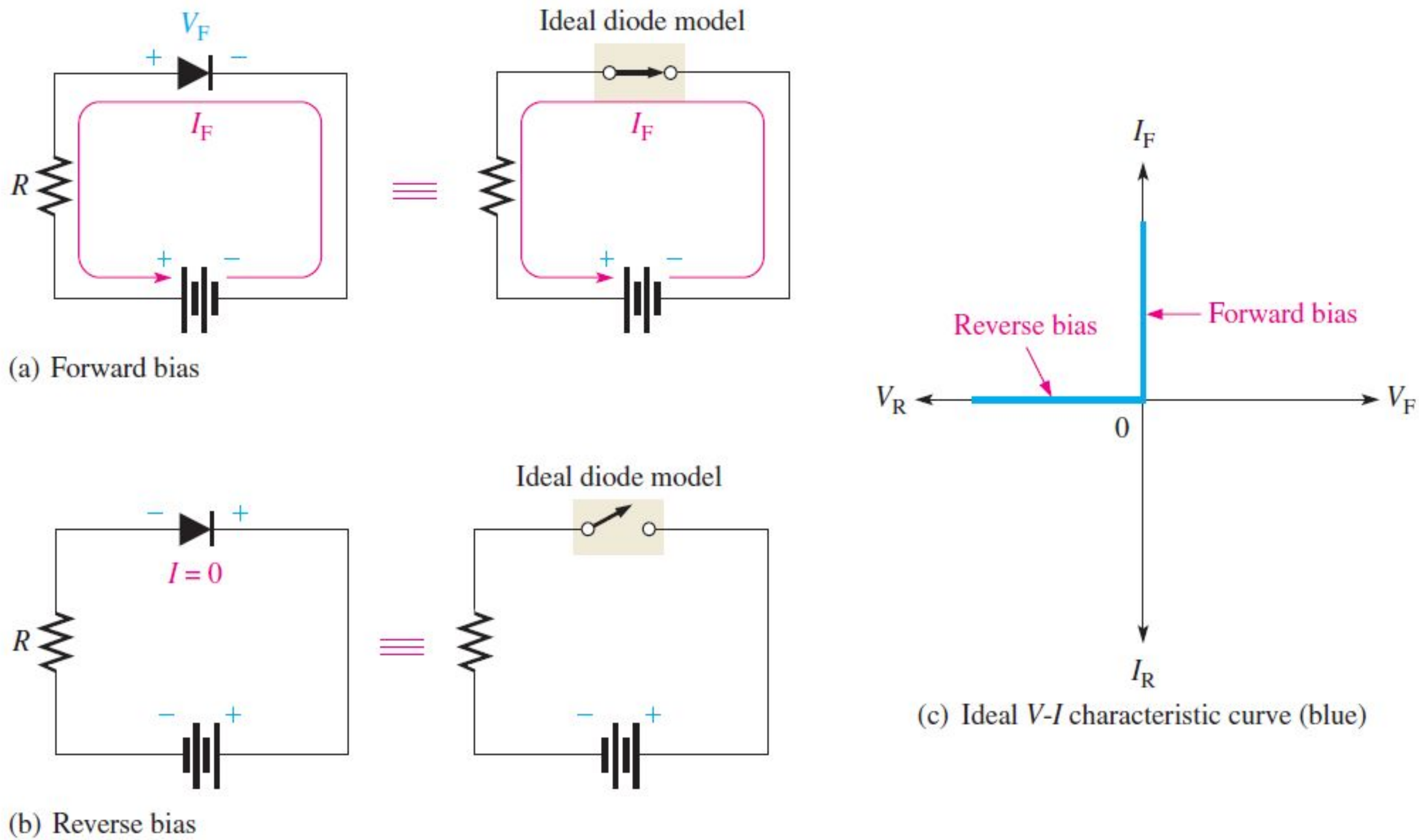


The Complete V-I Characteristic Curve of a diode



Diode Approximations

The Ideal Diode Model



(a) Forward bias

(b) Reverse bias

(c) Ideal *V-I* characteristic curve (blue)

The Ideal Diode Model

voltage across it when forward-biased –

$$V_F = 0$$

The forward current is determined by the bias voltage and the limiting resistor using Ohm's law -

$$I_F = \frac{V_{BIAS}}{R_{LIMIT}}$$

Since the reverse current is neglected, its value is assumed to be zero-

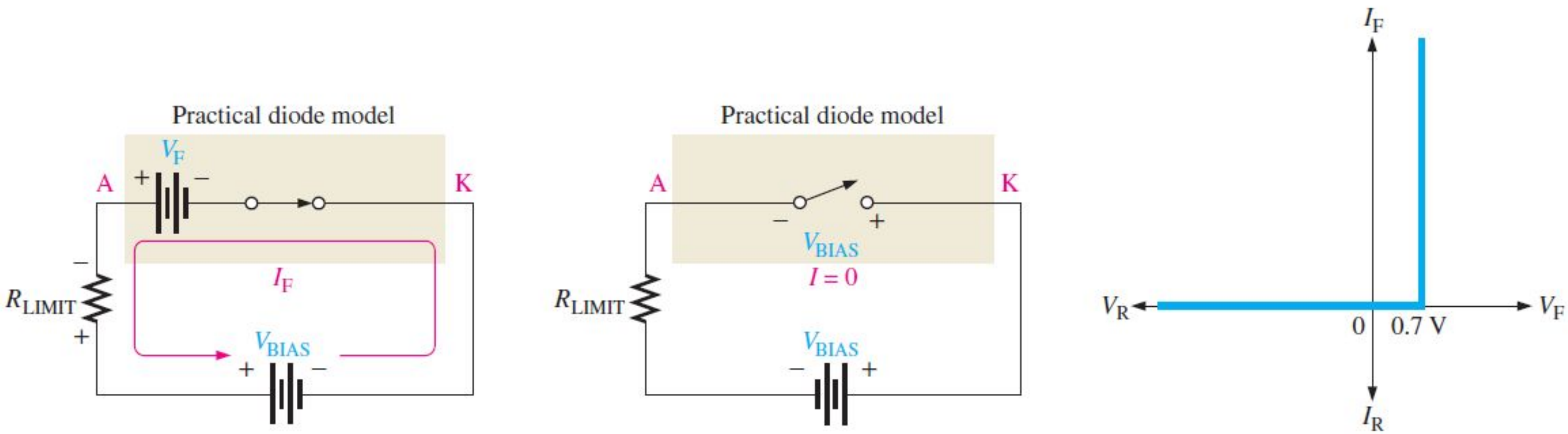
$$I_R = 0$$

The reverse voltage equals the bias voltage-

$$\mathrm{V_R} = V_{BIAS}$$

Diode Approximations

The Practical Diode Model



(a) Forward bias (b) Reverse bias (c) Characteristic curve (silicon)

Barrier potential for Si diode= 0.7 V

The Practical Diode Model

The voltage across it when forward-biased –

$$V_F = 0.7\text{ V}$$

The forward current is determined as-

$$\mathrm{V_{BIAS}} - \mathrm{V_F} - \mathrm{V_{R_{LIMIT}}} = 0$$

$$\mathrm{V_{R_{LIMIT}}} = \mathrm{I_F\ R_{LIMIT}}$$

Solving for I_F-

$$I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}}$$

The reverse current is neglected, its value is assumed to be zero-

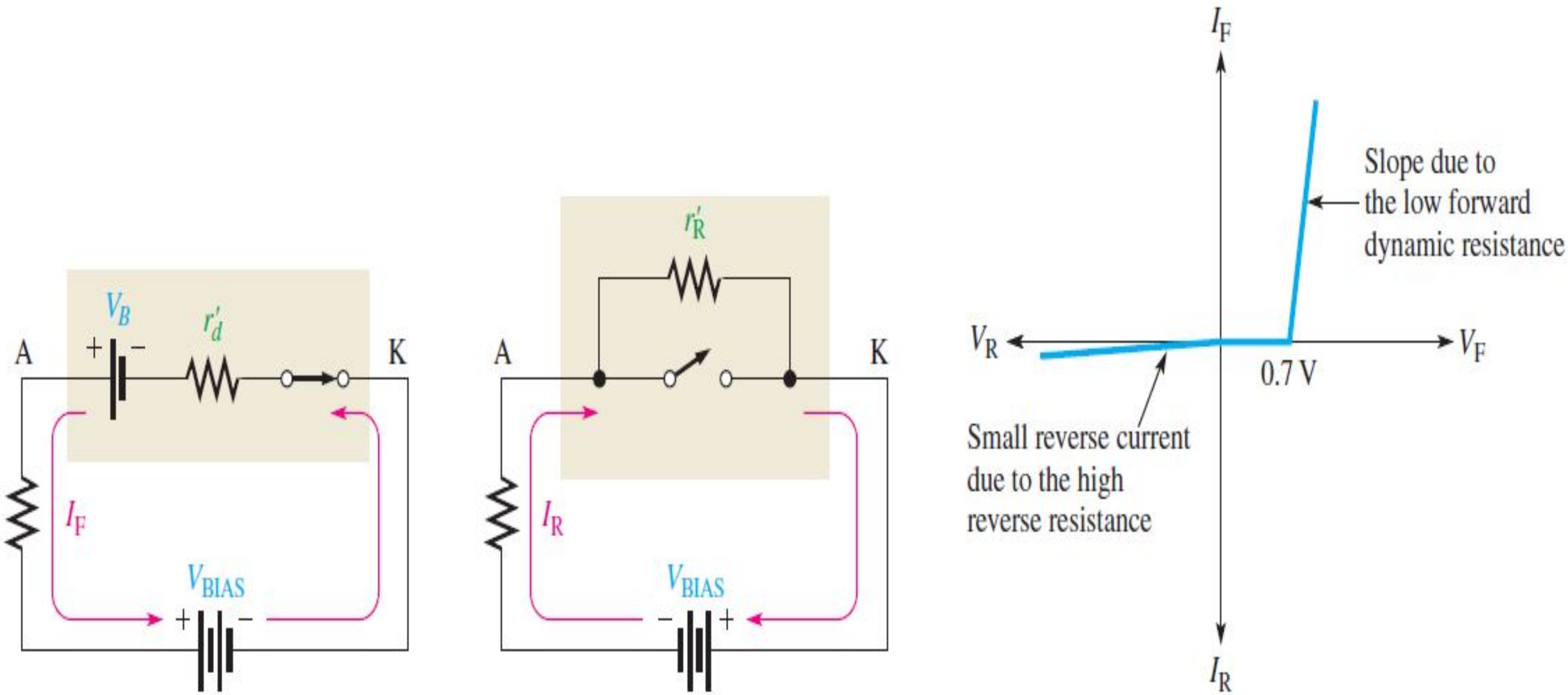
$$I_R = 0$$

The reverse voltage equals the bias voltage-

$$\mathrm{V_R} = V_{BIAS}$$

Diode Approximations

The Complete Diode Model



(a) Forward bias (b) Reverse bias (c) *V-I* characteristic curve

The Complete Diode Model

voltage across it when forward-biased –

$$V_F = 0.7 + I_F r'_d$$

The forward current is determined as-

$$\mathrm{V_{BIAS}} - \mathrm{V_F} - \mathrm{V_{R_{LIMIT}}} = 0$$

$$\mathrm{V_{R_{LIMIT}}} = \mathrm{I_F}\,\mathrm{R_{LIMIT}}$$

Solving for I_F-

$$I_F = \frac{V_{BIAS} - 0.7}{R_{LIMIT} + r'_d}$$

Diode Current Equation

- The relation between applied voltage V across the diode and current I flowing through the diode can be expressed mathematically as:

$$I = I_0\left(e^{\left(\frac{V}{\eta V_T}\right)} - 1\right)$$

where

I =The current flowing through the diode

V= The voltage applied across the diode

I_0= Doide saturation current (approx. doubles for every 10° C rise in temperature)

η = The exponential ideality factor

= 2 for Si p-n junction diode

= 1 for Ge p-n junction diode

V_T= Volt equivalent of temp

= T/11,600 (at room temp T=300°K) and V_T = 0.026 V or 26 mV

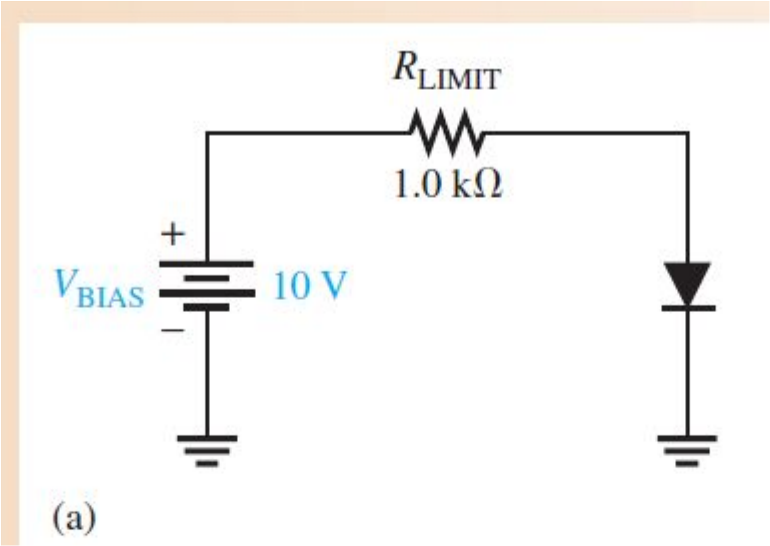
q =Charge on the electron $= 1.6 \times 10^{-19}$C

K =Boltzman's constant $= 1.38 \times 10^{-23}$ J/ ^oK

T = Temperature in ^oK

Example 1

- Determine the forward voltage and forward current for the diode in Figure below for each of the diode models. Also find the voltage across the limiting resistor in each case. Assume at the determined value of forward current, r’d=10 ohms



Example 1

Solution **(a)** Ideal model:

$$V_F = \mathbf{0\ V}$$

$$I_F = \frac{V_{BIAS}}{R_{LIMIT}} = \frac{10\ \text{V}}{1.0\ \text{k}\Omega} = \mathbf{10\ mA}$$

$$V_{R_{LIMIT}} = I_F R_{LIMIT} = (10\ \text{mA})(1.0\ \text{k}\Omega) = \mathbf{10\ V}$$

Practical model:

$$V_F = \mathbf{0.7\ V}$$

$$I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}} = \frac{10\ \text{V} - 0.7\ \text{V}}{1.0\ \text{k}\Omega} = \frac{9.3\ \text{V}}{1.0\ \text{k}\Omega} = \mathbf{9.3\ mA}$$

$$V_{R_{LIMIT}} = I_F R_{LIMIT} = (9.3\ \text{mA})(1.0\ \text{k}\Omega) = \mathbf{9.3\ V}$$

Complete model:

$$I_F = \frac{V_{BIAS} - 0.7\ \text{V}}{R_{LIMIT} + r'_d} = \frac{10\ \text{V} - 0.7\ \text{V}}{1.0\ \text{k}\Omega + 10\ \Omega} = \frac{9.3\ \text{V}}{1010\ \Omega} = \mathbf{9.21\ mA}$$

$$V_F = 0.7\ V + I_F r'_d = 0.7\ \text{V} + (9.21\ \text{mA})(10\ \Omega) = \mathbf{792\ mV}$$

$$V_{R_{LIMIT}} = I_F R_{LIMIT} = (9.21\ \text{mA})(1.0\ \text{k}\Omega) = \mathbf{9.21\ V}$$

Applications of Diode

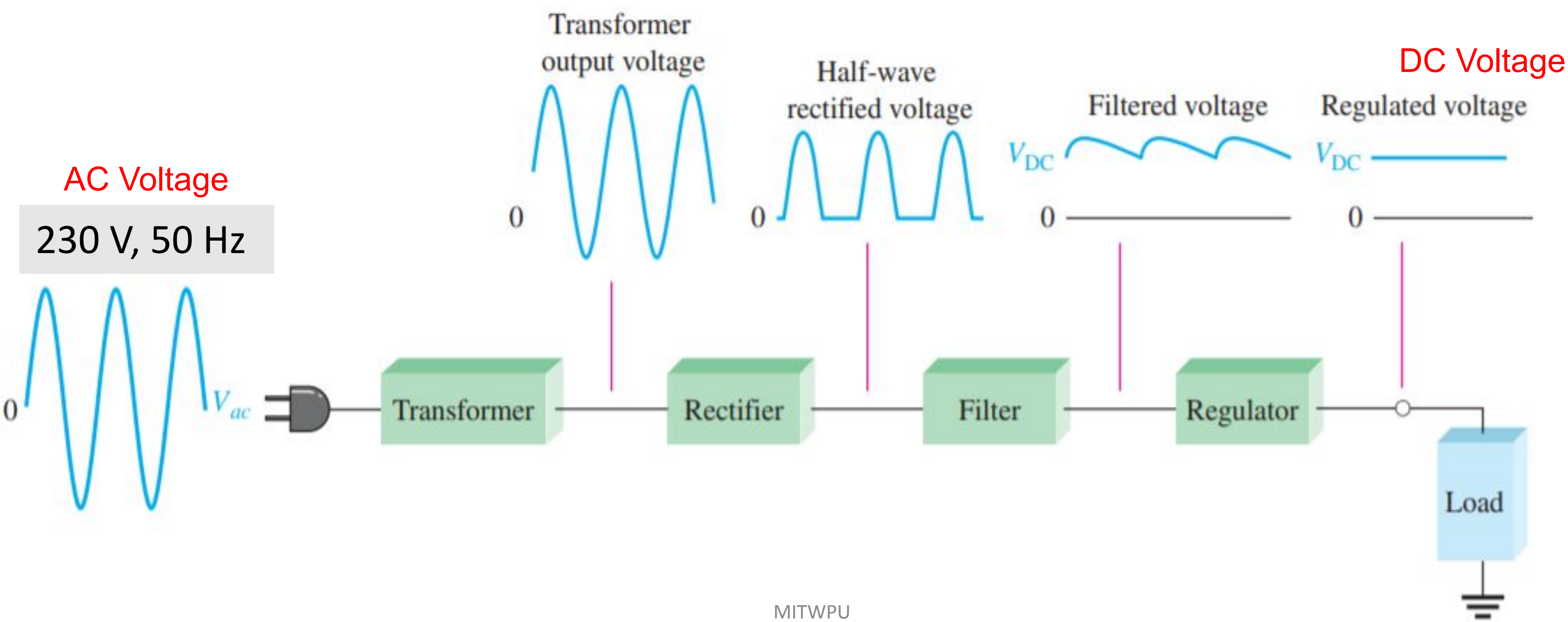
- Used as RECTIFIERS to convert AC to DC

Pls visit- https://www.youtube.com/watch?v=8Bzt-FFvRgQ

- Rectifiers are found in all DC power supplies
- Diodes are used as switches in some applications
- Zener diodes are used as Voltage regulators
- Reverse Current Protection Circuits
- Voltage Multipliers

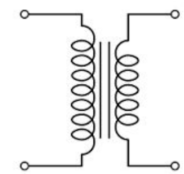
Regulated DC Power Supply

- Rectification- a process of converting AC voltage into the corresponding DC voltage
- DC power supply - one of the most commonly used circuit
- Voltage produced is used to power all types of electronic circuits i.e. consumer electronics, computers, industrial controllers, and most laboratory instrumentation systems and equipment
- The DC voltage level required depends on the application, but most applications require relatively low voltages

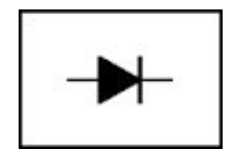


Building blocks of a DC power supply

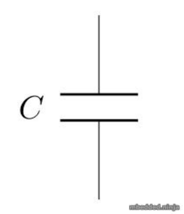
- ✔ **Step down Transformer**
  - Reduces the ac voltage to a tolerable level



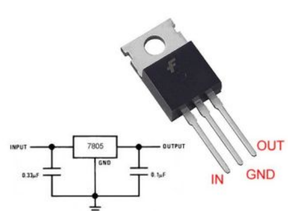
- ✔ **Rectifier**
  - Converts ac to pulsating dc



- ✔ **Filter**
  - Converts rectifier output to steady ripple-free voltage which is close to pure dc (ac part is removed)



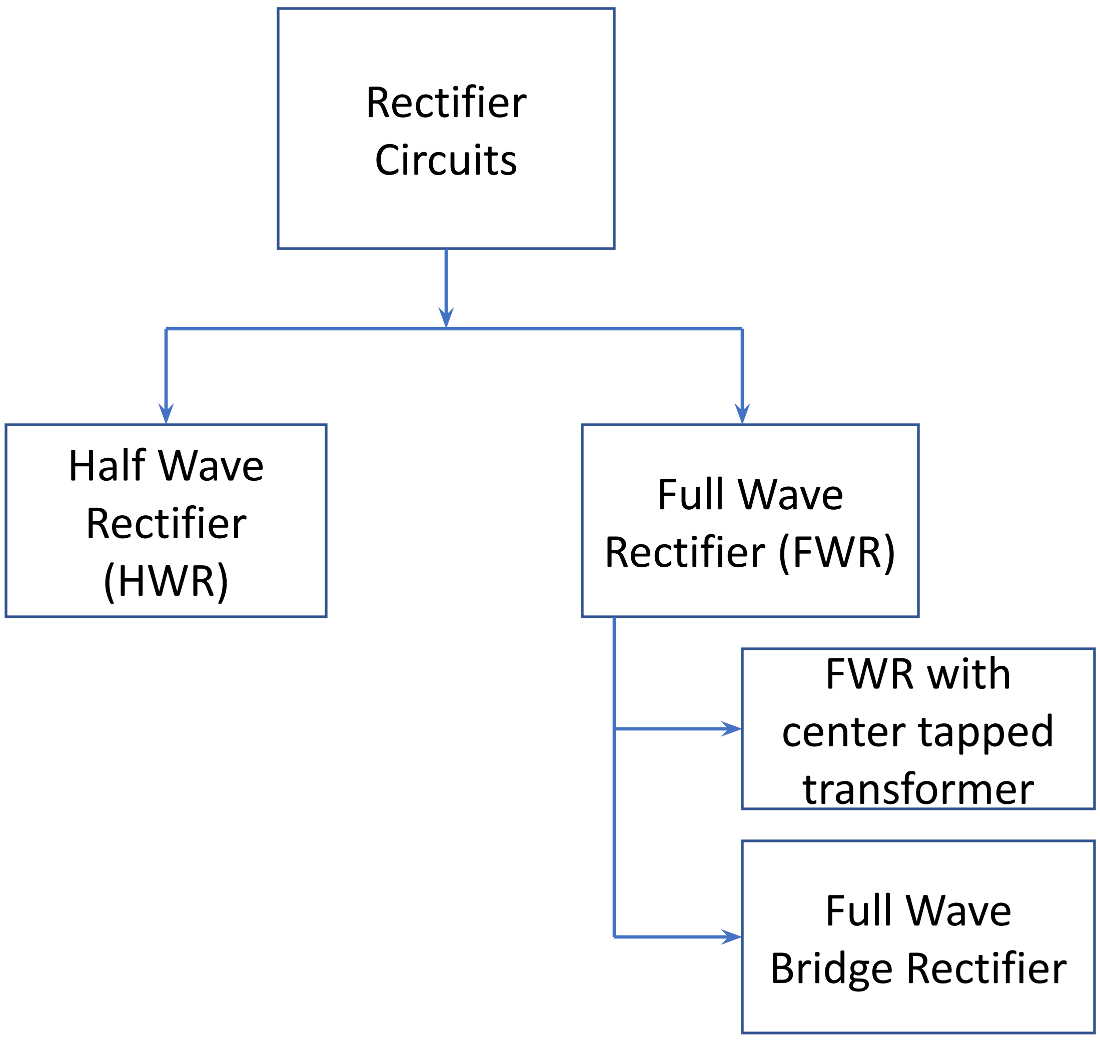
- ✔ **Regulator**
  - Keeps the dc output constant even if the input or load fluctuates.



