INSTRUMENTATION ENGINEERING

ANALOG ELECTRONICS

Comprehensive Theory
with Solved Examples *and* Practice Questions

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1

Diode Circuits

1.1 INTRODUCTION

The simplest and most fundamental non-linear circuit element is a diode. Just like a resistor, the diode has two terminals; but unlike the resistor which has a linear (straight-line) relationship between the current flowing through it and the voltage appearing across it, the diode has non-linear i-v characteristics. The analysis of non-linear electronic circuits is not as straight-forward as the analysis of linear electric circuits. However, there are electronic functions that can be implemented only by non-linear circuits. Examples include the generation of dc voltages from sinusoidal voltages and the implementation of logic functions.

1.2 DIODE CIRCUITS : DC ANALYSIS AND MODELS

Mathematical relationships, or ***models***, that describes the current-voltage characteristics of electrical elements allow us to analyze and design circuits without having to fabricate and test them in the laboratory. An example is Ohm's law, which describes the properties of a resistor. In this section, we will develop the dc analysis and modelling techniques of diode circuits.

To begin to understand diode circuits, consider an ***ideal diode***. It is a two terminal device having the circuit symbol and the i-v characteristics shown in figure below.

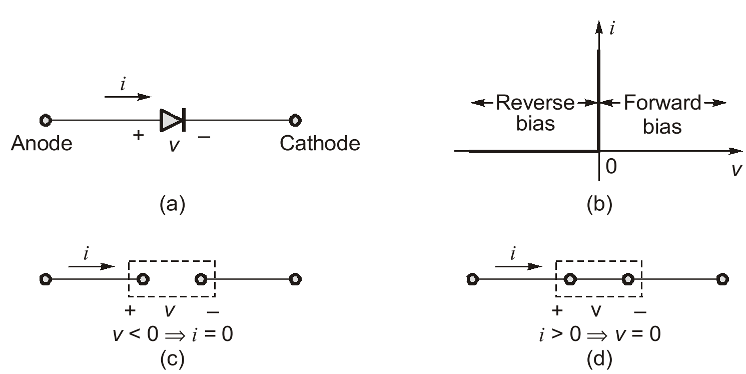


Figure: *The ideal diode: (a) Diode circuit symbol ; (b) i-v characteristics; (c) Equivalent circuit in the reverse direction (d) Equivalent circuit in the forward direction.*

The terminal characteristics of the ideal diode can be interpreted to follows:

- If a negative voltage is applied to the diode, no current flows and the diode behaves as an ***open circuit*** [as shown in Figure (c)]. Diodes operated in this mode are said to be ***reverse biased***.
- On the other hand, if a positive current is applied to the ideal diode, zero voltage drop appears across the diode. In other words the ideal diode behaves as a ***short circuit*** in the forward direction [as shown in Figure (d)]. Diodes operated in this mode are said to be ***forward biased***

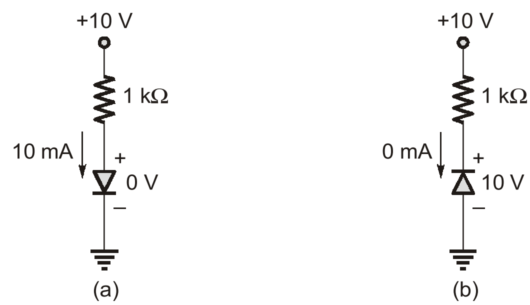


Figure : *The two modes of operation of ideal diodes and the use of external circuit to limit (a) the forward current and (b) the reverse voltage*

From the above description it should be noted that the external circuit must be designed to limit the forward current through a conducting diode, and the reverse voltage across a cut-off diode to predetermined values. Above figure shows two diode circuits that illustrate this point. In the circuit of Figure (a) the diode is obviously conducting. Thus its voltage drop will be zero, and the current through it will be determined by the +10 V supply and the 1 kΩ resistor as 10 mA. The diode in the circuit is obviously cut-off, and thus its current will be zero which in turn means that the entire 10 V supply will appear as reverse bias across the diode.

For practical diodes, i-v characteristics is shown as

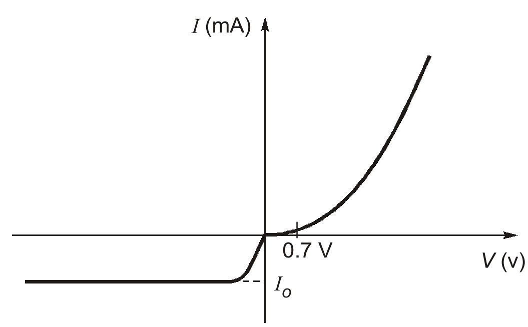


Figure : *Practical characteristics of diode*

When the practical diode characteristics are compared to the ideal diode characteristics, one considers the only major difference is that, during forward biased condition. Voltage drop across the diode is 0.7 V (for silicon diode) rather than 0 V, and during reverse biased condition current flows across the diode is approximately I_o(reverse saturation current in μA) rather than 0 A.

1.2.1 Load-Line Analysis

The circuit of below figure is the simplest of diode configurations. Solving the circuit is all about finding the current and voltage levels that will satisfy both the characteristics of the diode and the chosen network parameters at the same time.