Rectifier

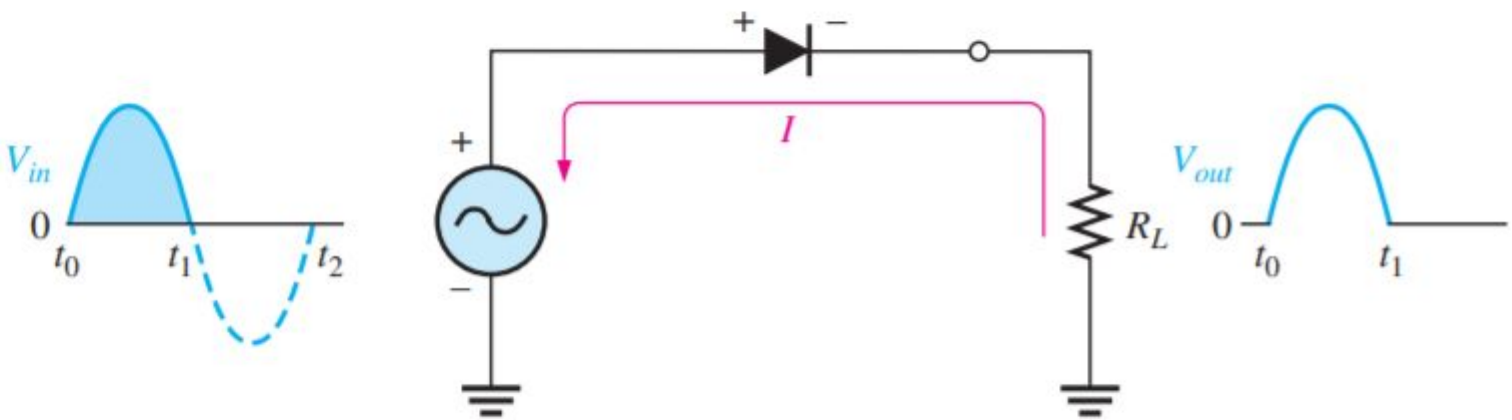
- An electronic device used for converting AC voltage/current into a unidirectional DC voltage/current.
- Diodes are used in rectifiers because of their ability to conduct current in only one direction and block current in the other direction.
- Rectifiers are used in several electronic devices we come across in our daily life, eg. TV, Radio, PC, adaptors, mobile chargers etc.
- Rectifiers form the basis for electronic power supplies and battery charging circuits.
- Energy Star program provides information on the energy consumption of products and devices using different standardized methods
- Power supplies to comply with the Energy Star requirements, must have a minimum 80% efficiency rating for all rated power output.

Classification of Rectifiers



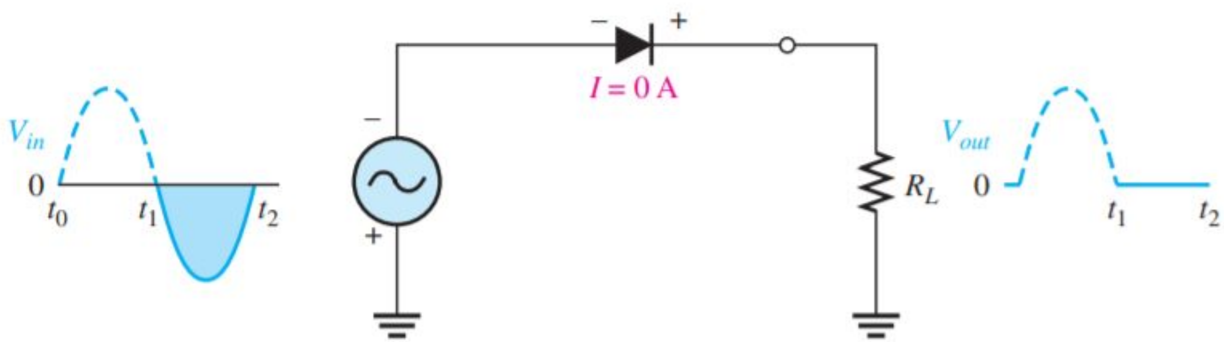
Half Wave Rectifier Circuit

HWR animation can be seen at : https://www.youtube.com/watch?v=8Bzt-FFvRgQ

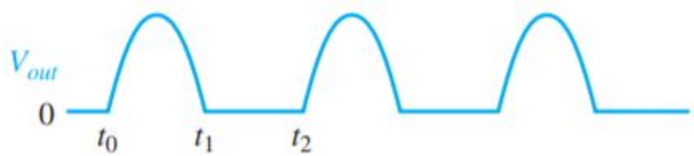


- A diode is connected to an ac source and to a load resistor, R_L, This forms a half-wave rectifier.
- All ground symbols represent the same point electrically.
- Considering the diode as ideal diode, during +ve half cycle of the input voltage , input voltage (Vin) goes positive, the diode is forward-biased and conducts current through the load resistor.
- The current produces an output voltage across the load RL, which has the same shape as the positive half-cycle of the input voltage.

Half Wave Rectifier Circuit contd..



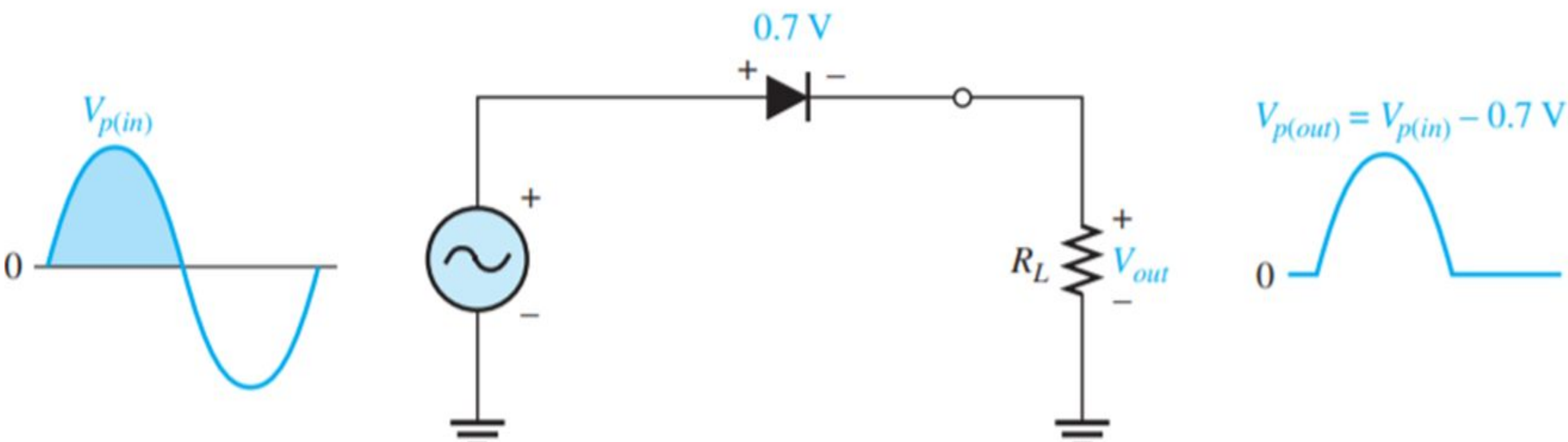
(b) During the negative alternation of the input voltage, the current is 0, so the output voltage is also 0.



- When the input voltage goes negative during the second half of its cycle, the diode is reverse-biased.
- There is no current, so the voltage across the load resistor is 0 V.
- The net result is that only the positive half-cycles of the ac input voltage appear across the load.
- Output does not change polarity, hence it is a pulsating dc voltage.

Effect of the Barrier Potential on the Half-Wave Rectifier Output

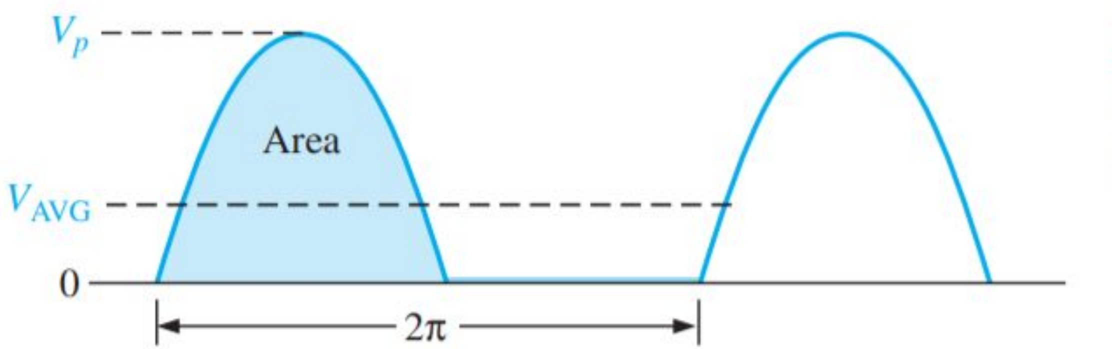
- During positive half-cycle, the input voltage must overcome the barrier potential before the diode becomes forward-biased.
- This results in a half-wave output with a peak value that is 0.7 V less than the peak value of the input.



$$V_{P(out)} = V_{P(in)} - 0.7$$

Average Value of the Half-Wave Output Voltage

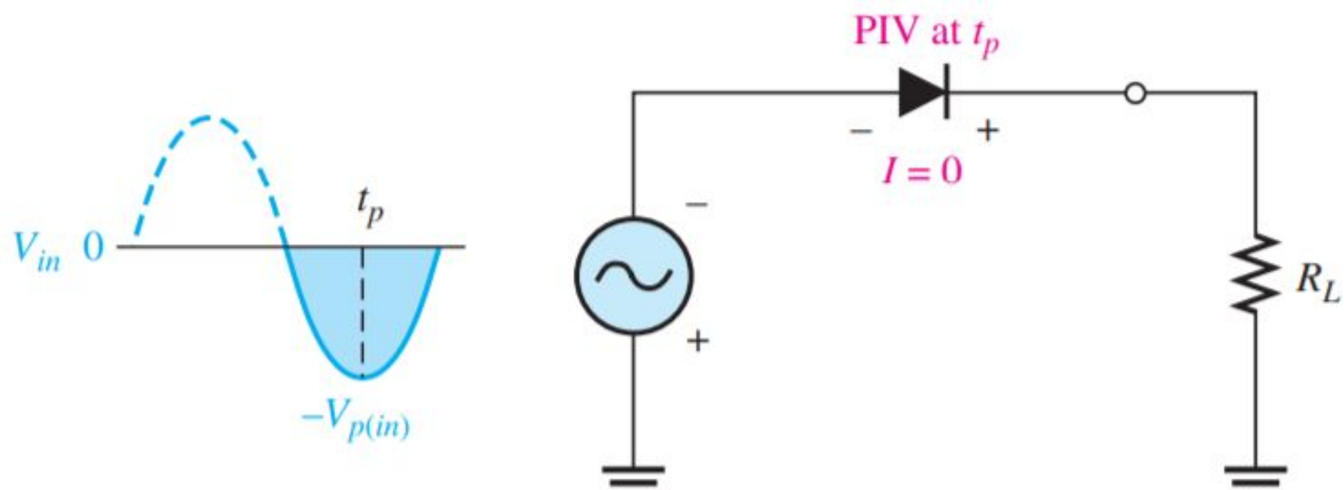
- Output voltage = value measured on a dc voltmeter.
- Mathematically, it is determined by finding the area under the curve over a full cycle, as illustrated in Figure, then dividing by the number of radians in a full cycle.
- Equation shows that V_{AVG} is approx= 31.8% of Vp for a half-wave rectified voltage.



Peak Inverse Voltage (PIV)

- PIV occurs at the peak of each half-cycle of the input voltage when the diode is reverse-biased.
- Diode must be capable of withstanding this amount of repetitive reverse voltage.
- PIV, occurs at the peak of each negative alternation of the input voltage when the diode is reverse-biased.
- A diode should be rated at least 20% higher than the PIV.

$$PIV = V_{P(in)} \qquad \text{eq.----(3)}$$



Half-wave Rectifier with Transformer coupled input voltage.

Transformer coupling provides two advantages:

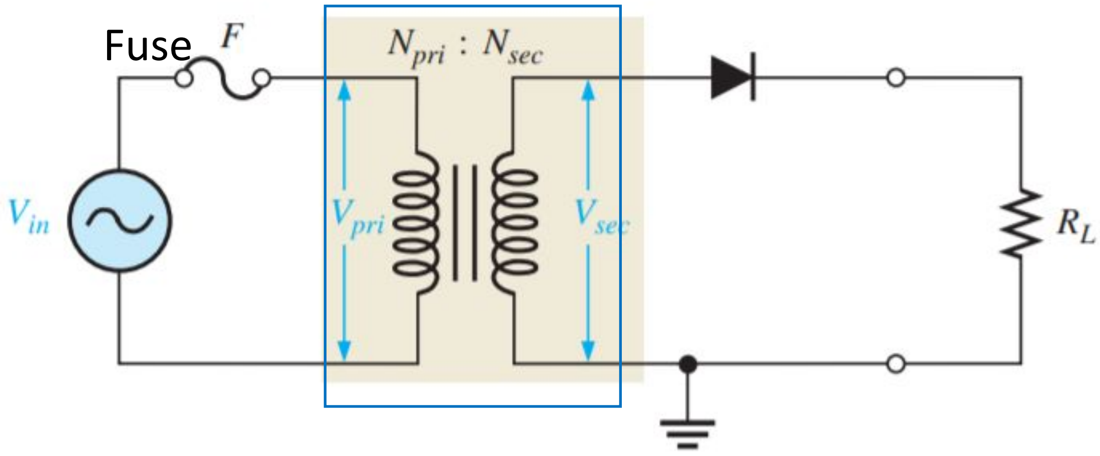
Allows the source voltage to be stepped down as needed.

Ac source is electrically isolated from the rectifier, thus preventing a shock hazard in the secondary circuit.

Turns Ratio, n = $\frac{N_{sec}}{N_{pri}}$

n > 1 for Step up transformer

n < 1 for step down transformer



The secondary voltage of a transformer equals the turns ratio, n times the primary voltage.

$$V_{sec} = nV_{pri}$$

if n=1, $V_{sec} = V_{pri}$

Diode datasheet

1N4001, 1N4002, 1N4003, 1N4004, 1N4005, 1N4006, 1N4007

www.vishay.com

Vishay General Semiconductor

General Purpose Plastic Rectifier

DO-41 (DO-204AL)

FEATURES

- Low forward voltage drop
- Low leakage current
- High forward surge capability
- Solder dip 275 °C max. 10 s, per JESD 22-B106
- Material categorization: for definitions of compliance please see www.vishay.com/doc?99912

RoHS COMPLIANT

PRIMARY CHARACTERISTICS	
$I_{F(AV)}$	1.0 A
V_{RRM}	50 V, 100 V, 200 V, 400 V, 600 V, 800 V, 1000 V
I_{FSM} (8.3 ms sine-wave)	30 A
I_{FSM} (square wave $t_p = 1$ ms)	45 A
V_F	1.1 V
I_R	5.0 µA
T_J max.	150 °C
Package	DO-41 (DO-204AL)
Circuit configuration	Single

TYPICAL APPLICATIONS

For use in general purpose rectification of power supplies, inverters, converters, and freewheeling diodes application.

MECHANICAL DATA

Case: DO-41 (DO-204AL), molded epoxy body
Molding compound meets UL 94 V-0 flammability rating
Base P/N-E3 - RoHS-compliant, commercial grade

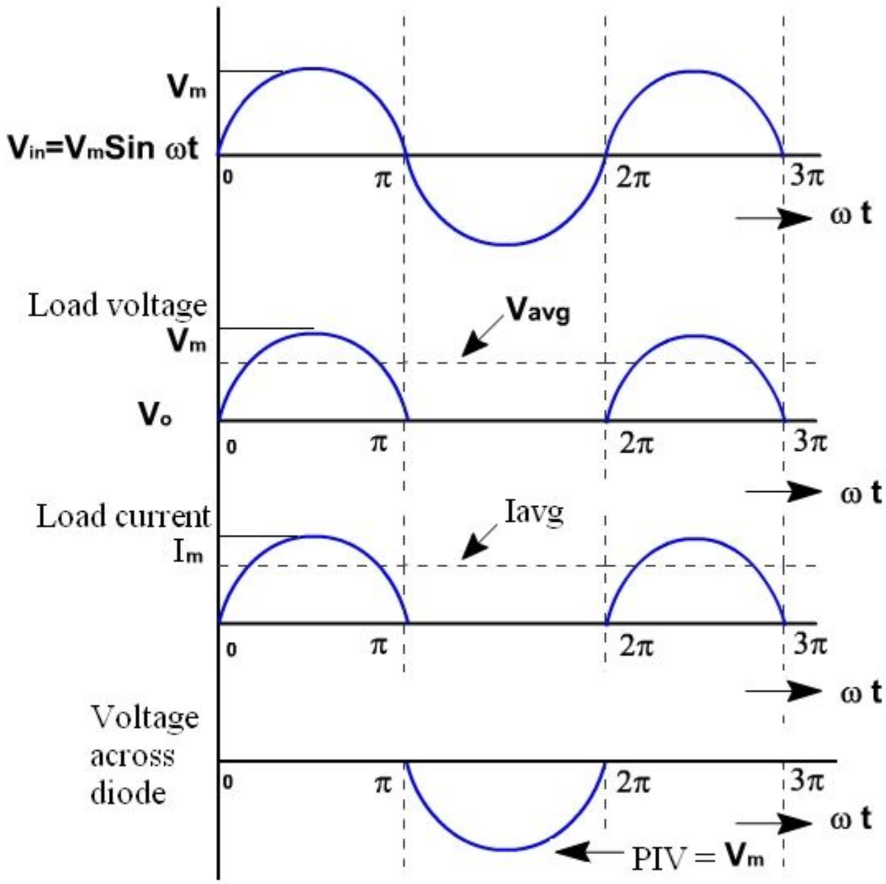
Terminals: matte tin plated leads, solderable per J-STD-002 and JESD 22-B102
E3 suffix meets JESD 201 class 1A whisker test

Polarity: color band denotes cathode end

MAXIMUM RATINGS (T_A = 25 °C unless otherwise noted)

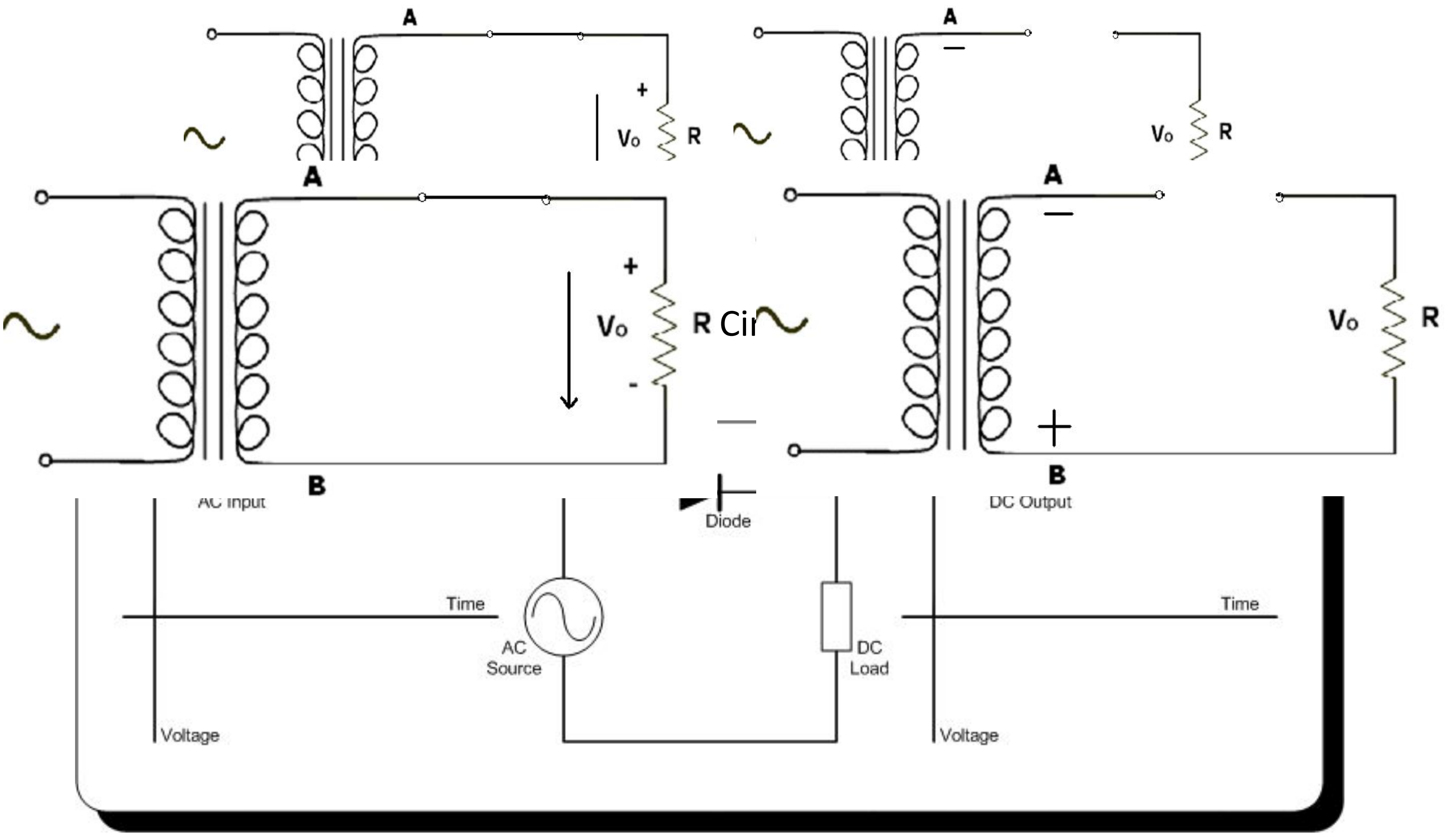
PARAMETER		SYMBOL	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	UNIT
Maximum repetitive peak reverse voltage		V_{RRM}	50	100	200	400	600	800	1000	V
Maximum RMS voltage		V_{RMS}	35	70	140	280	420	560	700	V
Maximum DC blocking voltage		V_{DC}	50	100	200	400	600	800	1000	V
Maximum average forward rectified current 0.375" (9.5 mm) lead length at T_A = 75 °C		$I_{F(AV)}$	1.0							A
Peak forward surge current 8.3 ms single half sine-wave superimposed on rated load		I_{FSM}	30							A
Non-repetitive peak forward surge current square waveform T_A = 25 °C (fig. 3)	t_p = 1 ms	I_{FSM}	45							A
	t_p = 2 ms		35							
	t_p = 5 ms		30							

Waveforms



Vm
Vin=VmSin ωt
0
π
2π
3π
ω t
Load voltage
Vm
Vavg
Vo
0
π
2π
3π
ω t
Load current
Im
Iavg
0
π
2π
3π
ω t
Voltage
across
diode
0
π
2π
3π
ω t
PIV = Vm

Operation of the circuit

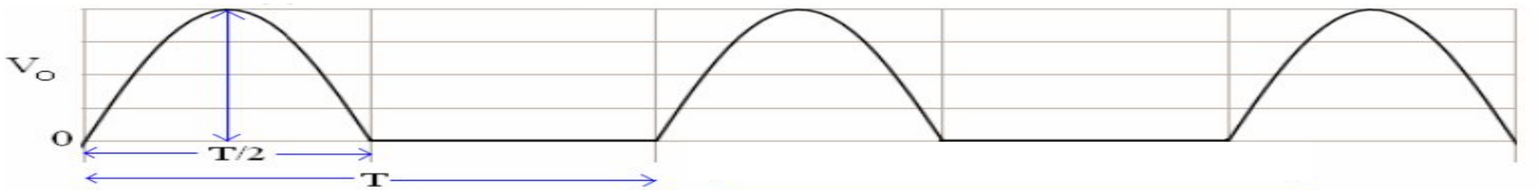


Animated working of HWR

Parameters of HWR

- Average Load Current ($I_{L_{DC}}$)
- Average Load Voltage($V_{L_{DC}}$)
- RMS Load Current ($I_{L_{RMS}}$)
- RMS Load Voltage ($V_{L_{RMS}}$)
- Rectifier efficiency (η)
- Ripple Factor
- Voltage Regulation
- Rectification Efficiency and TUF (Transformer Utilization Factor)
- Peak Inverse Voltage (PIV)

DC or Average Load Current (I_{dc})



$$v = V_m \,\text{sin}\omega t$$

$$i = \frac{v}{R} = \frac{V_m sin\omega t}{R} = I_m \text{sin}\omega t$$

mean value of the current (neglecting the reverse current) = I_{dc}

$$I_{dc} = \frac{1}{2\pi}\int_0^{\pi} I_m Sin\omega t \; d(\omega t) = \frac{-I_m}{2\pi}[cos\omega t]_0^{\pi}$$

$$\boldsymbol{I_{dc} = \frac{I_m}{\pi}}$$

AC or RMS LOAD CURRENT (I_{rms})

RMS means: Squaring, Finding mean, & Finding Square root

$$I_{rms} = \frac{I_m}{2}$$

Also called effective value of the load current

$$I_{dc} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin\omega t \, d(\omega t) = \frac{I_m}{2\pi}\Big[-\cos\omega t\Big]_0^{\pi}$$

$$= \frac{I_m}{2\pi}[-\cos\pi + \cos 0] = \frac{I_m}{2\pi}[1+1]$$

$$\therefore \qquad \boxed{I_{dc} = \frac{I_m}{\pi} = 0.318 I_m}$$

Similarly if the r.m.s. value of the current is I_{rms} then:

$$I_{rms} = \sqrt{\left[\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \, d(\omega t)\right]}$$

$$= \sqrt{\left[\frac{I_m^2}{2\pi}\int_0^{\pi} \tfrac{1}{2}(1 - \cos 2\omega t)\, d(\omega t)\right]}$$

$$= \sqrt{\left\{\frac{I_m^2}{2\pi} \times \frac{1}{2}\Big[\omega t + \tfrac{1}{2}\sin 2\omega t\Big]_0^{\pi}\right\}} = \sqrt{\left\{\frac{I_m^2}{4\pi}[\pi]\right\}}$$

$$\therefore \qquad \boxed{I_{rms} = \frac{I_m}{2} = 0.5 I_m}$$

DC/Average and RMS Value Load Voltage

-

The voltage across the load during the positive half-cycles is given by

$$v_R = Ri = RI_m \sin \omega t = V_m \sin \omega t$$

$$\text{Mean value of the load voltage} = V_{dc} = \frac{V_m}{\pi}$$

$$\text{RMS value of the load voltage} = V_{rms} = \frac{V_m}{2}$$

Rectifier efficiency for HWR

Rectifier efficiency is defined as the percentage of ac input power, actually converted into the average load power.

$$\text{Efficiency } \eta = \frac{\text{power in the load due to d.c. component of current}}{\text{total power dissipated in the circuit}} = \frac{P_{dc}}{P_{ac}}$$

•

$$P_{dc} = I_{dc}^2 \times R_L = \left(\frac{{I_m}^2}{\pi^2}\right) \times R_L$$

$$P_{ac} = I_{rms}^2 \times \left(R_L + R_S + R_f\right) = \frac{{I_m}^2}{4} \times \left(R_L + R_S + R_f\right)$$

$$\eta = \frac{P_{dc}}{P_{ac}} = 0.406 \qquad - - -R_L \gg R_S + R_f$$

$\%\eta = 40.6\%$

Ripple Factor

- Output of HW rectifier contains pulsating component called ripples.

Ripple factor is used to measure amount of pulsation present in the output of the rectifier. It tells how smooth the output is.

$$Ripple\ Factor = \frac{RMS\ value\ of\ ac\ component}{Average\ or\ DC\ component\ present\ in\ the\ output}$$

$$r = \sqrt{\left(\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1\right)}$$

$$I_{rms} = \frac{I_m}{2} \quad \text{and} \quad I_{dc} = \frac{I_m}{\pi}$$

Hence

r = 1.211

TUF (Transformer Utilization Factor)

- How much is the utilization of transformer.

$$TUF = \frac{DC\ power\ delivered\ to\ the\ load}{ac\ power\ rating\ of\ the\ transformer}$$

$$TUF = \frac{\left({I_m}^2/_{\pi^2}\right) \times R_L}{(V_{rms} \times I_{rms})}$$

TUF = 0.287

Low TUF means transformer is not fully utilized.

Advantages of HWR

- Simple construction, Small size
- Less number of components are required

Applications of HWR

- In the eliminators for pocket radios or eliminators for Walkman or in the low cost power supplies.

Disadvantages of HWR

- Ripple factor is high (1.21)
- Low rectification efficiency (40%)
- Low TUF(only 28%) which shows that transformer is not utilized effectively.
- Low DC output voltage and current.
- Larger filter components are required.
- Because of these disadvantages HWR is not normally used in practice.
- Possibility of core saturation due to unidirectional current flow through transformer. To avoid this size of transformer should be increased.

Examples- Homework

1. What is the average value of the half-wave rectified voltage in Figure 2–21?

   If $V_p = 60$ V, V_{AVG} =?

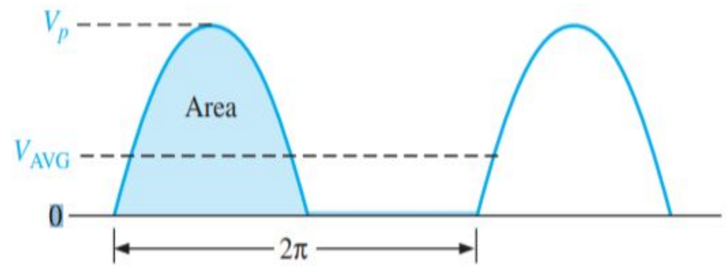
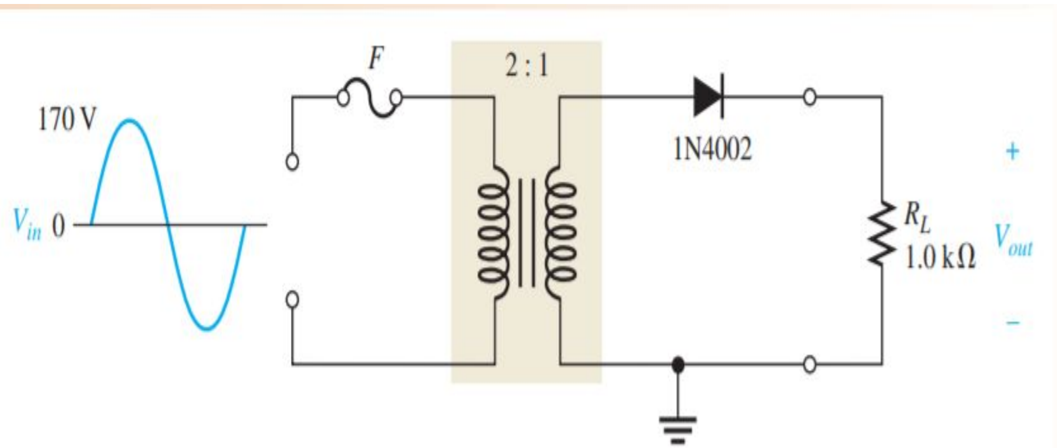


FIGURE 2–21

Average value of the half-wave rectified signal.

2. Determine the peak value of the output voltage for Figure if the turns ratio is 0.5.



Examples- Answers

1. What is the average value of the half-wave rectified voltage in Figure 2–21?

   If V_p = 60 V, V_{AVG} =?

   V_{AVG}=60/3.14=19.1 V

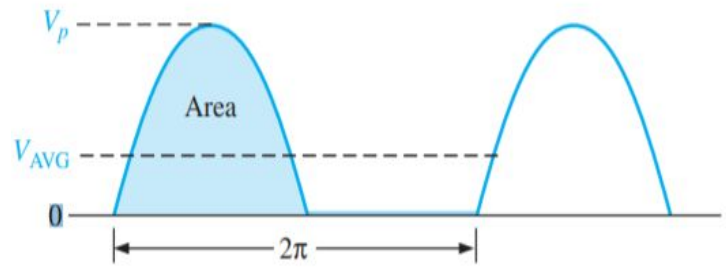


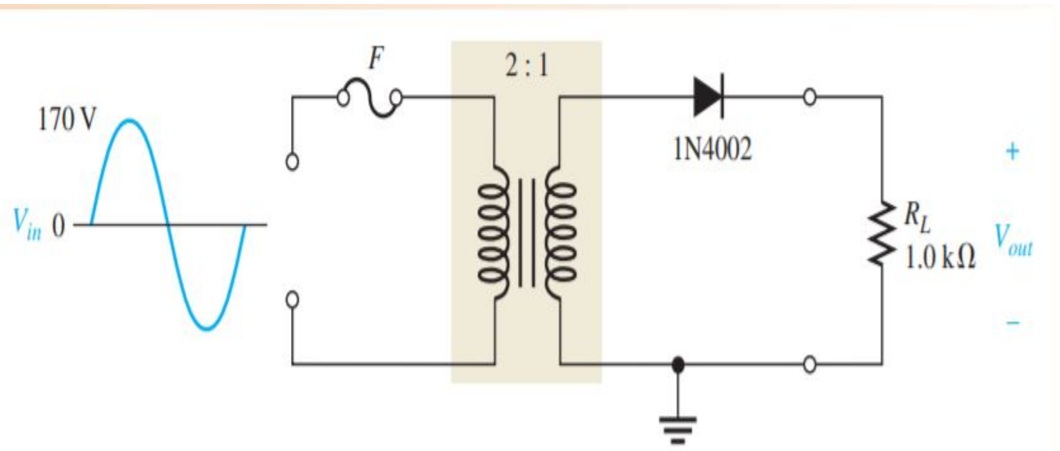
FIGURE 2–21

Average value of the half-wave rectified signal.

2. Determine the peak value of the output voltage for Figure if the turns ratio is 0.5.

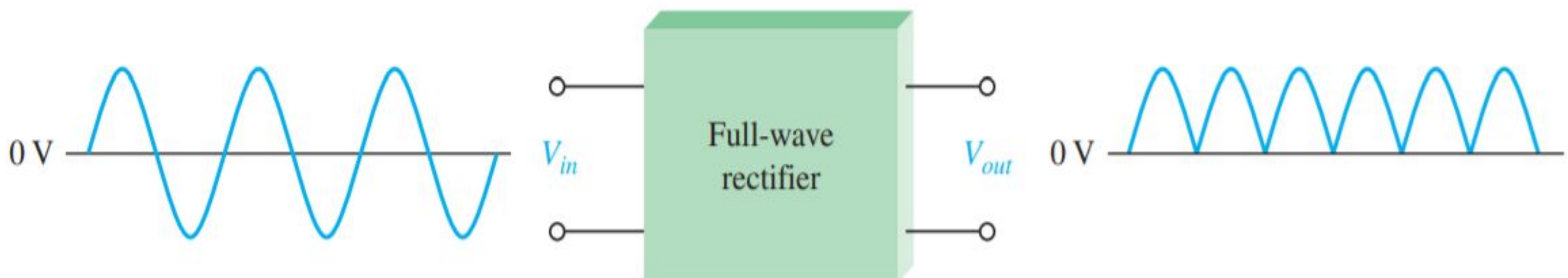
Vsec=n x Vpri

=0.5 x 170 =85V



FWR- Full Wave Rectifiers

- FWR is the most commonly used rectifier type in dc power supplies.
- A full-wave rectifier allows unidirectional (one-way) current through the load during the entire input cycle.
- A half-wave rectifier allows current through the load only during one-half of the cycle.
- The result of full-wave rectification is an output voltage with a frequency twice the input frequency
- Two types of full-wave rectifiers are :
  - Center-tapped FWR
  - Full wave bridge rectifier.



Full Wave Rectifiers

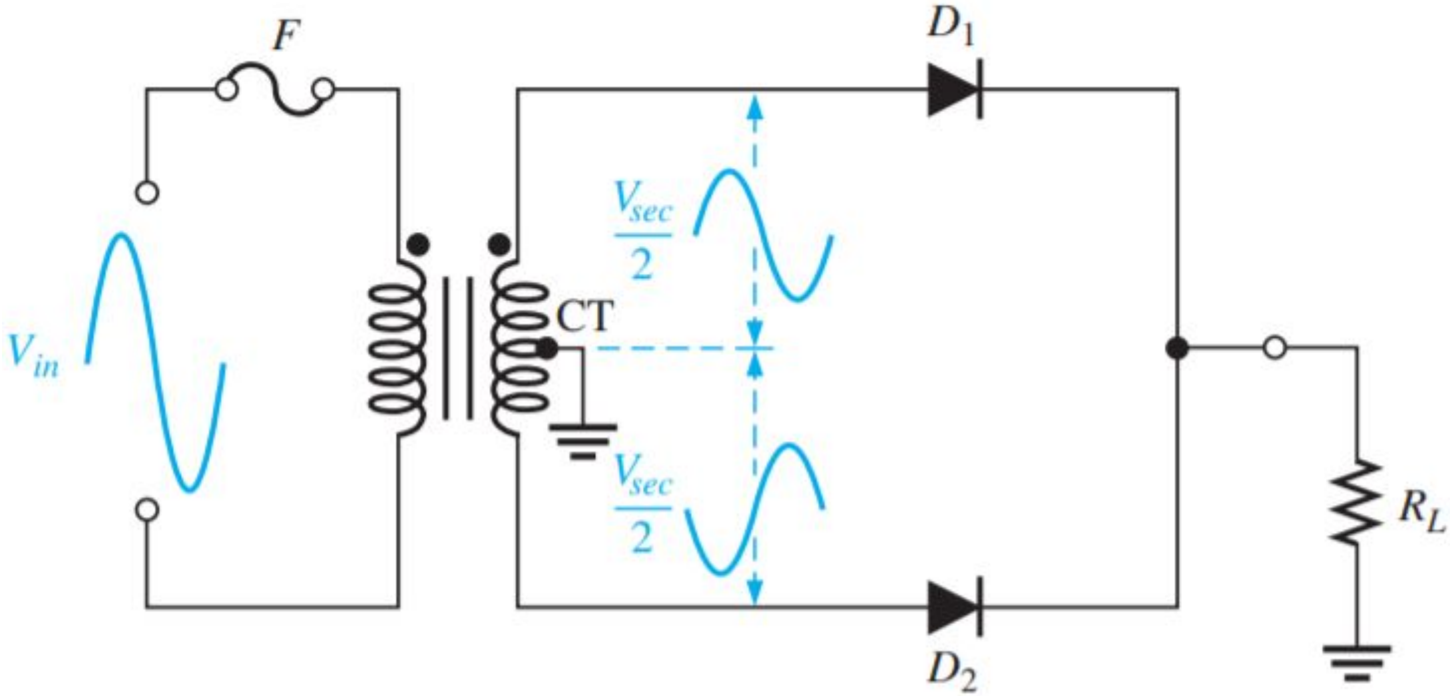
- The average value (value measured on a dc voltmeter) for a full-wave rectified sinusoidal voltage is twice that of the half-wave
- V_{AVG} is approximately 63.7% of Vp for a full-wave rectified voltage.

$$V_{AVG} = \frac{2V_P}{\pi}$$

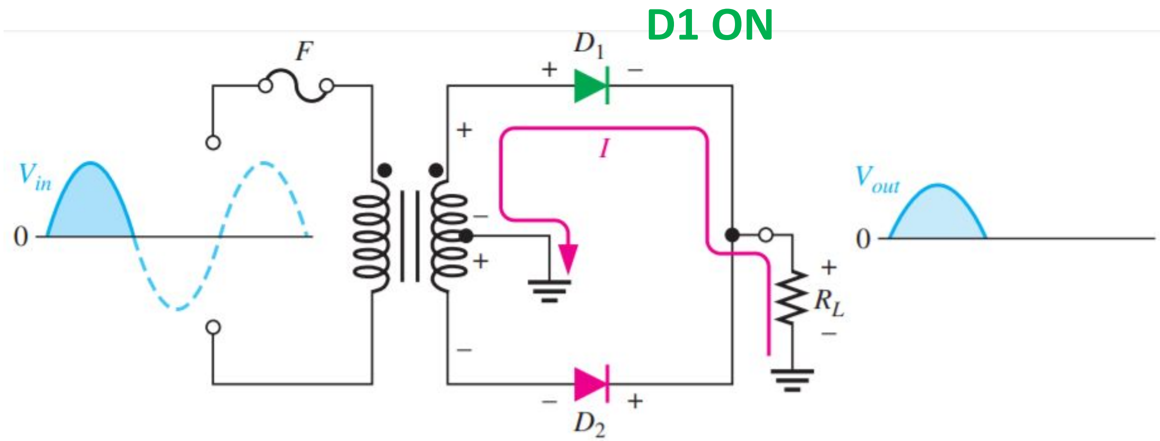
Centre-Tapped Full-Wave Rectifier Operation

- A centre-tapped rectifier is a type of full-wave rectifier that uses two diodes connected to the secondary of a center-tapped transformer.
- The input voltage is coupled through the transformer to the center-tapped secondary.
- Half of the total secondary voltage appears between the center tap and each end of the secondary winding as shown.

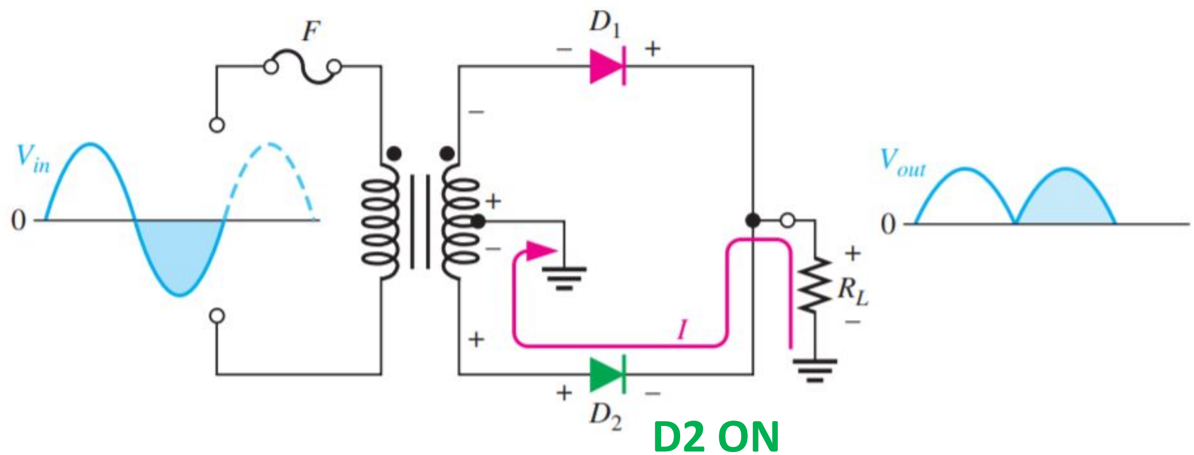
Full Wave Rectifiers
Center-tapped(CT) FWR



Operation of CT FWR-



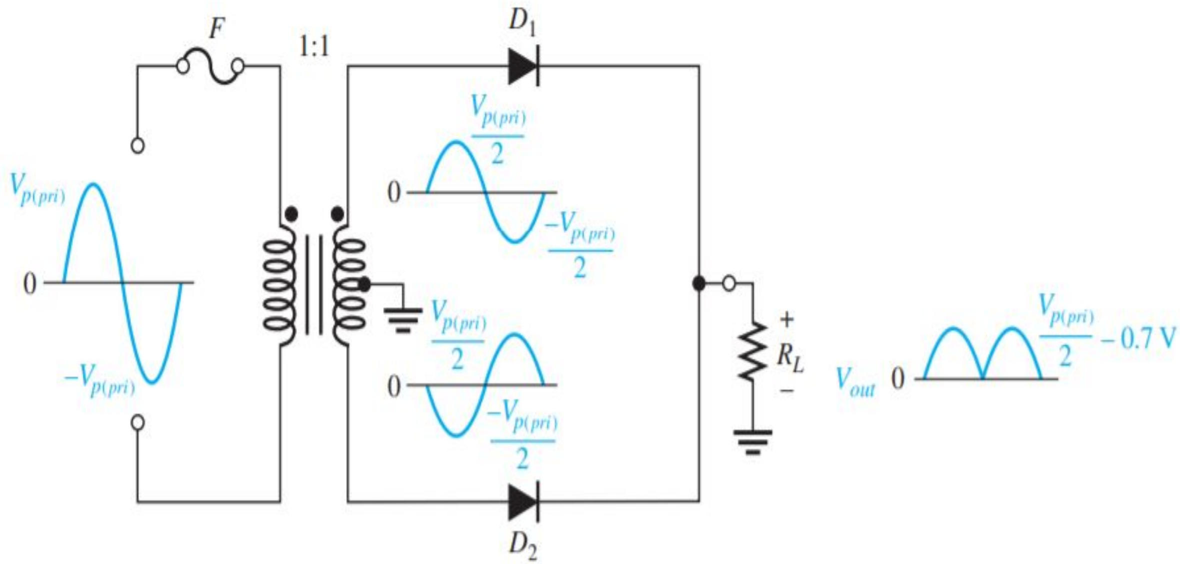
(a) During positive half-cycles, D1 is forward-biased and D2 is reverse-biased.



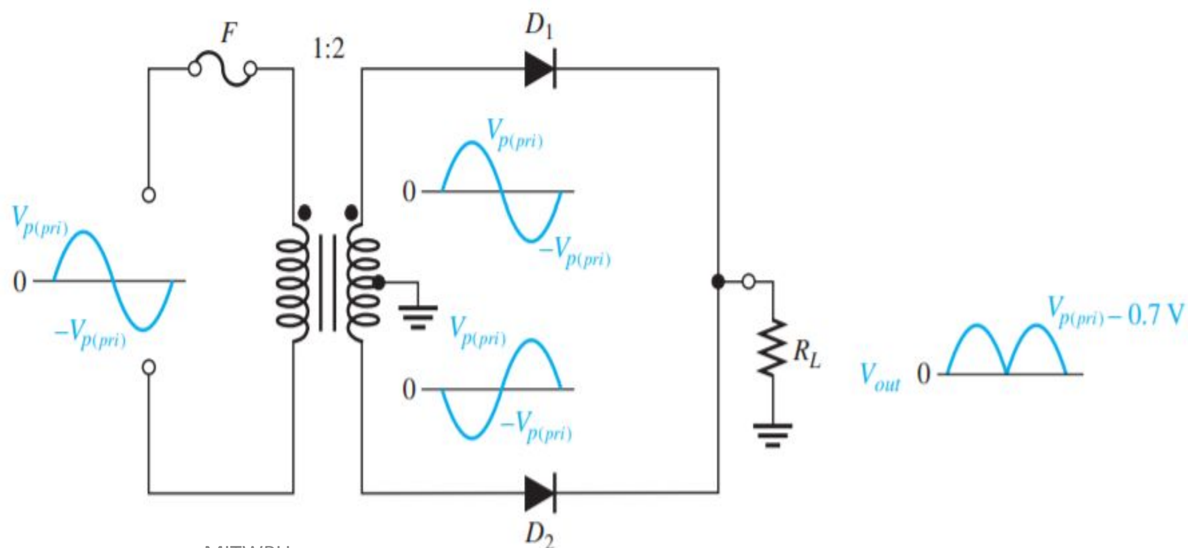
(b)During negative half-cycles, D2 is forward-biased and D1 is reverse-biased

Effect of the Turns Ratio on the Output Voltage

- If the transformer's turns ratio is= 1
  $V_{sec} = V_{pri}$
- Voltage across each half of the secondary is equal to $V_{pri}/2$



- To obtain an output voltage with a peak equal to the input peak (less the diode drop), a step-up transformer with a turns ratio of n = 2 must be used.
- $V_{sec} = 2V_{pri}$
- Voltage across each half of the secondary is equal to $\mathbf{V_{pri}}$



Full Wave Rectifiers

- In any case, the output voltage of a center-tapped full-wave rectifier is always one-half of the total secondary voltage less the diode drop, no matter what the turns ratio.

$$V_{out} = \frac{V_{sec}}{2} - 0.7\ \text{V}$$

Center Tapped FWR with AC input source:

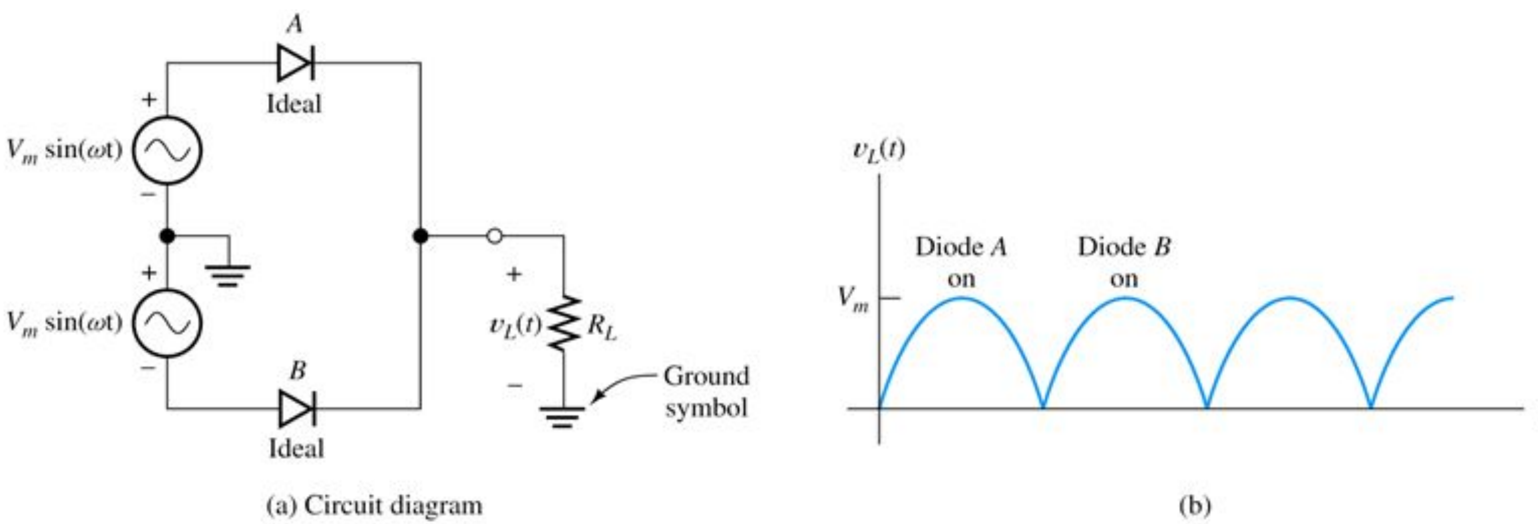
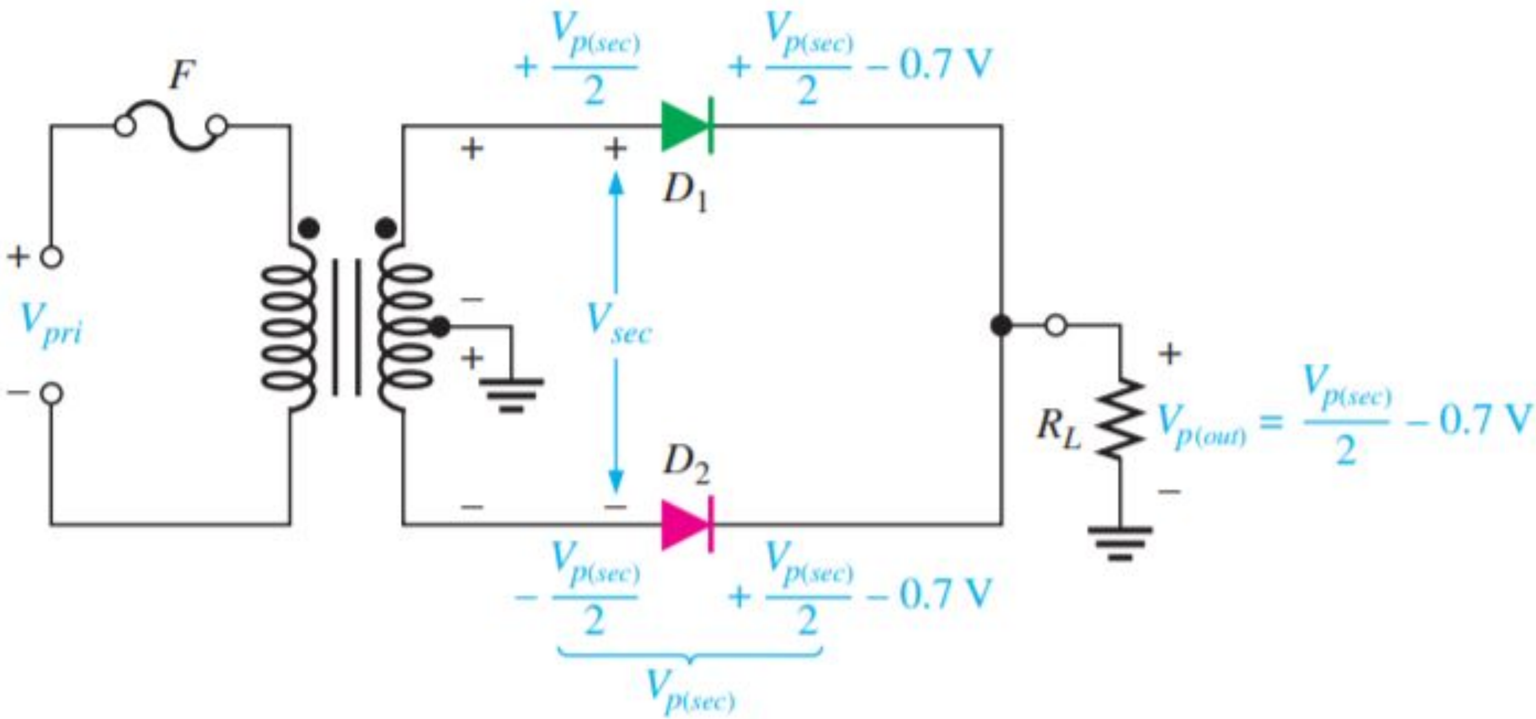


Figure Full-wave rectifier.

Peak Inverse Voltage (PIV)

- Each diode in the full-wave rectifier is alternately forward-biased and then reverse-biased.
- The maximum reverse voltage that each diode must withstand is the peak secondary voltage $V_{p(sec)}$.



PIV in FWR (Center tapped)

$$\text{PIV} = \left(\frac{V_{p(sec)}}{2} - 0.7\text{ V}\right) - \left(-\frac{V_{p(sec)}}{2}\right) = \frac{V_{p(sec)}}{2} + \frac{V_{p(sec)}}{2} - 0.7\text{ V}$$

$$= V_{p(sec)} - 0.7\text{ V}$$

$$V_{p(out)} = V_{p(sec)}/2 - 0.7\text{ V},$$

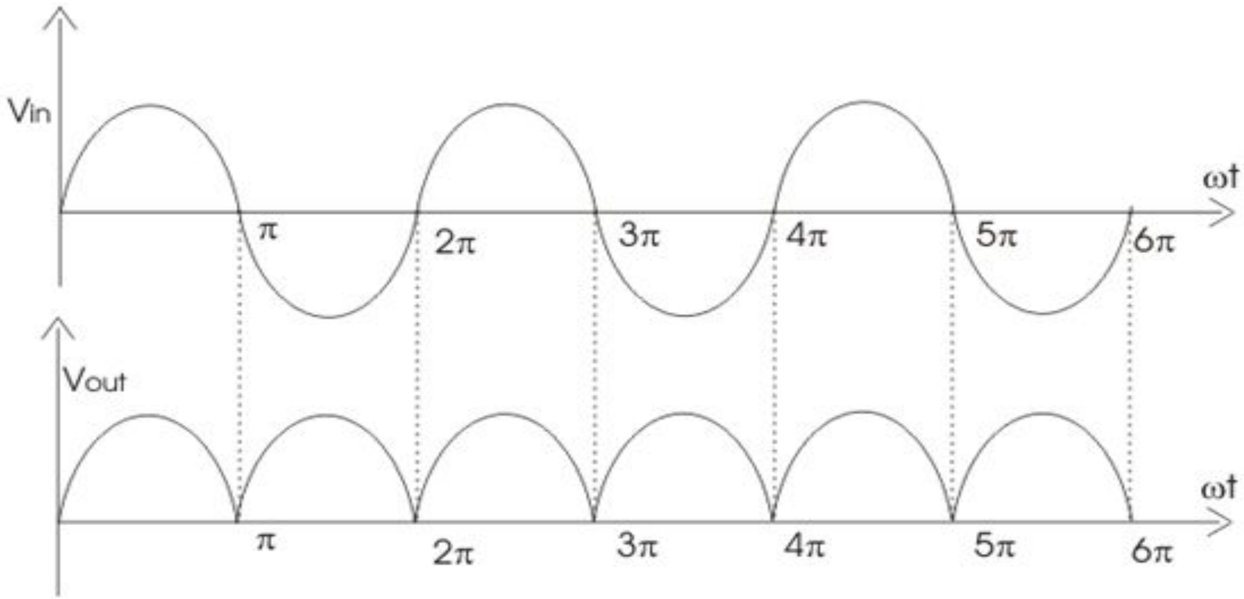
multiplying each term by 2 and transposing,

$$V_{p(sec)} = 2V_{p(out)} + 1.4\text{ V}$$

By substitution, the peak inverse voltage across either diode in a full-wave center-tapped rectifier is

$$\mathbf{PIV = 2}\boldsymbol{V_{p(out)}}\mathbf{ + 0.7\ V}$$

DC or Average Load Current (I_{dc})



$$I_{LDC} = \frac{1}{\pi}\int_0^{\pi} I_m Sin\omega t\, d\omega t = \frac{-I_m}{\pi}[cos\omega t]_0^{\pi}$$

Mean value of the load current is

$$\boxed{I_{dc} = \frac{2I_m}{\pi} = 0.637\mathrm{I_m}}$$

RMS value of the load current is

$$I_{rms} = \frac{I_m}{\sqrt{2}} = 0.707 I_m$$

- **DC or Average Load Voltage (V_{DC})**

$$V_{DC} = \frac{2V_m}{\pi}$$

where $V_m = peak\ secondary\ voltage$

AC or RMS Load Voltage (V_{rms})

$$\boldsymbol{V_{rms} = \frac{V_m}{\sqrt{2}}}$$

Full Wave Rectifier efficiency

- Rectifier efficiency is defined as the percentage of ac input power, actually converted into the average load power.

$$\eta = \frac{DC\ output\ power}{AC\ input\ power} = \frac{P_{DC}}{P_{ac}}$$

$$\eta = \frac{I_{dc}^2 R}{I_{rms}^2 R} = \left[\frac{2I_m}{\pi}\right]^2 \times \left[\frac{\sqrt{2}}{I_m}\right]^2 = \frac{8}{\pi^2}$$

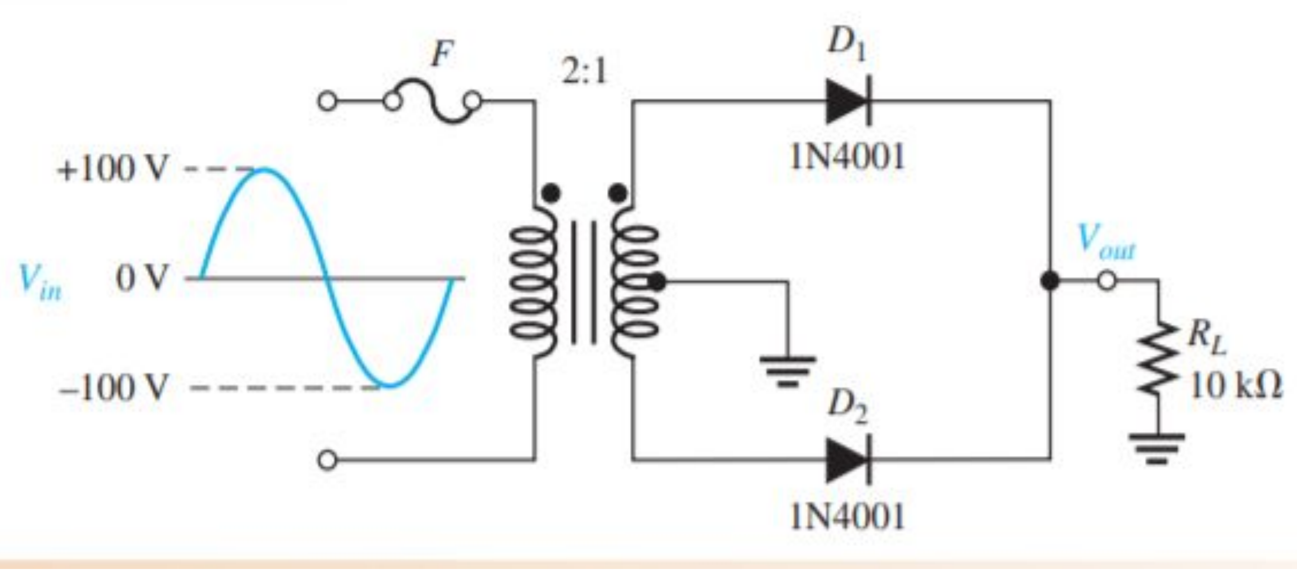
η= 0.81 or 81 %

- *Rectification efficiency of FWR is almost twice the rectifier efficiency of HWR*

EXAMPLE 3

(a) Draw the voltage waveforms across each half of the secondary winding and across R_L when a 100 V peak sine wave is applied to the primary winding in Figure 2–36.

(b) What minimum PIV rating must the diodes have?



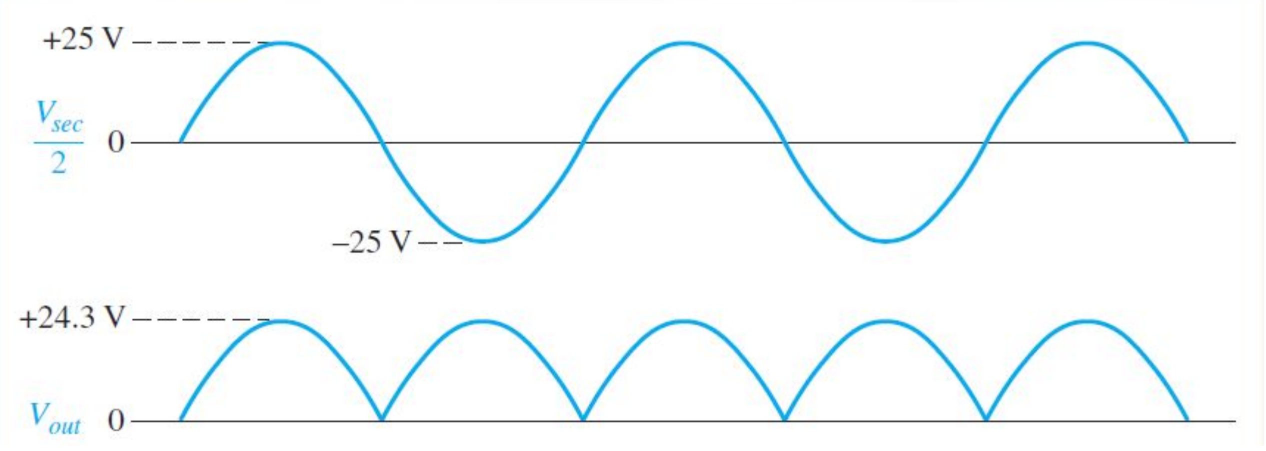
EXAMPLE 3- Answers

(a) The transformer turns ratio $n = 0.5$. The total peak secondary voltage is

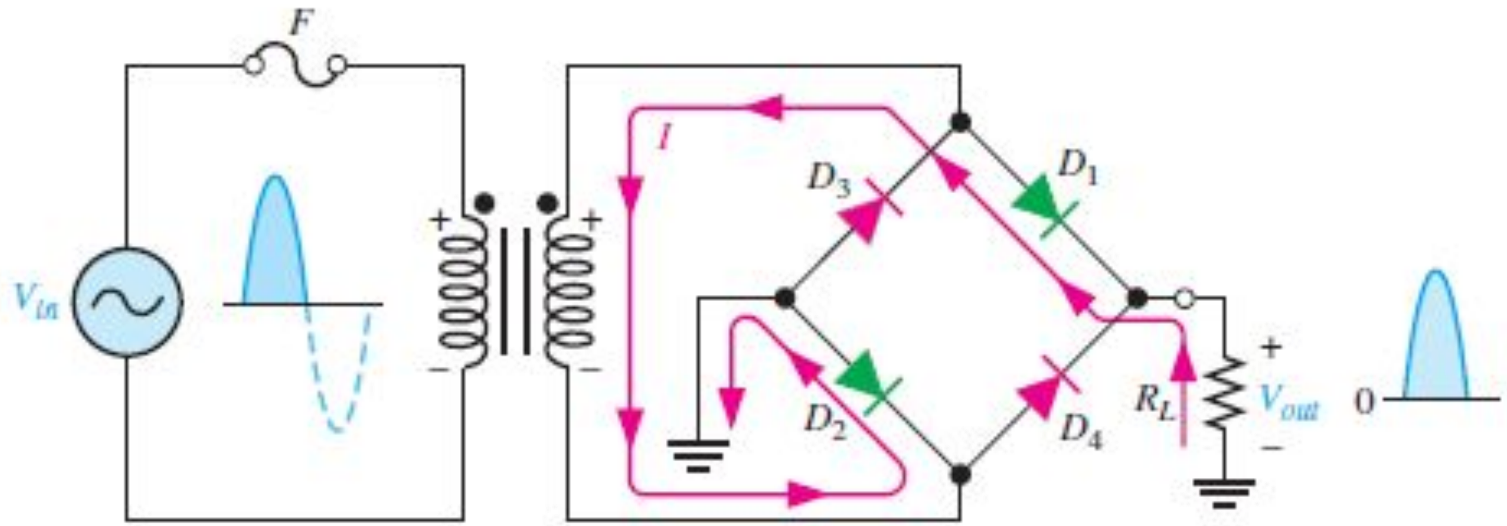
$$V_{p(sec)} = nV_{p(pri)} = 0.5(100\text{ V}) = 50\text{ V}$$

(b) Each diode must have a minimum PIV rating of

$$\text{PIV} = 2V_{p(out)} + 0.7\text{ V} = 2(24.3\text{ V}) + 0.7\text{ V} = \mathbf{49.3\ V}$$

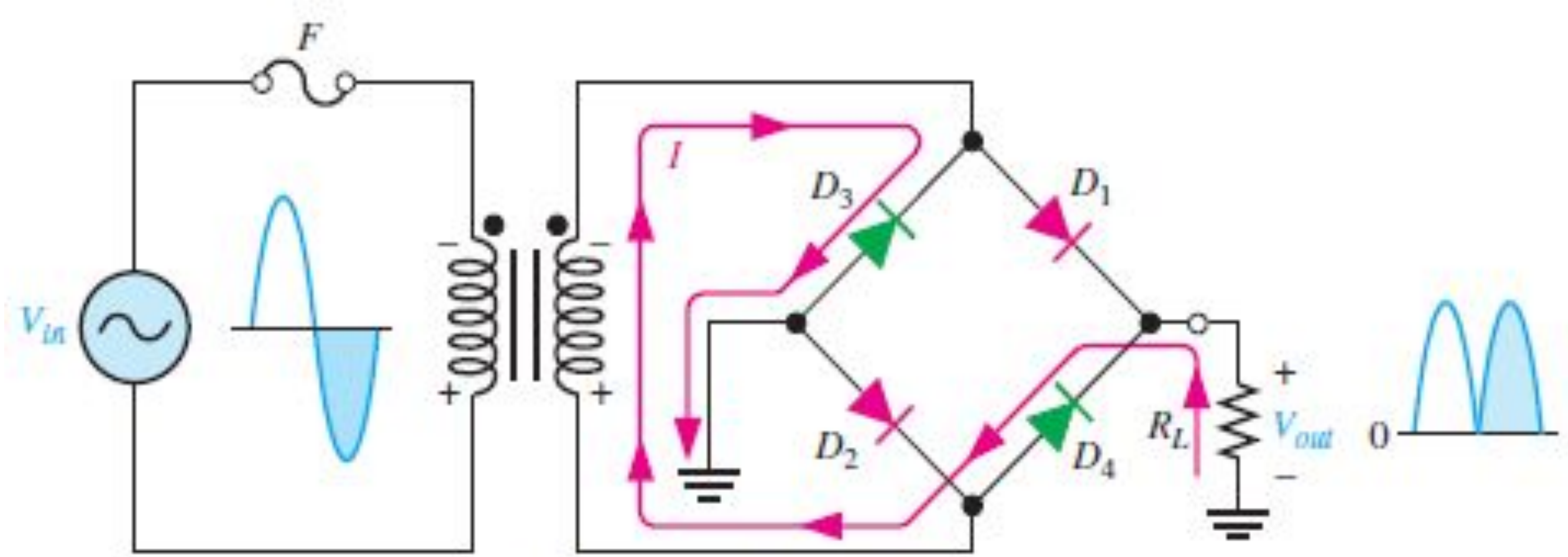


Full Wave Bridge Rectifier



(a) During the positive half-cycle of the input, D_1 and D_2 are forward-biased and conduct current. D_3 and D_4 are reverse-biased.

Full Wave Bridge Rectifier



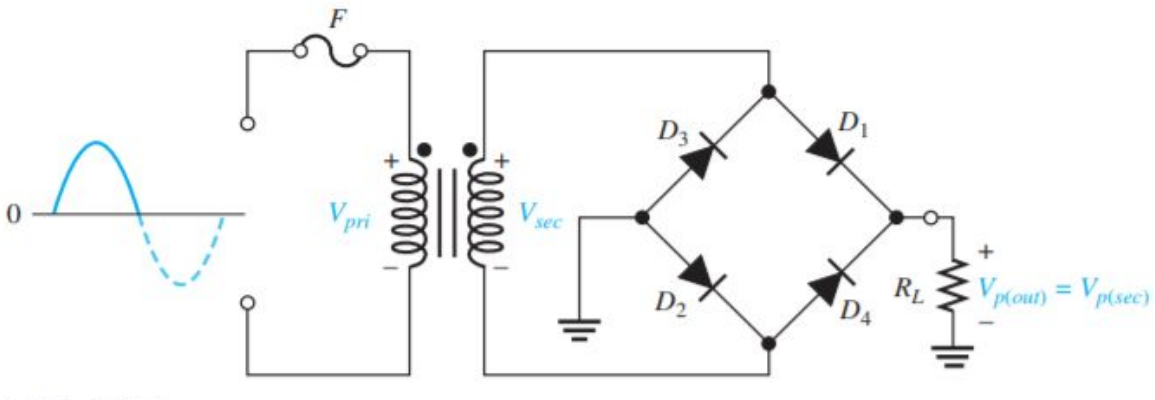
(b) During the negative half-cycle of the input, D_3 and D_4 are forward-biased and conduct current. D_1 and D_2 are reverse-biased.

- Positive half-cycle of the total secondary voltage: D1 and D2 are forward-biased.
- Neglecting the diode drops, the secondary voltage appears across the load resistor.
- The same is true when D3 and D4 are forward-biased during the negative half-cycle.

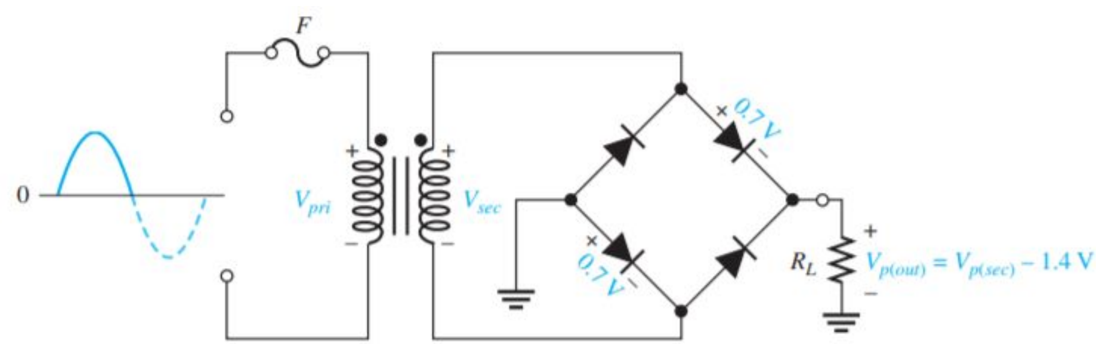
$$V_{p(out)} = V_{p(sec)}$$

- In FW bridge rectifier, two diodes are always in series with the load resistor during both the positive and negative half-cycles.

$$V_{p(out)} = V_{p(sec)} - 1.4\text{ V}$$



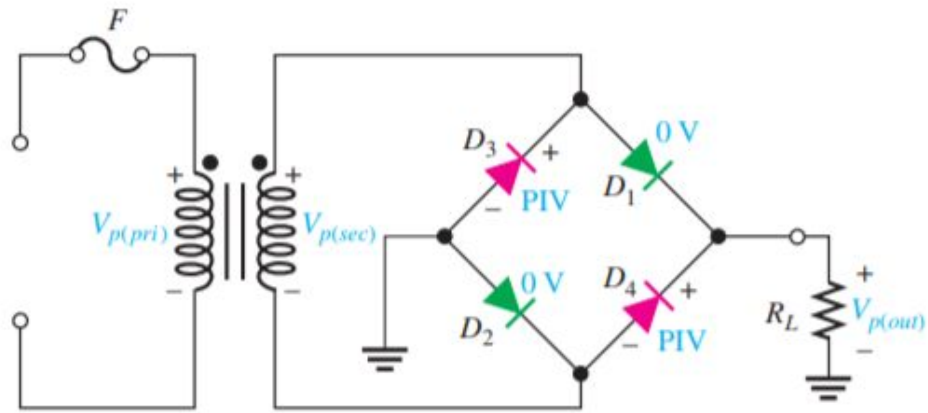
(a) Ideal diodes



(b) Practical diodes (Diode drops included)

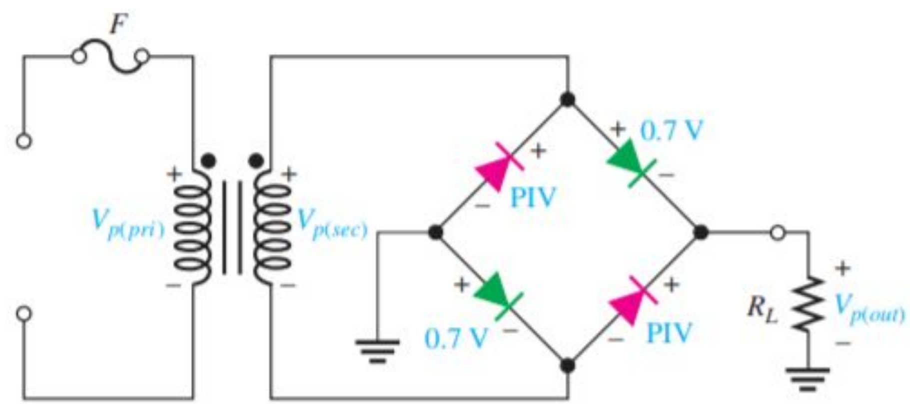
Peak Inverse Voltage(full wave bridge rectifier)

- **Ideal Model:** D1 and D2 are forward-biased and examine the reverse voltage across D3 and D4.
- D1 and D2 as shorts (ideal model),
- D3 and D4 have a peak inverse voltage equal to the peak secondary voltage.
- Since the output voltage is ideally equal to the secondary voltage
- **PIV = $V_{p(out)}$**



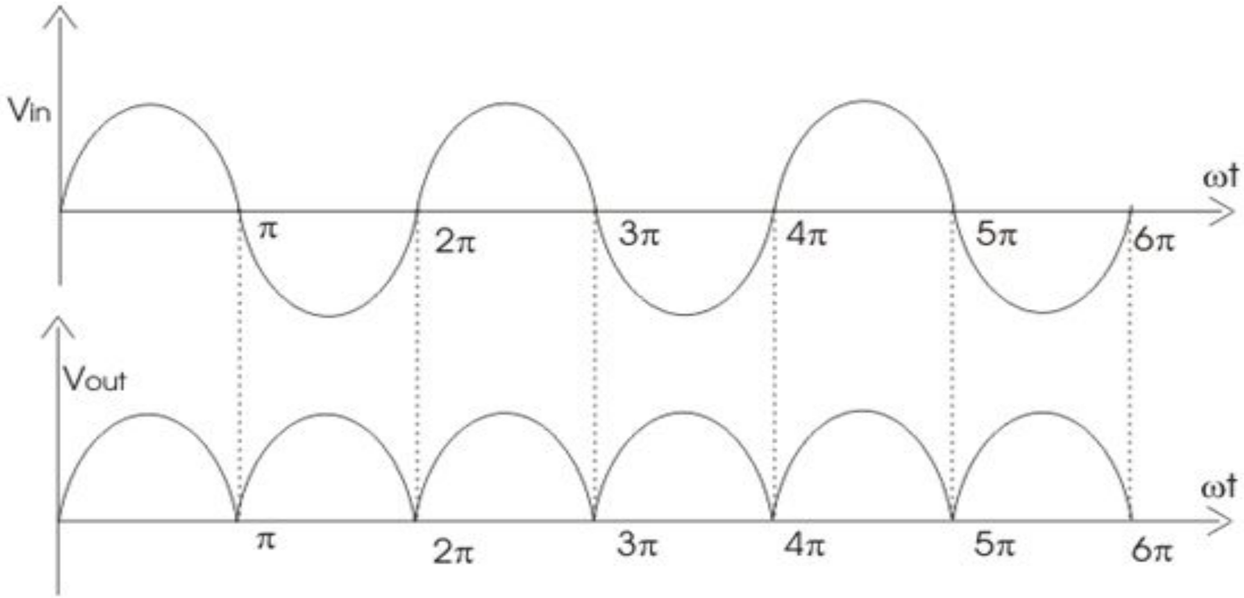
For the ideal diode model (forward-biased diodes D_1 and D_2 are shown in green), PIV = $V_{p(out)}$.

- **Practical model :** Including forward-biased diode drops
- **PIV = $V_{p(out)}$ + 0.7**
- PIV rating of the bridge diodes is less than that required for the center-tapped configuration.
- Neglecting diode drops, bridge rectifier requires diodes with half the PIV rating of those in a center-tapped rectifier for the same output voltage.



(b) For the practical diode model (forward-biased diodes D_1 and D_2 are shown in green), PIV = $V_{p(out)}$ + 0.7 V.

DC or Average Load Current (I_{dc}) and RMS load current



$$I_{LDC} = \frac{1}{\pi}\int_0^{\pi} I_m Sin\omega t\, d\omega t = \frac{-I_m}{\pi}[cos\omega t]_0^{\pi}$$

Mean value of the load current is

$$\boxed{\boldsymbol{I_{dc}} = \frac{\boldsymbol{2I_m}}{\boldsymbol{\pi}} = 0.637\mathrm{I_m}}$$

RMS value of the load current is

$$\boldsymbol{I_{rms}} = \frac{\boldsymbol{I_m}}{\sqrt{2}} = \mathbf{0.707}\boldsymbol{I_m}$$

- **DC or Average Load Voltage (V_{DC})**

$$V_{DC} = \frac{2V_m}{\pi}$$

where $V_m = peak\ secondary\ voltage$

AC or RMS Load Voltage (V_{rms})

$$\boldsymbol{V_{rms} = \frac{V_m}{\sqrt{2}}}$$

Rectifier efficiency

- Rectifier efficiency is defined as the percentage of ac input power, actually converted into the average load power.

$$\eta = \frac{\textit{DC output power}}{\textit{AC input power}} = \frac{P_{DC}}{P_{ac}}$$

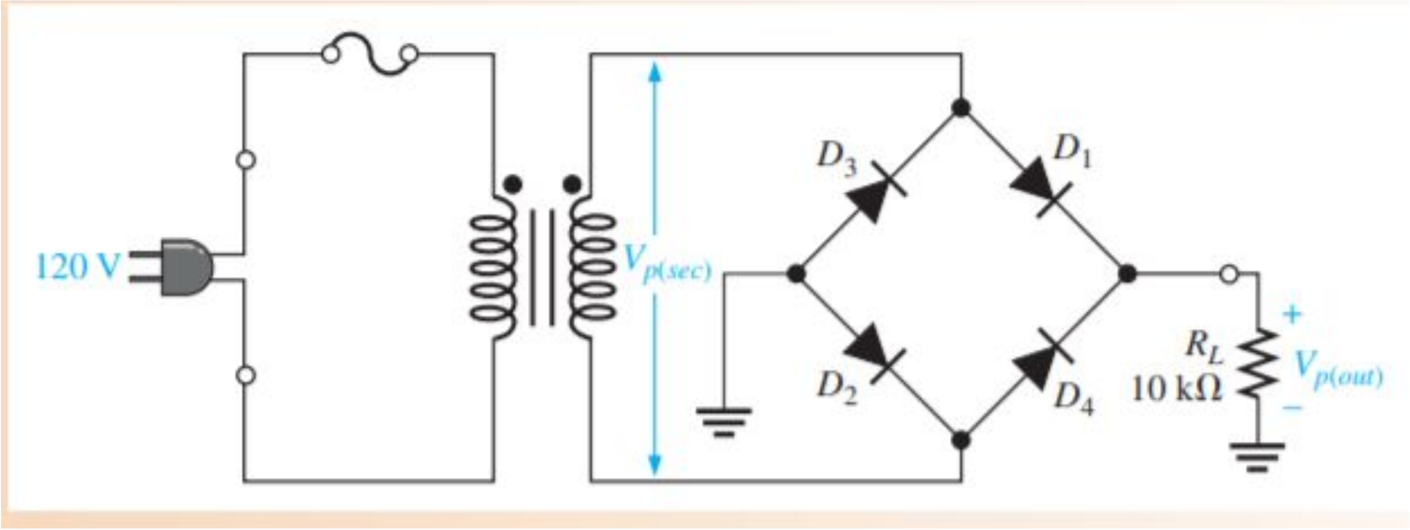
$$\eta = \frac{I_{\mathrm{dc}}^2 R}{I_{\mathrm{rms}}^2 R} = \left[\frac{2I_{\mathrm{m}}}{\pi}\right]^2 \times \left[\frac{\sqrt{2}}{I_{\mathrm{m}}}\right]^2 = \frac{8}{\pi^2}$$

η= 0.81 or 81 %

- *Rectification efficiency of FWR is almost twice the rectifier efficiency of HWR*

EXAMPLE 4

- Determine the peak output voltage for the bridge rectifier in Figure. Assuming the practical model, what PIV rating is required for the diodes?
- The transformer is specified to have a 12 V rms secondary voltage for the standard 120 V across the primary winding. What is the turns ratio of transformer?



EXAMPLE 4- Answers

The peak output voltage (taking into account the two diode drops) is

$$V_{p(sec)} = 1.414V_{rms} = 1.414(12\text{ V}) \cong 17\text{ V}$$

$$V_{p(out)} = V_{p(sec)} - 1.4\text{ V} = 17\text{ V} - 1.4\text{ V} = \mathbf{15.6\text{ V}}$$

The PIV rating for each diode is

$$\text{PIV} = V_{p(out)} + 0.7\text{ V} = 15.6\text{ V} + 0.7\text{ V} = \mathbf{16.3\text{ V}}$$

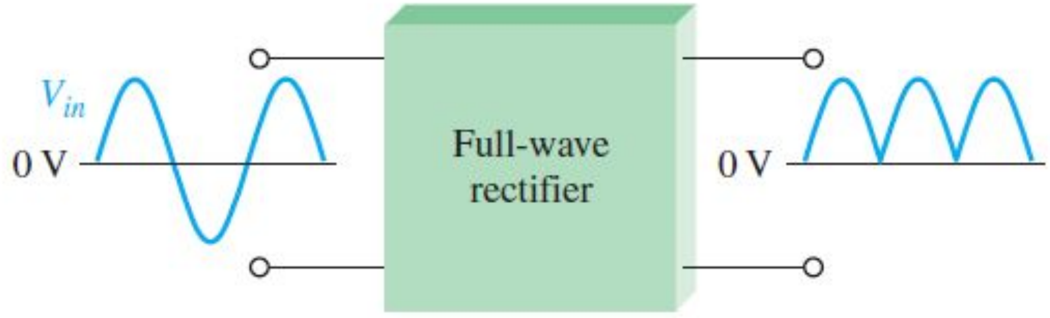
Comparison of Rectifier circuits

Parameters	Half-wave	Centre tapped Full-wave	Bridge
No of Diodes	1	2	4
Rectifier Efficiency	40.6%	81.2%	81.2%
Peak Inverse Voltage	V_M	$2V_M$	V_M
Average / DC load Current			$2I_m/\pi$
Vdc (no load)	V_m/π	$2V_m/\pi$	$2V_m/\pi$
Output Frequency	f	2f	2f
Transformer Utilisation Factor	0.287	0.693	0.812
Ripple Factor	1.21	0.48	0.48
P_{dc}	$(I_m^2 / \pi^2) * R_L$	$4 * (I_m^2 / \pi^2) * R_L$	$4 * (I_m^2 / \pi^2) * R_L$
P_{ac}	$(I_m^2 / 4) * (R_L + R_s + R_f)$	$(I_m^2 / 2) * (R_L + R_s + R_f)$	$(I_m^2 / 2) * (R_L + R_s + 2R_f)$

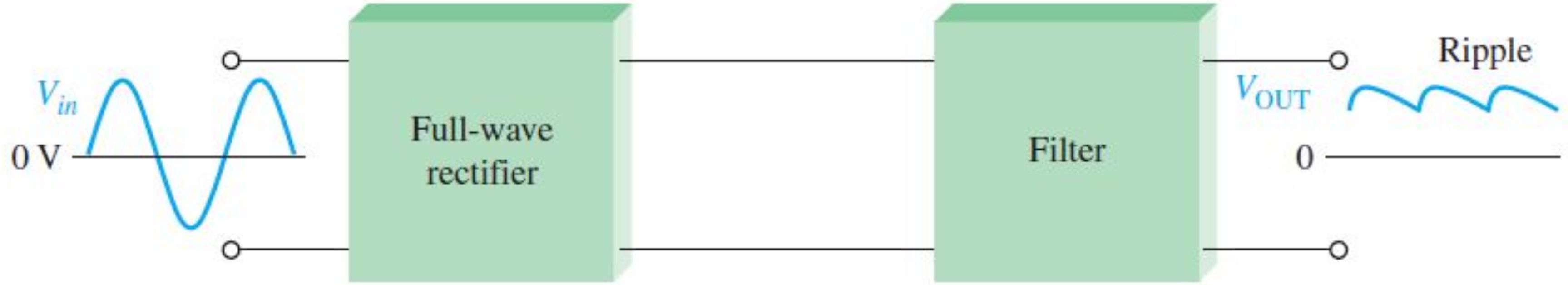
Filters

- Rectification means direct current (DC)
- The output current of the half wave and full wave rectifier contain large ac components
- There is ripple voltage across R_L
- Filters are the electronic circuits used along with rectifiers in order to get a pure ripple free dc voltage
- Types of Filters

Filters



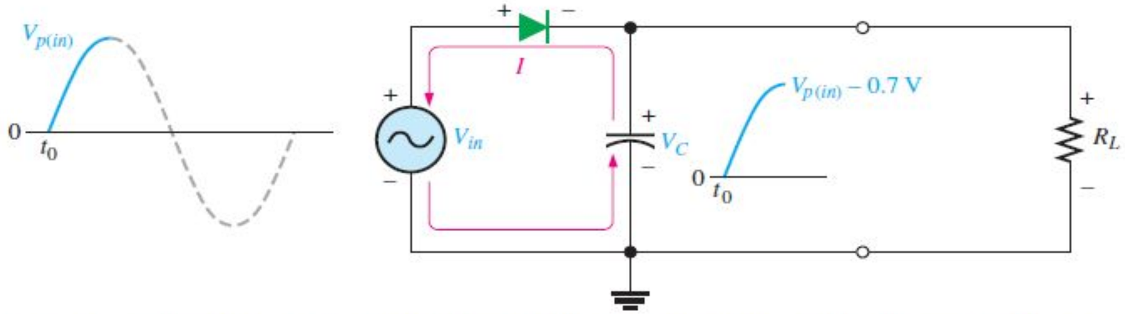
(a) Rectifier without a filter



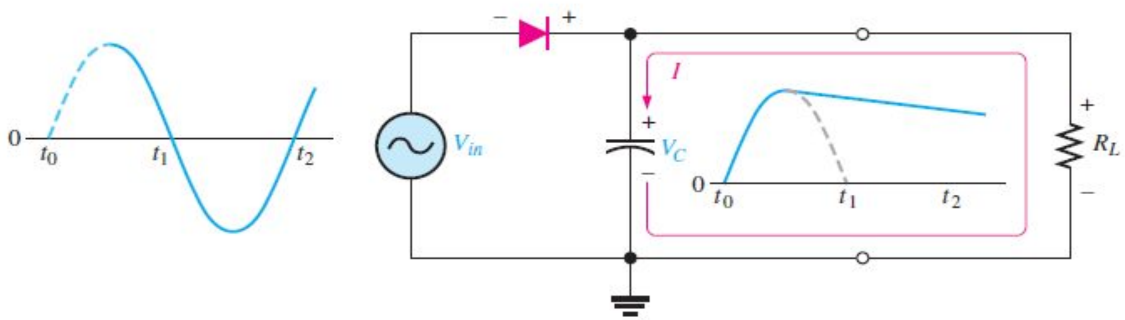
(b) Rectifier with a filter (output ripple is exaggerated)

Ripple factor , r = 1/ 2fCR√3

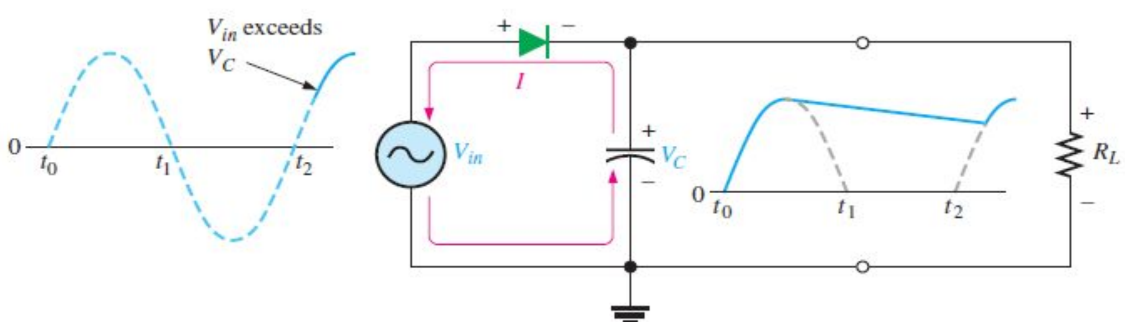
Half-Wave Rectifier with Smoothing Capacitor



(a) Initial charging of the capacitor (diode is forward-biased) happens only once when power is turned on.

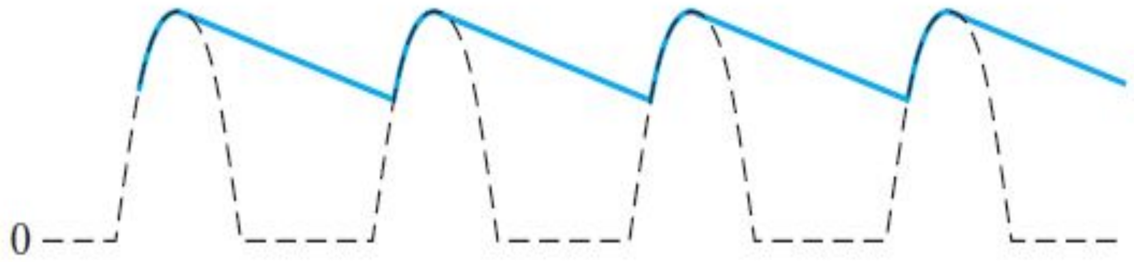


(b) The capacitor discharges through R_L after peak of positive alternation when the diode is reverse-biased. This discharging occurs during the portion of the input voltage indicated by the solid dark blue curve.

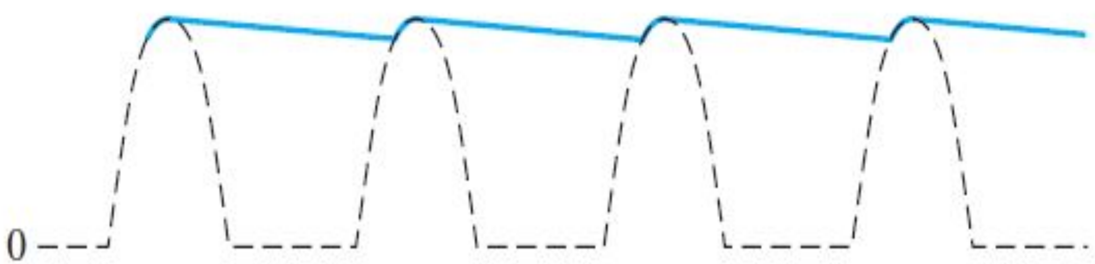


(c) The capacitor charges back to peak of input when the diode becomes forward-biased. This charging occurs during the portion of the input voltage indicated by the solid dark blue curve.

Ripple Comparison



(a) Larger ripple (blue) means less effective filtering.



(b) Smaller ripple means more effective filtering. Generally, the larger the capacitor value, the smaller the ripple for the same input and load.

Full-Wave Center tap Rectifier Circuits

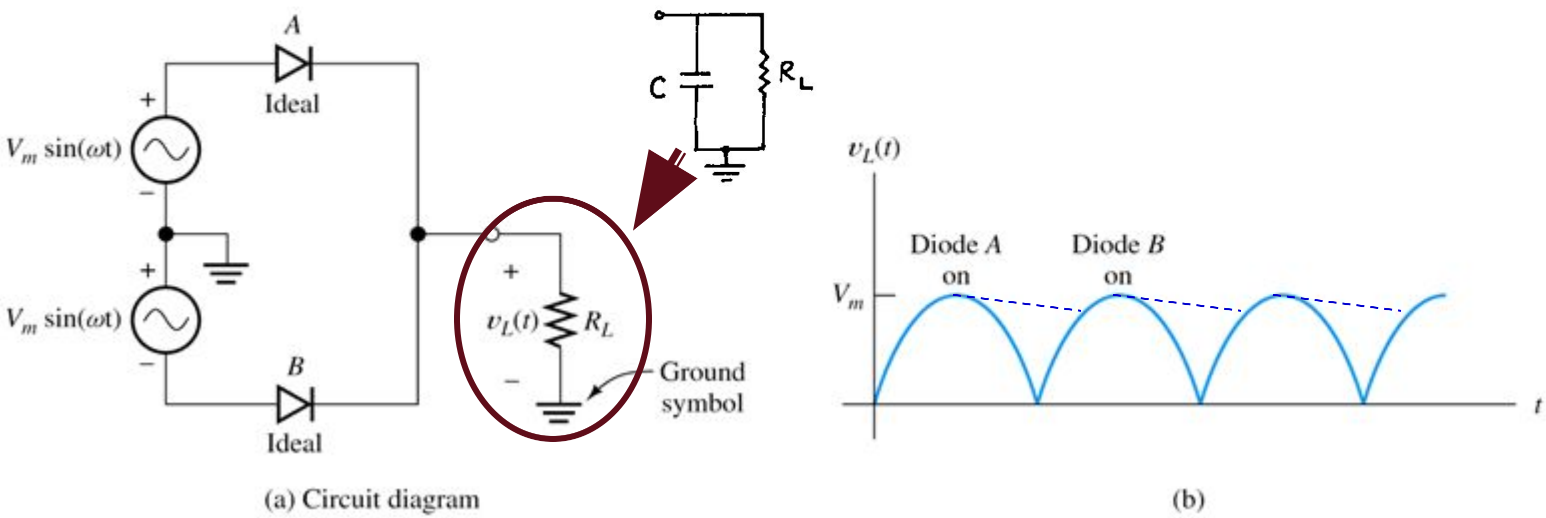
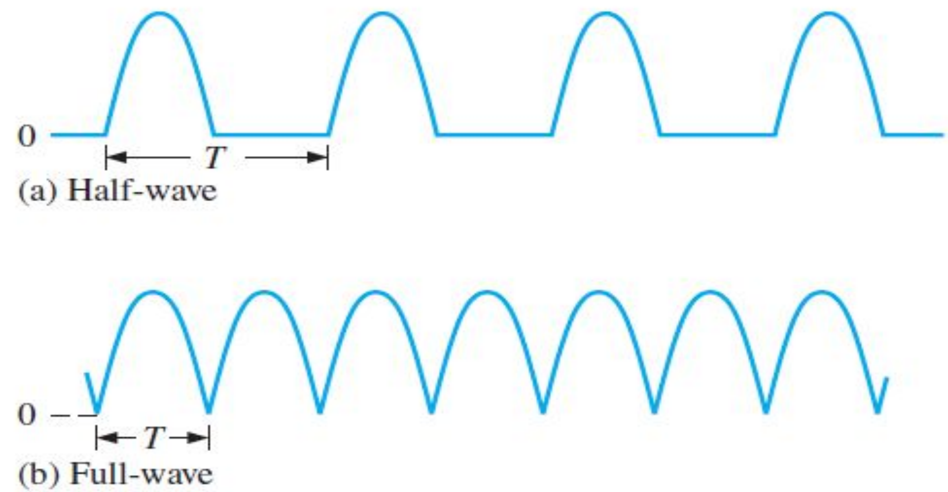


Figure Full-wave rectifier.

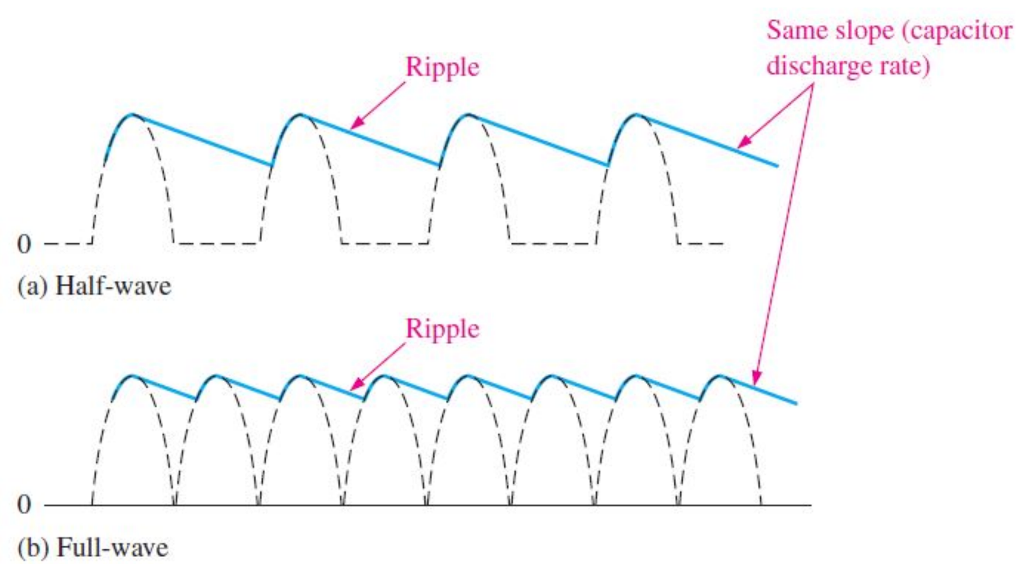
* We can also smooth the output by using a large capacitance.

Ripple Voltage

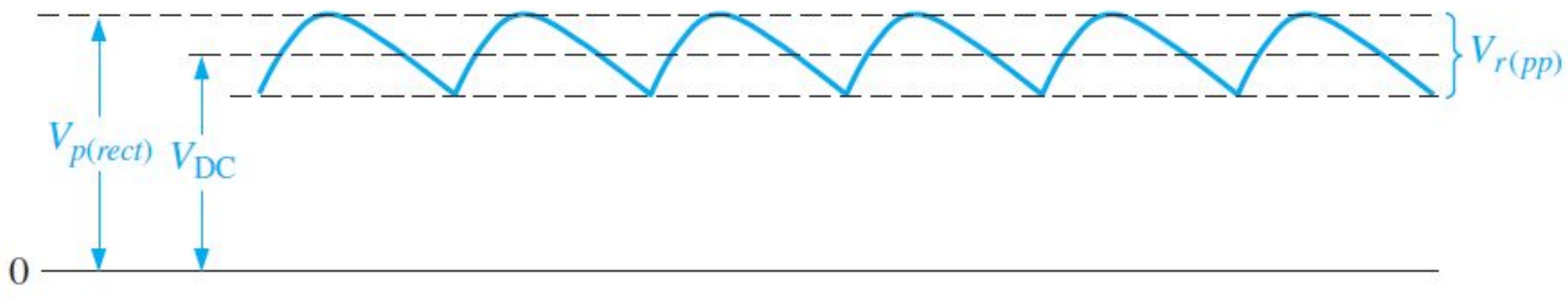
The period of a full-wave rectified voltage is half that of a half-wave rectified voltage. The output frequency of a full-wave rectifier is twice that of a half-wave rectifier.



Comparison of ripple voltages for
half-wave and full-wave rectified voltages with the same filter capacitor and load and derived from the same sinusoidal input voltage.



Ripple Factor



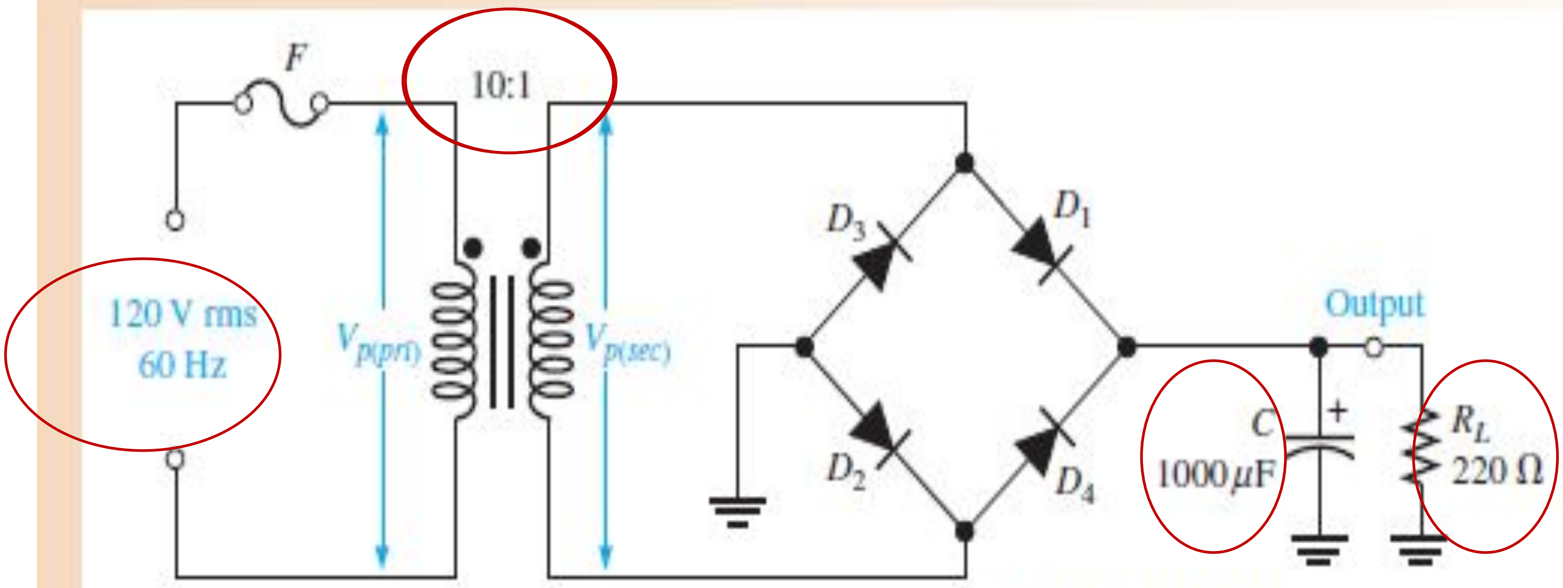
$$r = \frac{V_{r(pp)}}{V_{DC}}$$

$$V_{r(pp)} \cong \left(\frac{1}{fR_LC}\right)V_{p(rect)}$$

$$V_{DC} \cong \left(1 - \frac{1}{2fR_LC}\right)V_{p(rect)}$$

Problem- Full-Wave Bridge Rectifier with C filter

Determine the ripple factor for the filtered bridge rectifier with a load as indicated in Figure 2–48.



All diodes are 1N4001.

The transformer turns ratio is $n = 0.1$. The peak primary voltage is

$$V_{p(pri)} = 1.414V_{rms} = 1.414(120\text{ V}) = 170\text{ V}$$

The peak secondary voltage is

$$V_{p(sec)} = nV_{p(pri)} = 0.1(170\text{ V}) = 17.0\text{ V}$$

The unfiltered peak full-wave rectified voltage is

$$V_{p(rect)} = V_{p(sec)} - 1.4\text{ V} = 17.0\text{ V} - 1.4\text{ V} = 15.6\text{ V}$$

The frequency of a full-wave rectified voltage is 120 Hz. The approximate peak-to-peak ripple voltage at the output is

$$V_{r(pp)} \cong \left(\frac{1}{fR_LC}\right)V_{p(rect)} = \left(\frac{1}{(120\text{ Hz})(220\ \Omega)(1000\ \mu\text{F})}\right)15.6\text{ V} = 0.591\text{ V}$$

The approximate dc value of the output voltage is determined as follows:

$$V_{\text{DC}} = \left(1 - \frac{1}{2fR_LC}\right)V_{p(rect)} = \left(1 - \frac{1}{(240\text{ Hz})(220\ \Omega)(1000\ \mu\text{F})}\right)15.6\text{ V} = 15.3\text{ V}$$

The resulting ripple factor is

$$r = \frac{V_{r(pp)}}{V_{\text{DC}}} = \frac{0.591\text{ V}}{15.3\text{ V}} = 0.039$$

The percent ripple is 3.9%.

Determine the peak-to-peak ripple voltage if the filter capacitor in Figure 2–48 is increased to 2200 μF and the load resistance changes to 2.2 kΩ.

HW Problem Data

- FWR bridge with Filter capacitor
- Vin=230 V RMS, 50 Hz
- Transformer turns ratio=0.1
- Load Resistance, RL=1000 Ohms
- Filter Capacitor, C= 470 microFarad

Special Purpose Diode- Zener Diode

Symbol

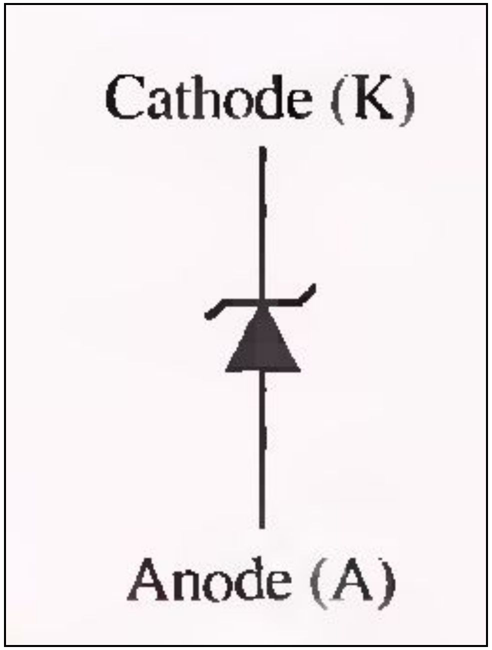
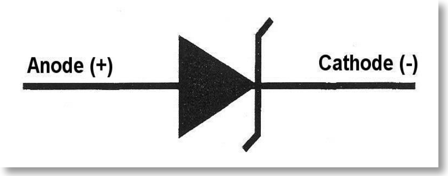


Image of a Zener diode

Outline

- Introduction of Zener Diode
- Construction of Zener Diode
- Working of Zener Diode
- Application of Zener Diode
- Numericals of Zener Diode

Introduction



- The **zener diode** is a silicon pn junction device that differs from rectifier diodes because *it is designed for operation in the reverse-breakdown region*. (Reverse biased condition)
- The basic function of **zener diode** is to maintain a specific voltage across it's terminals within given limits of line or load change.
- Typically it is used for providing a stable reference voltage for use in regulated power supplies and other equipment.

Datasheet of Zener Diode

VISHAY.

www.vishay.com

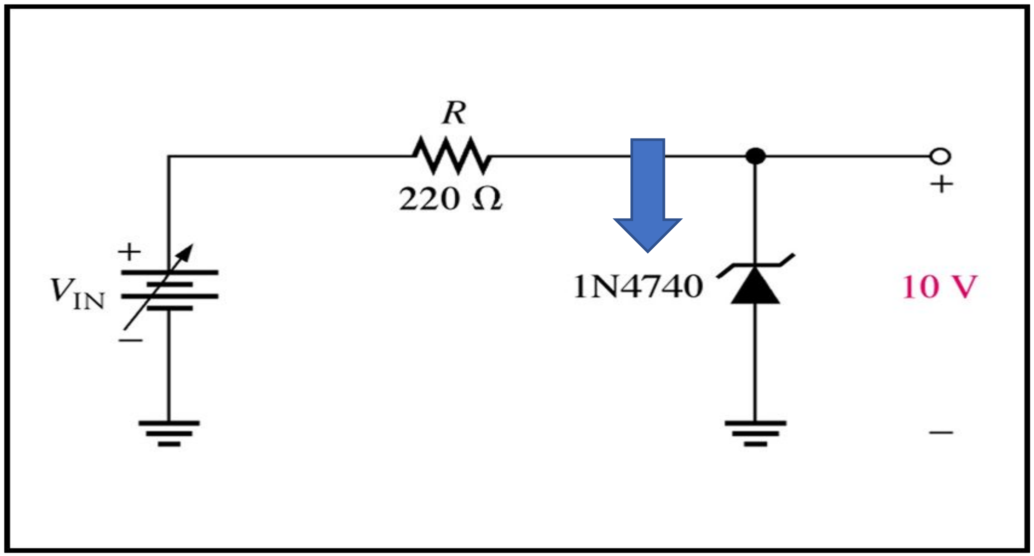
1N4728A to 1N4764A

Vishay Semiconductors

ELECTRICAL CHARACTERISTICS (T_{amb} = 25 °C, unless otherwise specified)

PART NUMBER	ZENER VOLTAGE RANGE [1]	TEST CURRENT		REVERSE LEAKAGE CURRENT		DYNAMIC RESISTANCE f = 1 kHz		SURGE CURRENT [3]	REGULATOR CURRENT [2]
	V_Z at I_{ZT1}	I_{ZT1}	I_{ZT2}	I_R at V_R		Z_{ZT} at I_{ZT1}	Z_{ZK} at I_{ZT2}	I_R	I_{ZM}
	V	mA	mA	μA	V	Ω		mA	mA
	NOM.			MAX.		TYP.	MAX.		MAX.
1N4728A	3.3	76	1	100	1	10	400	1380	276
1N4729A	3.6	69	1	100	1	10	400	1260	252
1N4730A	3.9	64	1	50	1	9	400	1190	234
1N4731A	4.3	58	1	10	1	9	400	1070	217
1N4732A	4.7	53	1	10	1	8	500	970	193
1N4733A	5.1	49	1	10	1	7	550	890	178
1N4734A	5.6	45	1	10	2	5	600	810	162
1N4735A	6.2	41	1	10	3	2	700	730	146
1N4736A	6.8	37	1	10	4	3.5	700	660	133
1N4737A	7.5	34	0.5	10	5	4	700	605	121
1N4738A	8.2	31	0.5	10	6	4.5	700	550	110
1N4739A	9.1	28	0.5	10	7	5	700	500	100
1N4740A	10	25	0.25	10	7.6	7	700	454	91
1N4741A	11	23	0.25	5	8.4	8	700	414	83
1N4742A	12	21	0.25	5	9.1	9	700	380	76
1N4743A	13	19	0.25	5	9.9	10	700	344	69
1N4744A	15	17	0.25	5	11.4	14	700	304	61

Regulated output voltage from unregulated input voltage using Zener diode 1N4740



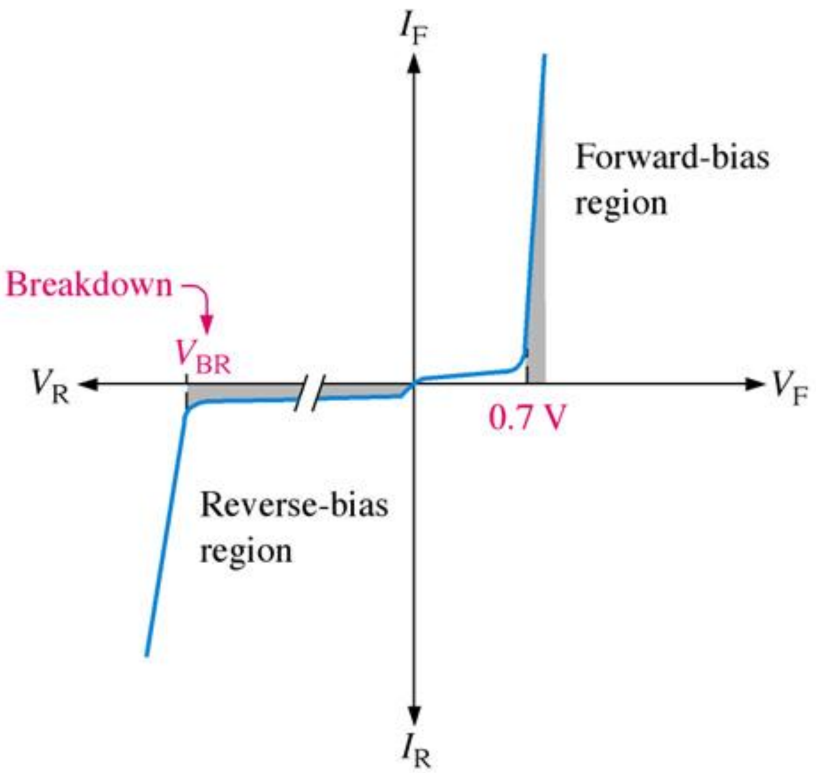
This particular zener circuit will work to maintain 10 V across the load.

Construction of Zener

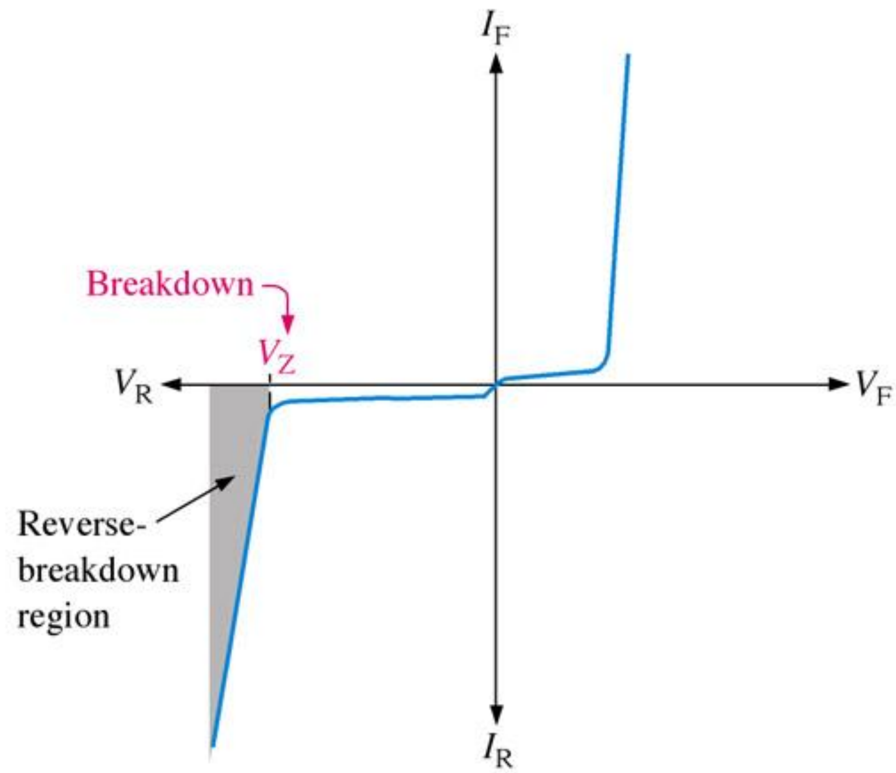
- Zener diodes are designed to operate in reverse breakdown. Two types of reverse breakdown in a zener diode are *avalanche* and *Zener*.
- The avalanche break down occurs in both rectifier and zener diodes at a sufficiently high reverse voltage.
- **Zener breakdown** occurs in a Zener diode at low reverse voltages.
- A Zener diode is **heavily doped** to reduced the breakdown voltage. This causes a very thin depletion region at the junction.
- The Zener diodes breakdown characteristics are determined by the doping process during manufacturing

Working of Zener Diode

This typical characteristic curve illustrates the operating range for a Zener diode. Note that it's forward characteristics is just like a normal diode.



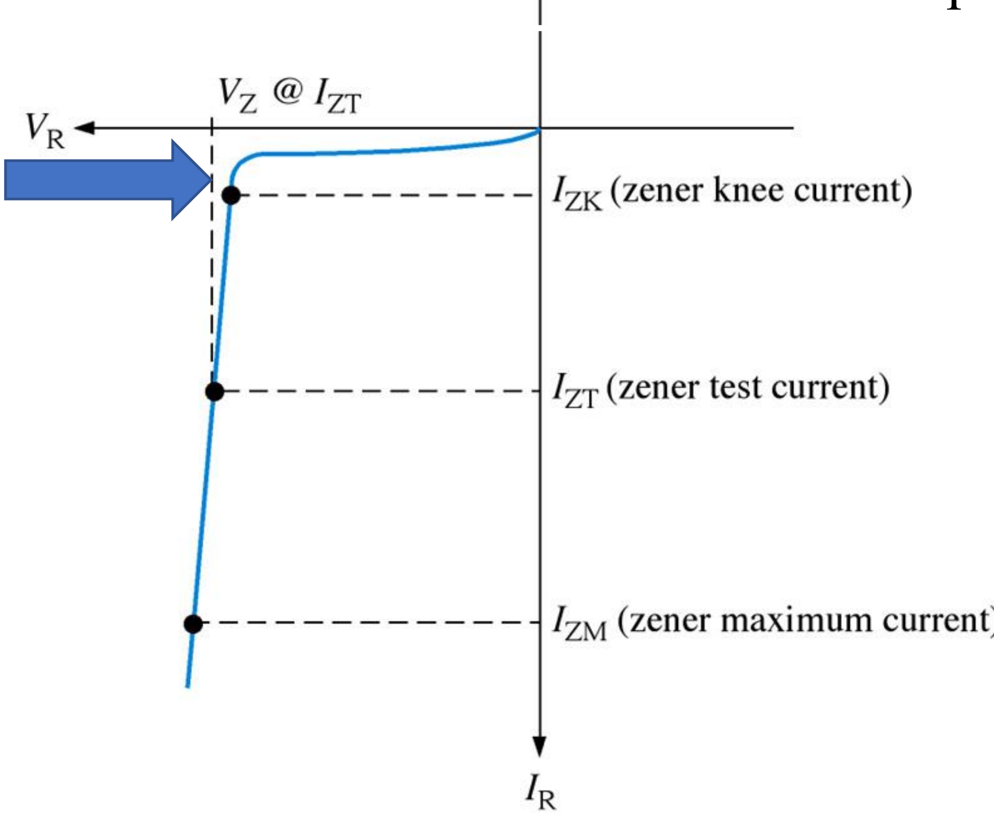
(a) The normal operating regions for a rectifier diode are shown as shaded areas.



(b) The normal operating region for a zener diode is shaded.

Breakdown Characteristics

Figure shows the reverse portion of a zener diode's characteristic curve. As the reverse voltage (V_R) is increased, the reverse current (I_R) remains extremely small up to the "knee" of the curve. The reverse current is also called the zener current, I_Z. At this point, the breakdown effect begins; the internal zener resistance, also called zener impedance (Z_Z), begins to decrease as reverse current increases rapidly.



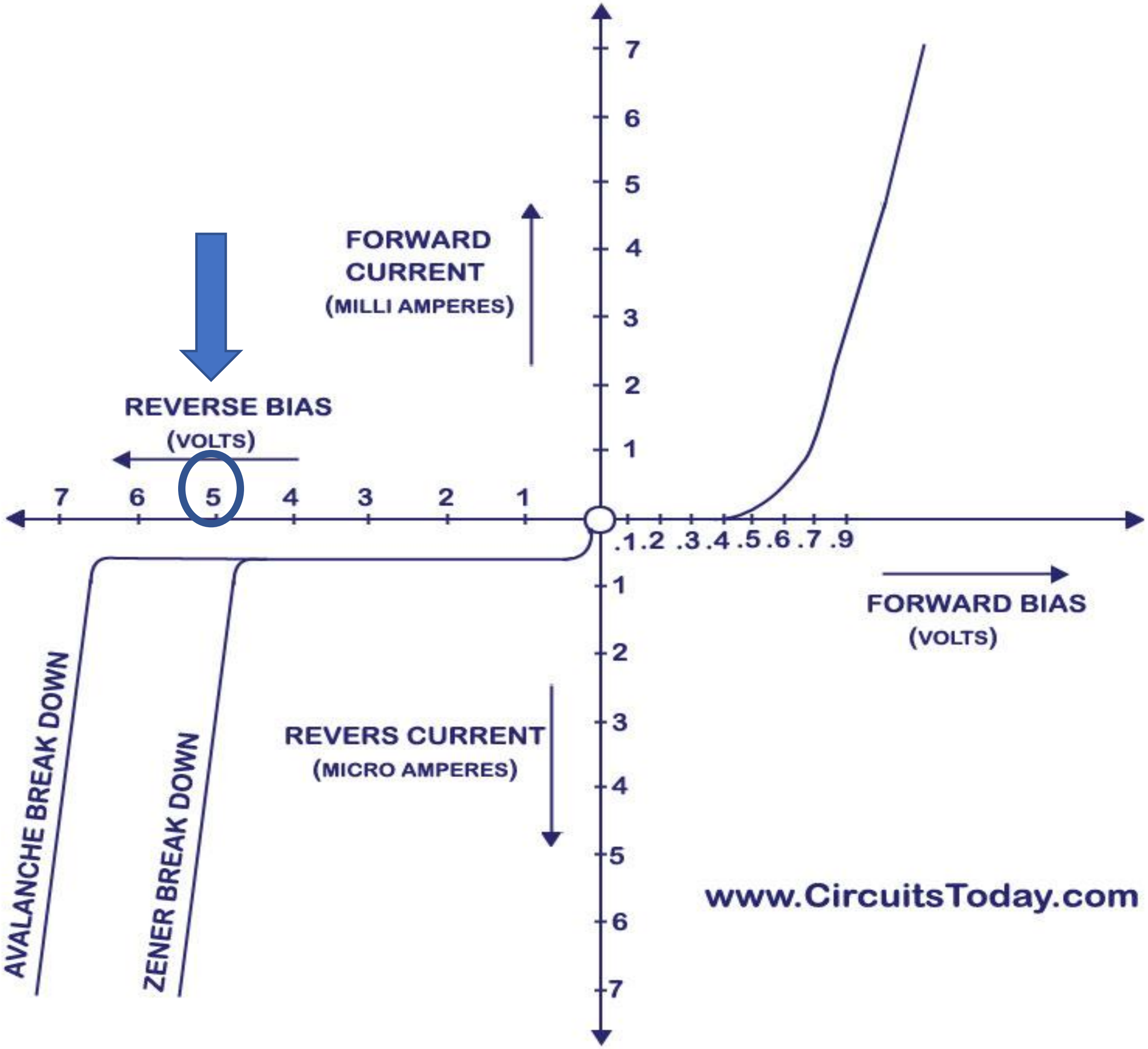
Zener Breakdown

- Zener diodes are designed to operate in reverse breakdown.
- Types of reverse breakdown in a zener diode: avalanche and zener.
- Avalanche Effect:
  - High reverse-bias voltage imparts energy to the free minority electrons so that as they speed through the p region.
  - They collide with atoms with enough energy to knock valence electrons out of orbit and into the conduction band.
  - The newly created conduction electrons are also high in energy and repeat the process.
  - If one electron knocks only two others out of their valence orbit during its travel through the p region, the numbers quickly multiply.
  - As these high-energy electrons go through the depletion region, they have enough energy to go through the n region as conduction electrons, rather than combining with holes
- The avalanche effect, occurs in both rectifier and zener diodes at a sufficiently high reverse voltage.

Zener Breakdown

- Zener breakdown occurs in a zener diode at low reverse voltages.
- Near the zener breakdown voltage (VZ), the field is intense enough to pull electrons from their valence bands and create current.
- Zener Diodes with Vz < approx. 5 V operate predominately in zener breakdown.
- Those with breakdown voltages greater than approximately 5 V operate predominately in avalanche breakdown.
- Both types are called zener diodes
- Zeners are commercially available with breakdown voltages from less than 1 V to more than 250 V with specified tolerances from 1% to 20%.

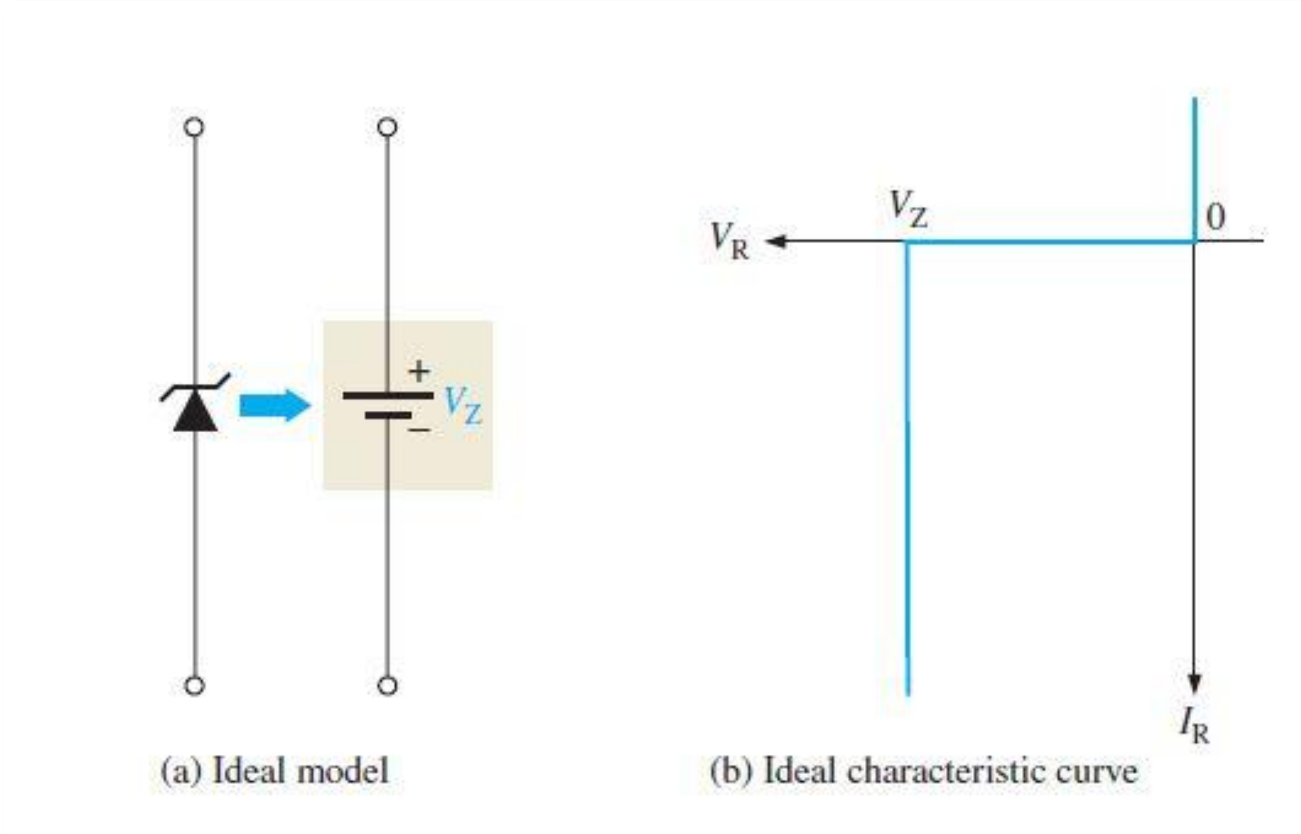
PN JUNCTION BREAKDOWN CHARACTERISTICS



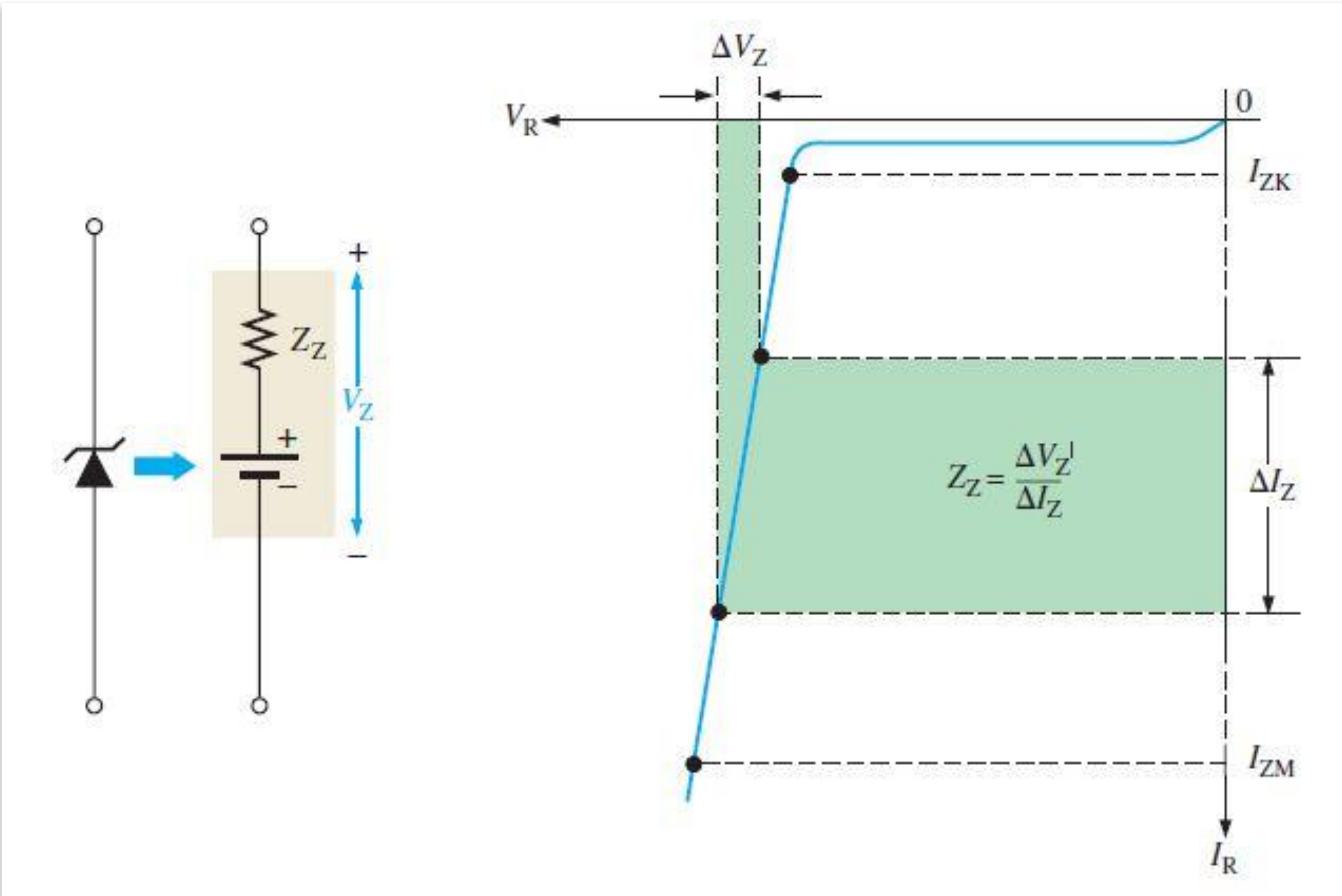
DIFFERENCE BETWEEN ZENER AND AVALANCHE BREAKDOWN

Sr. No.	Zener Breakdown	Avalanche breakdown
1	This occurs at junction which being heavily doped have narrow depletion layer	This occurs at junction which being lightly doped have wide depletion layer.
2	This breakdown voltage sets a very strong electric field across this narrow layer.	Here electric field is not strong enough to produce Zener breakdown.
3	Here electric field is very strong to rupture the covalent bonds thereby generating electron-hole pairs. So even a small increase in reverse voltage is capable of producing Large number of current carriers.	Here minority carriers collide with semi conductor atoms, which breaks the covalent bonds and electron-hole pairs are generated. Newly generated charge carriers are accelerated by the electric field which results in more collision and generates avalanche of charge carriers. This results in avalanche breakdown.
4	Zener diode exhibits negative temp. coefficient i.e. breakdown voltage decreases as temperature increases.	Avalanche diodes exhibits positive temp. coefficient i.e breakdown voltage increases with increase in temperature.

Ideal Model & Ideal Characteristic Curve of Zener Diode



Practical Model & Practical Characteristic Curve of Zener Diode



Application of Zener Diode

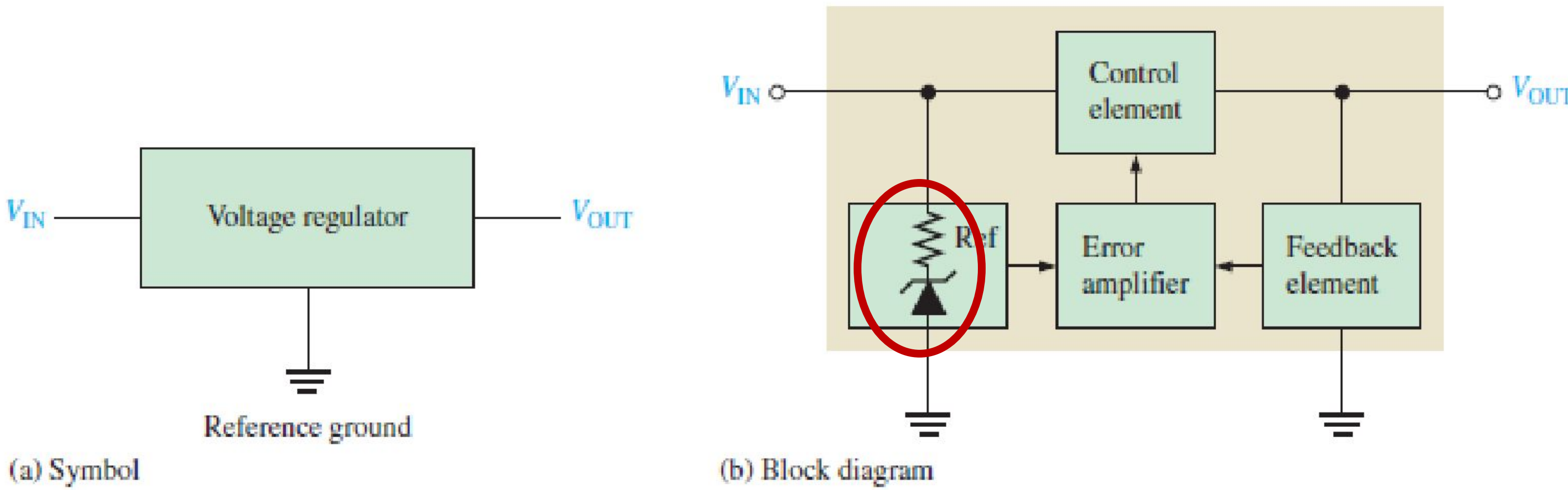
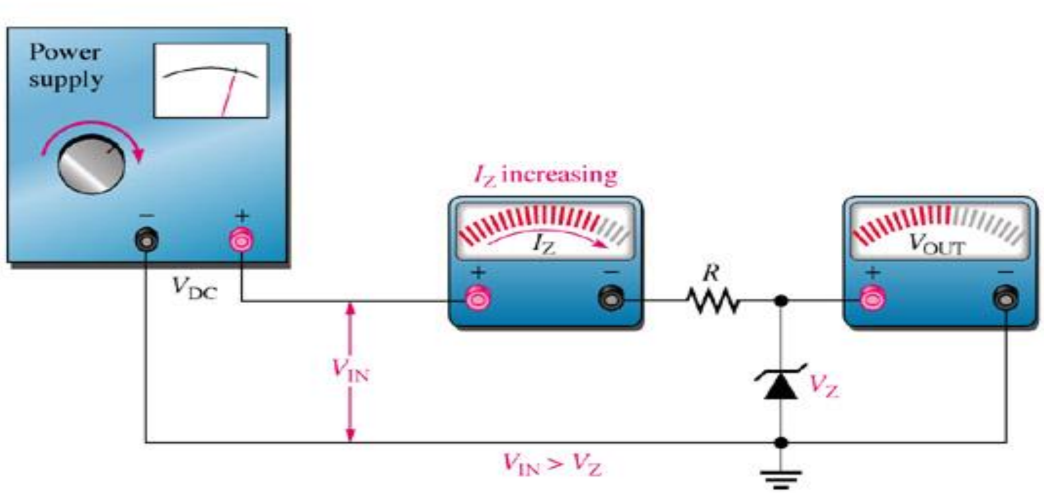


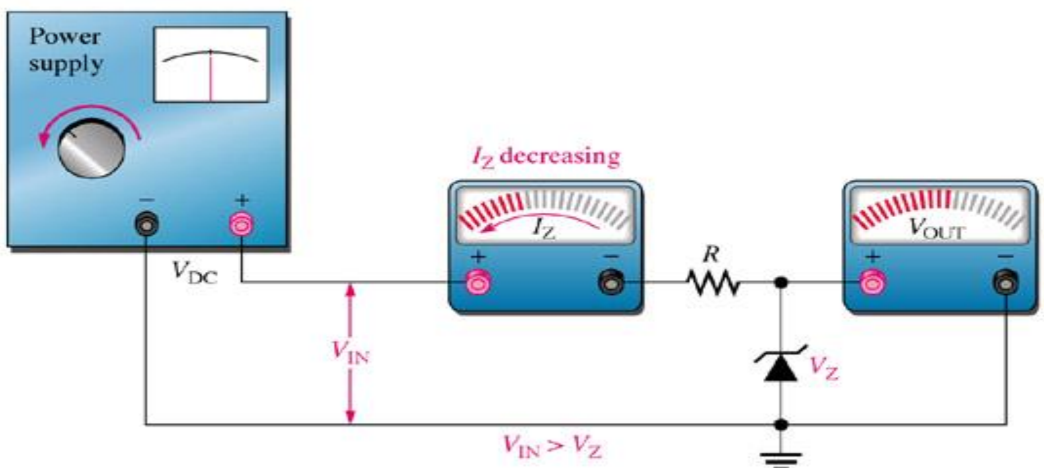
FIGURE 3–17

Three-terminal voltage regulators.

Zener Diode Applications –
Zener Regulation with a Varying Input Voltage



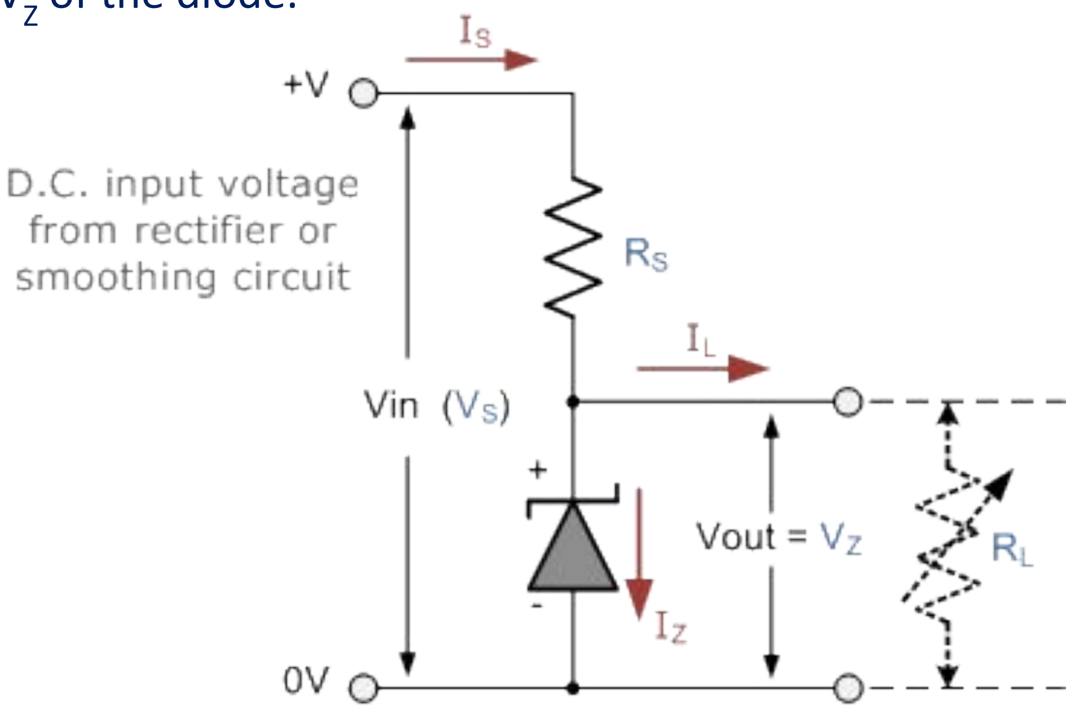
(a) As the input voltage increases, the output voltage remains constant ($I_{ZK} < I_Z < I_{ZM}$).



(b) As the input voltage decreases, the output voltage remains constant ($I_{ZK} < I_Z < I_{ZM}$).

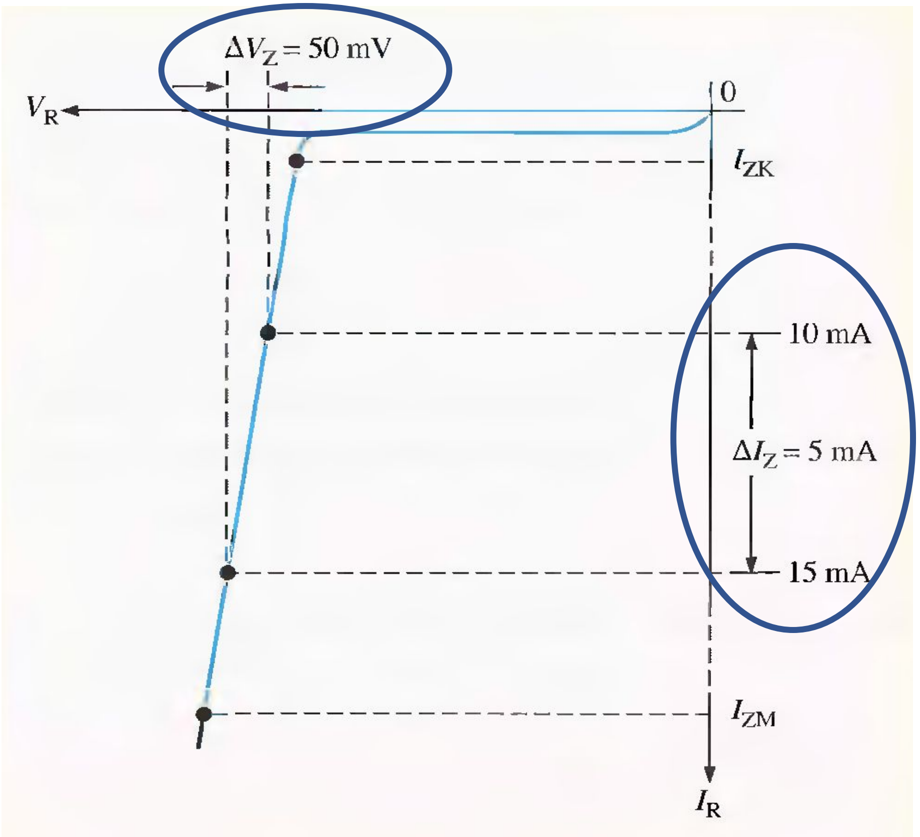
Zener Diode Application:
Zener diode as Voltage Regulator

- The zener voltage regulator consists of a current limiting resistor R_S connected in series with the input voltage V_S
- The zener diode connected in parallel with the load R_L in this reverse biased condition.
- The stabilised output voltage is always selected to be the same as the breakdown voltage V_Z of the diode.



Numerical on Zener Diode Impedance

A Zener diode exhibits a certain change in Vz for a certain change in Iz on a portion of the linear characteristic curve between I_{ZK} and I_{ZM} as illustrated in Figure. What is the Zener impedance Z_z?



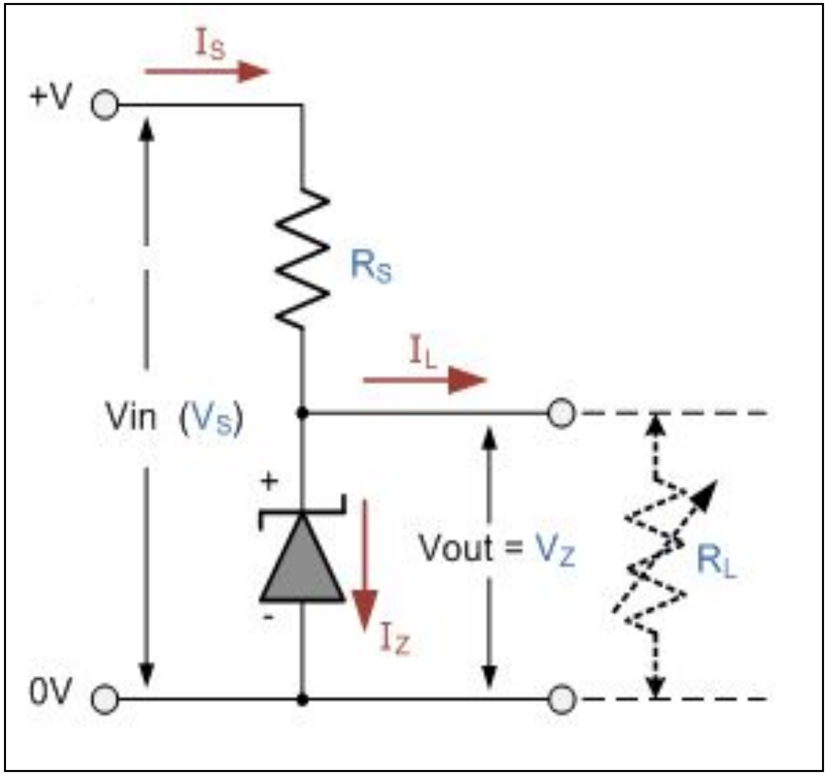
$$Z_Z = \frac{\Delta V_Z}{\Delta I_Z}$$

Zz= 50mV/5mA

= 10 Ohms

Example 1: Zener Regulator

- A 5.0V stabilized power supply is required to be produced from a 12V DC power supply input source. The maximum power rating Pz of the zener diode is 2W.



Using the zener regulator circuit calculate:

a) The maximum current flowing through the zener diode.

b) The value of the series resistor, Rs, with no load

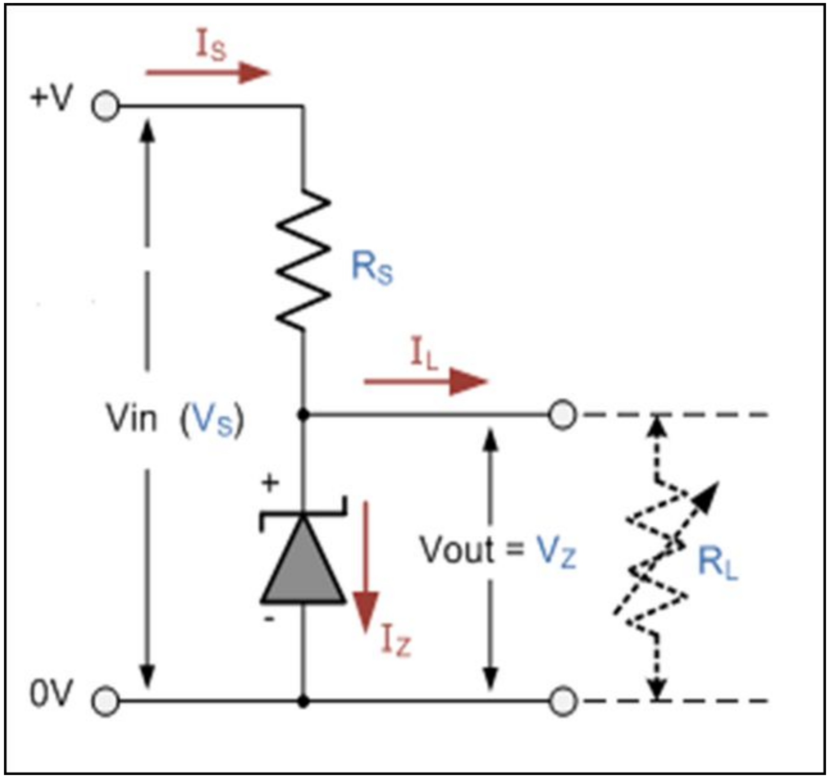
c) The load current I_L if a load resistor of 1kΩ is connected across the Zener diode.

d) The zener current Iz at full load

Power dissipation in Zener diode, $P_{zmax}=I_{zmax}.V_z$

(a) $Iz = \text{Maximum Current} = \dfrac{\text{Watts}}{\text{Voltage}} = \dfrac{2w}{5v} = 400mA$

$V_{in}=Vs= V_{RS}+V_Z$

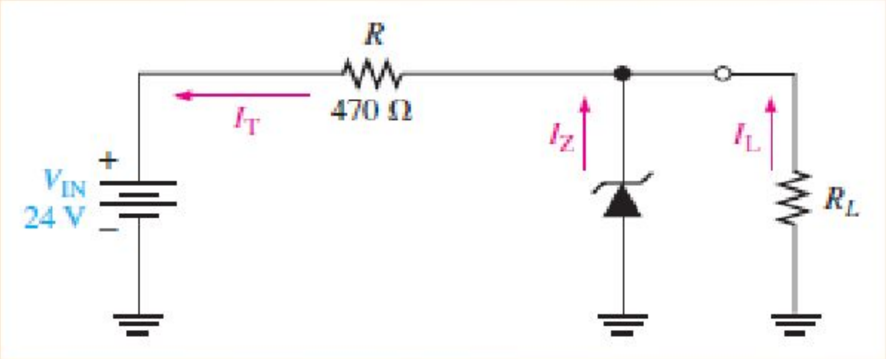


(b) $R_S = \dfrac{V_S - V_Z}{I_Z} = \dfrac{12-5}{400mA} = 17.5\Omega$

(c) $I_L = \dfrac{V_Z}{R_L} = \dfrac{5v}{1000\Omega} = 5mA$

(d) $I_Z = I_S - I_L = 400mA - 5mA = 395mA$

Example 2



Solution When $I_L = 0$ A ($R_L = \infty$), I_Z is maximum and equal to the total circuit current I_T.

$$I_{Z(max)} = I_T = \frac{V_{IN} - V_Z}{R} = \frac{24\text{ V} - 12\text{ V}}{470\ \Omega} = 25.5\text{ mA}$$

If R_L is removed from the circuit, the load current is 0 A. Since $I_{Z(max)}$ is less than I_{ZM}, 0 A is an acceptable minimum value for I_L because the zener can handle all of the 25.5 mA.

$$I_{L(min)} = 0\text{ A}$$

The maximum value of I_L occurs when I_Z is minimum ($I_Z = I_{ZK}$), so

$$I_{L(max)} = I_T - I_{ZK} = 25.5\text{ mA} - 1\text{ mA} = \mathbf{24.5\text{ mA}}$$

The minimum value of R_L is

$$R_{L(min)} = \frac{V_Z}{I_{L(max)}} = \frac{12\text{ V}}{24.5\text{ mA}} = \mathbf{490\ \Omega}$$

Therefore, if R_L is less than 490 Ω, R_L will draw more of the total current away from the zener and I_Z will be reduced below I_{ZK}. This will cause the zener to lose regulation. Regulation is maintained for any value of R_L between 490 Ω and infinity.

Homework Problem

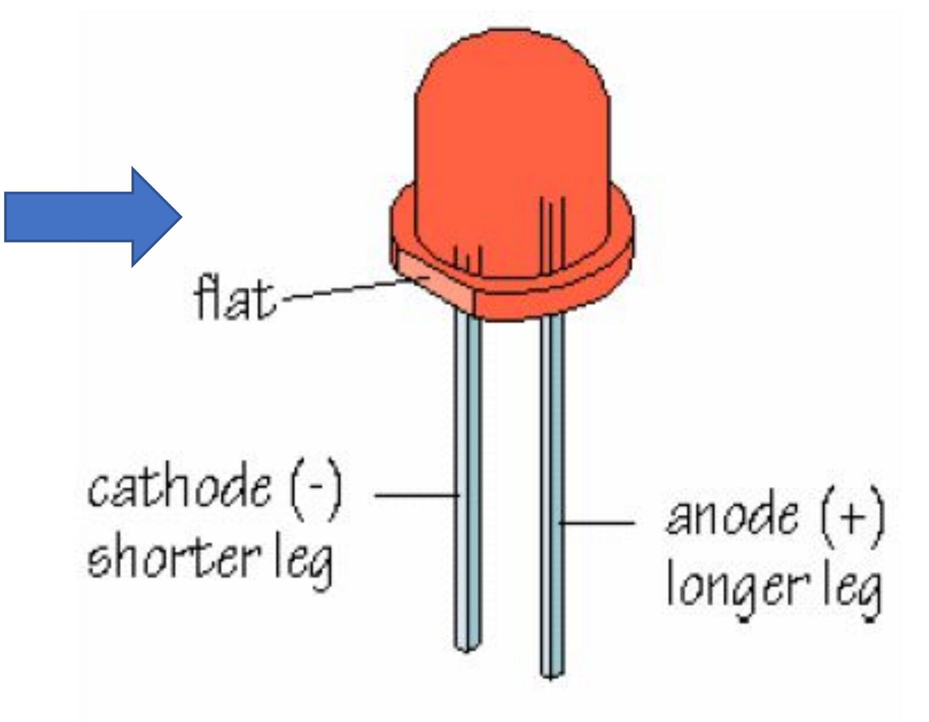
Find the minimum and maximum load currents for which the circuit in Figure 3–14 will maintain regulation. Determine the minimum value of R_L that can be used. $V_Z = 3.3$ V (constant), $I_{ZK} = 1$ mA, and $I_{ZM} = 150$ mA. Assume an ideal zener.

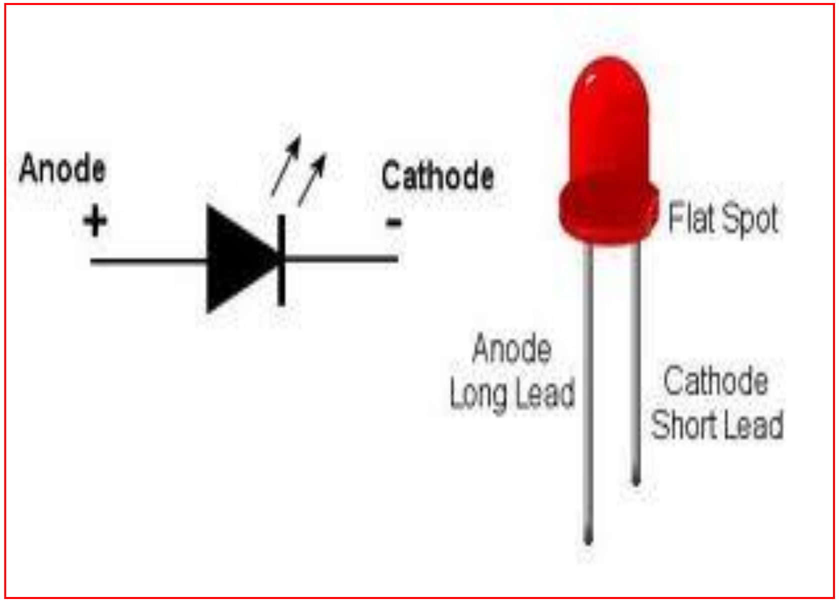
Zener diode Summary

- A zener diode is always operated in its reverse biased condition.
- A voltage regulator circuit can be designed using a zener diode to maintain a constant DC output voltage across the load in spite of variations in the input voltage or changes in the load current.
- The zener voltage regulator consists of a current limiting resistor Rs connected in series with the input voltage Vs with the zener diode connected in parallel with the load R_L in this reverse biased condition.
- The stabilized output voltage is always selected to be the same as the breakdown voltage Vz of the diode.

Special Type of diode
Light Emitting Diode: LED

LED Symbol and Structure





LED Operation

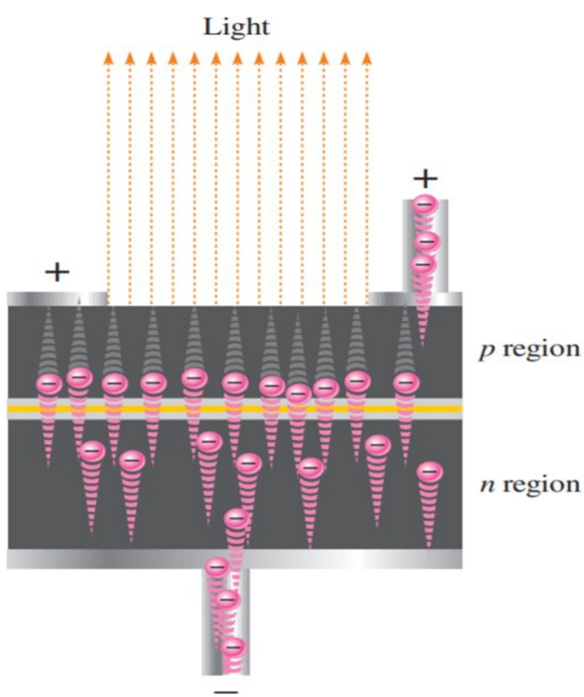
- When LED is forward-biased electrons cross the pn junction from the n-type material and recombine with holes in the p-type material.

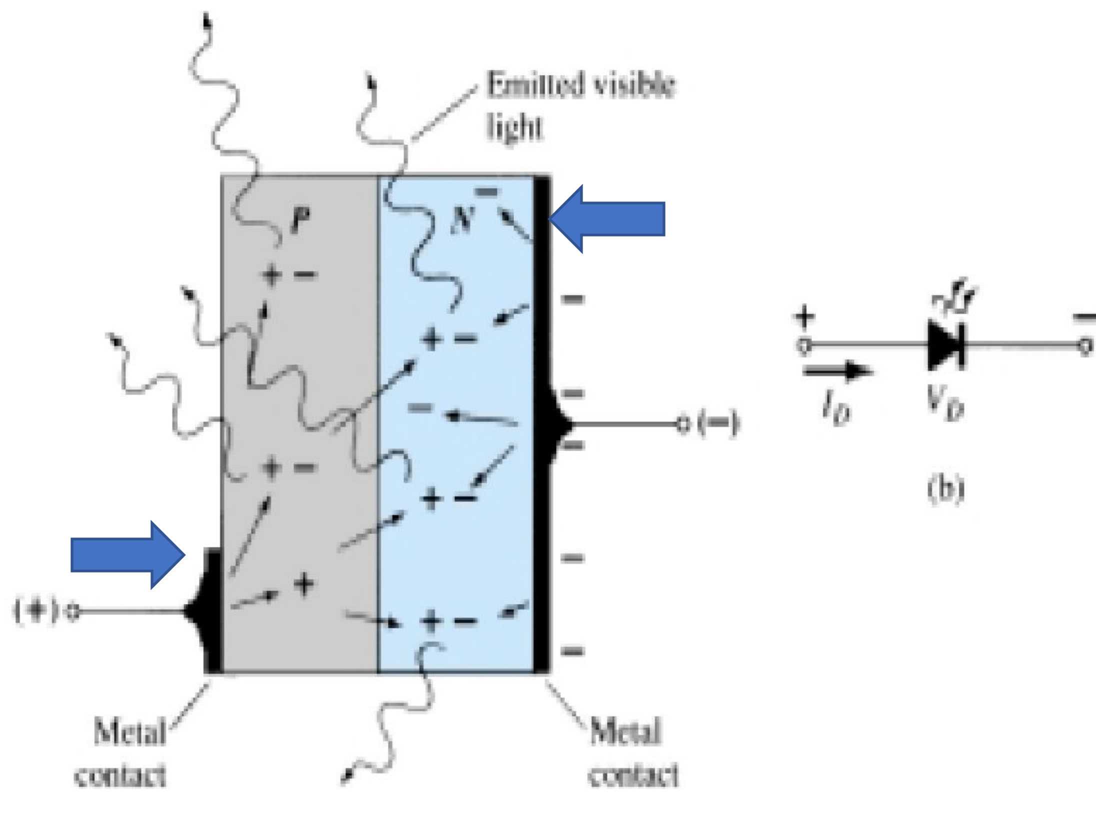
- The free electrons are in the conduction band and at a higher energy than the holes in the valence band. **The Energy difference between the electrons and the holes corresponds to the energy of visible light.**

- When recombination takes place, the recombining electrons release energy in the form of photons. The emitted light tends to be monochromatic (one colour) that depends on the band gap and impurities.

Electroluminescence in LED

- ***The process of giving off light by applying an electrical source of energy is called electroluminescence.***
- A large exposed surface area on one layer of the semiconducting material permits the photons to be emitted as visible light



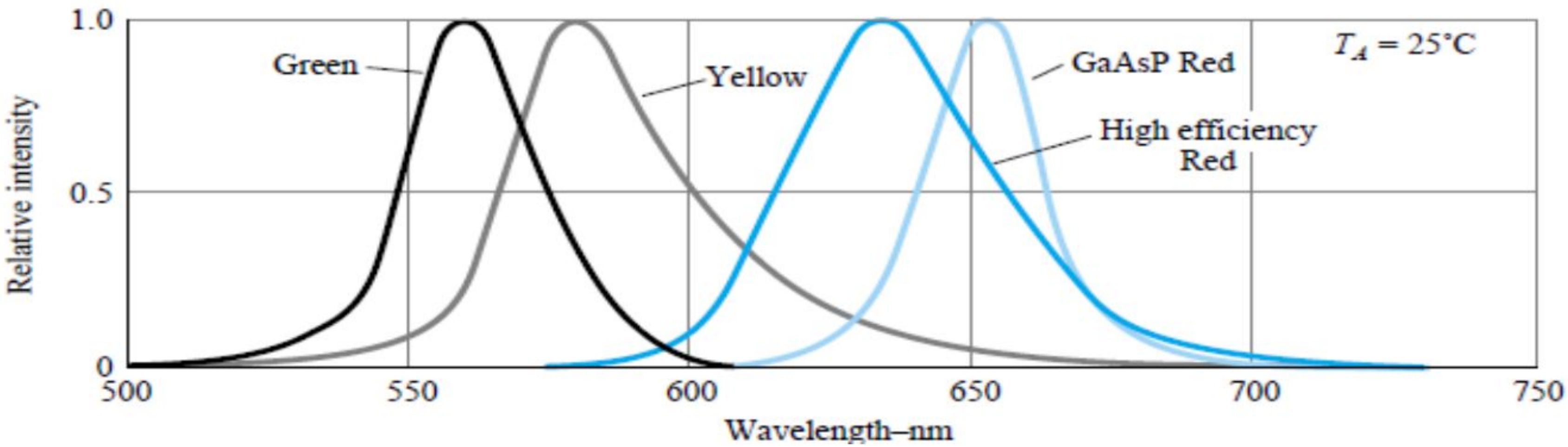


(a)

Types of LEDs- Visible light & IR

- Various impurities are added during the doping process to establish the wavelength of the emitted light. The wavelength determines the color of visible light. E.g 650 nm - red

- IR LEDs: Some LEDs emit photons that are not part of the visible spectrum but have longer wavelengths and are in the infrared (IR) portion of the spectrum (700 nm – 1700 nm).

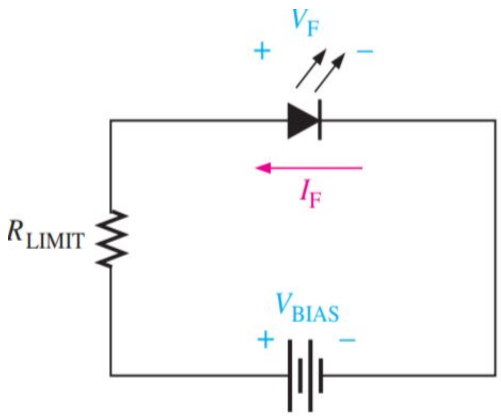


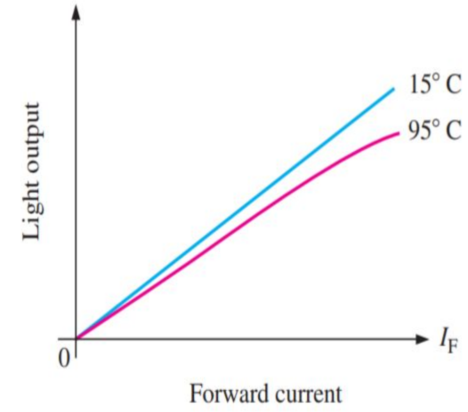
Materials used for LED decide its colour

- Gallium Arsenide (GaAs) – infra-red
- Gallium Arsenide Phosphide (GaAsP) – red to infra-red, orange
- Aluminium Gallium Arsenide Phosphide (AlGaAsP) – high-brightness red, orange-red, orange, and yellow
- Gallium Phosphide (GaP) – red, yellow and green
- Aluminium Gallium Phosphide (AlGaP) – green
- Gallium Nitride (GaN) – green
- Gallium Indium Nitride (GaInN) – near ultraviolet, bluish-green and blue
- Zinc Selenide (ZnSe) – blue
- Aluminium Gallium Nitride (AlGaN) – ultraviolet

LED Biasing

- The forward voltage across an LED is considerably greater than for a silicon diode.
- **LED Cut-in voltage**: Typically, the maximum V_F for LEDs is between 1.2 V and 3.2 V, depending on the material.
- **Reverse breakdown voltage** for an LED is much less than for a silicon rectifier diode (3 V to 10 V is typical).
- The LED emits light in response to a sufficient forward current, as shown in Figure. An increase in I_F corresponds proportionally to an increase in light output.
- The light output (both intensity and color) is also dependent on temperature. Light intensity goes down with higher temperature as indicated in the figure.

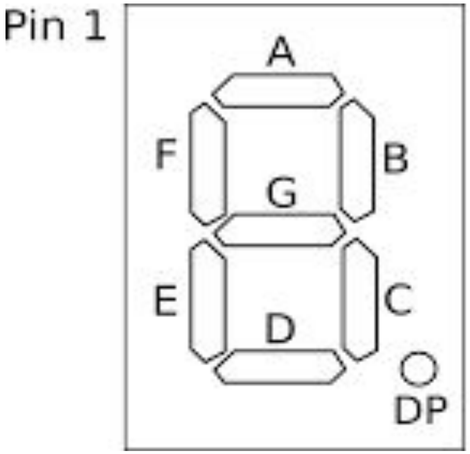


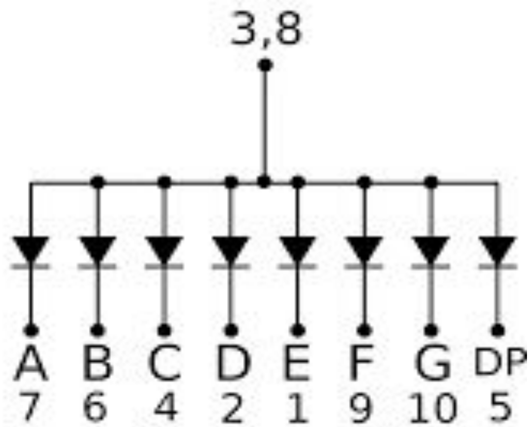


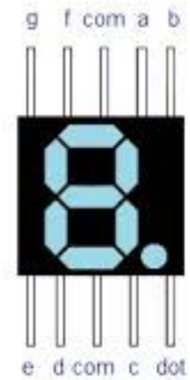
Applications

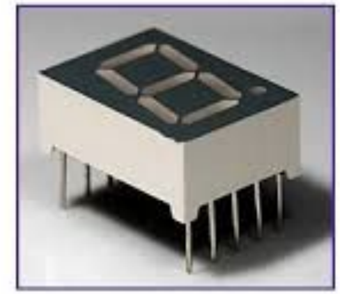
- Seven Segment Display
- Infrared remote control
- Indicators

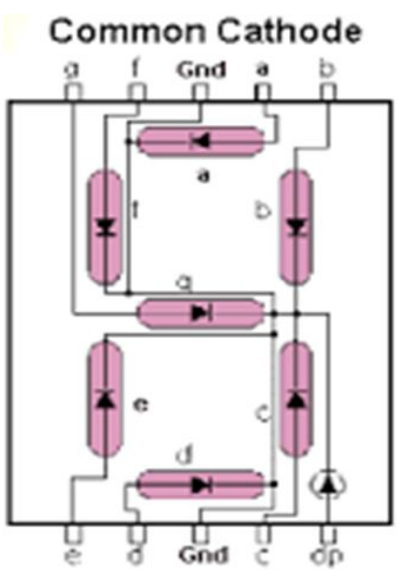
LED Seven Segment Display and types

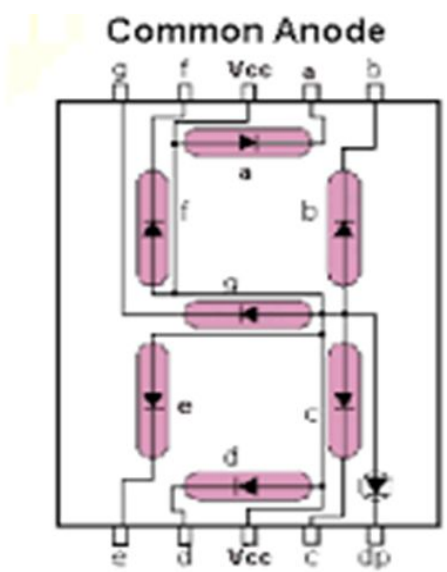


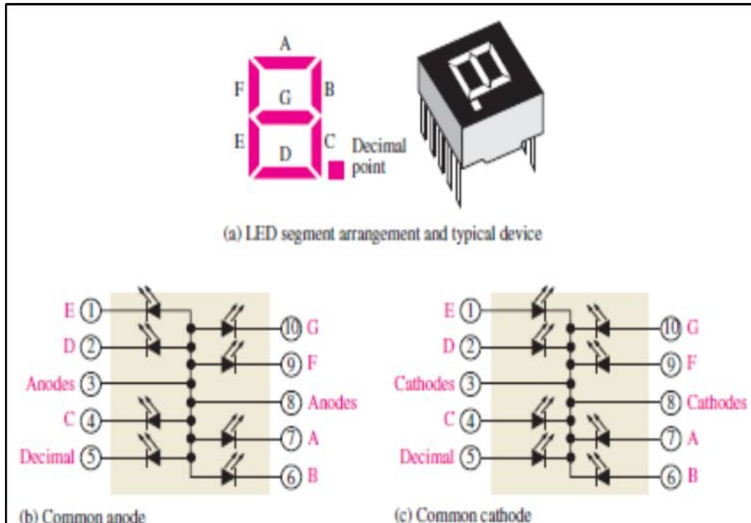












▲ FIGURE 3–35

The 7-segment LED display.

Thank You !