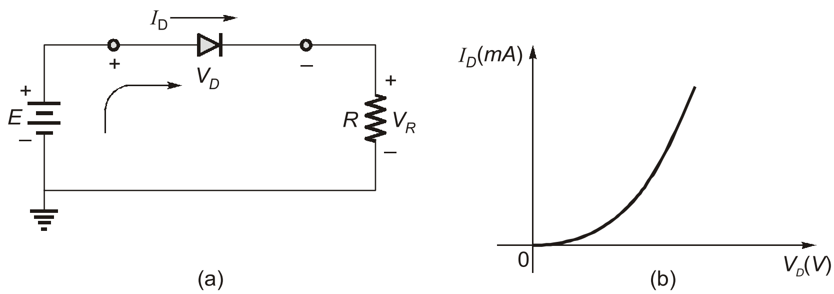


Figure : *Series diode configuration (a) Circuit (b) Characteristics*

In below figure the diode characteristics are placed on the same set of axis as a straight line defined by the parameters of the network. The straight line is called a ***load line*** because the intersection of the vertical axis is defined by the applied load *R*. The analysis to follow is therefore called ***load-line analysis***. The intersection of the two curves will define the solution for the network and define the current and the voltage levels for the network.

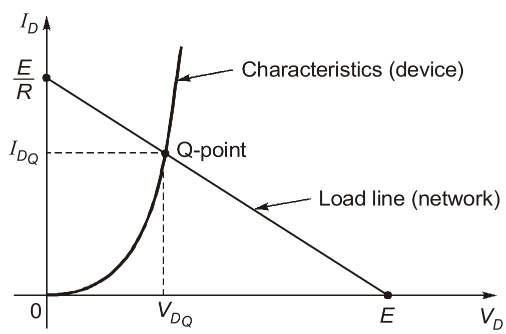


Figure : *Drawing the load line and finding the point of operation*

- The intersection of the load line on the characteristics of figure can be determined by applying Kirchhoff's voltage law in the clockwise direction, which results in

$$E - V_D - V_R = 0$$

or $$E = V_D + I_D R \qquad \text{...(1.1)}$$

- The two variables of the equation (1.1), V_D and I_D, are the same as the diode axis variables of above fig. This similarity permits plotting equation (1.1) on the same characteristics of figure.
- Set, $V_D = 0$ V in equation (1.1)

$$E = 0\text{ V} + I_D R$$

$$\therefore \quad I_D = \frac{E}{R}\bigg|_{V_D = 0\text{ V}} \qquad \text{...(1.2)}$$

Equation (1.2) gives the magnitude of I_D on the vertical axis.

- Set, $I_D = 0$ A in equation (1.1)

$$E = V_D + (0\text{ A})\, R$$

$$\Rightarrow \quad E = V_D$$

$$\therefore \quad V_D = E\big|_{I_D = 0\text{ A}} \qquad \text{...(1.3)}$$

Equation (1.3) gives the magnitude of V_D on the horizontal axis.

- A straight line drawn between the two points will define the load line as depicted in figure. Change the level of *R* (the load), which will lead to the change in the intersection on the vertical axis. This will be resulted into the change in the slope of the load line and different point of intersection between the load line and the device characteristics.

- Now, we have a load line defined by the network and a characteristic curve defined by the device. The point of intersection between the two is the point of operation for this circuit.
- By simply drawing a line down to the horizontal axis, we can determine the diode voltage V_{DQ}, whereas a horizontal line from the point of intersection to the vertical axis will provide the level of I_{DQ}. The point of operation is usually called the ***quiescent point*** (abbreviated "***Q-point***") to reflect its "still, unmoving" qualities as defined by a dc network.
- The solution obtained at the intersection of the two curves is the same as would be obtained by a simultaneous mathematical solution of

$$I_D = \frac{E}{R} - \frac{V_D}{R} \quad \text{[Derived from equation 1.1]}$$

and

$$I_D = I_0(e^{V_D/\eta V_T} - 1) \quad \text{[Diode equation]}$$

1.2.2 Series Diode Configuration

The approximate models will now be used to investigate a number of series diode configurations with dc inputs. This will establish a foundation in diode analysis that will carry over into the sections and chapters to follow. The procedure described below, can infact be applied to the networks with any number of diodes in variety of configurations.

- For each configuration, firstly the state of each diode must be determined. Which diodes are "***on***" and which are "***off***"? Once determined, the appropriate equivalent can be substituted and the remaining parameters of the network can be determined.
- For the conduction region the only difference between the silicon diode and the ideal diode is the vertical shift in the characteristics, which is accounted for in the equivalent model by a dc supply of 0.7 V opposing the direction of forward current through the device. For voltages less than 0.7 V for a silicon diode and 0 V for the ideal diode the resistance is so high compared to the other elements of the network that its equivalent is the open circuit.
- ***In general, a diode is in the "on" state if the current established by the applied sources is such that its direction matches that of the arrow in the diode symbol, and $V_D \geq 0$ V for ideal diode, $V_D \geq 0.3$ V for germanium diode, $V_D \geq 0.7$ V for silicon diode, and $V_D \geq 1.2$ V for gallium arsenide diode.***

The below circuit of will be used to demonstrate the approach described in the above paragraphs.

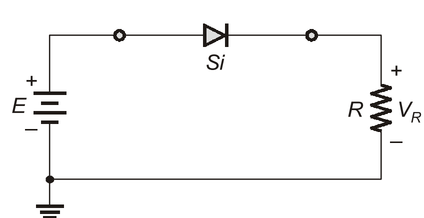


Figure : *Series diode configuration*

The state of the diode is first determined by mentally replacing the diode with a resistive element as shown in Figure (a). The resulting direction of I is a match with the arrow in the diode symbol, and since $E > V_\gamma$ (cut-in voltage of diode), the diode is in the "on" state. The network is redrawn as shown in Figure (b) with the appropriate equivalent model for the forward biased silicon diode.

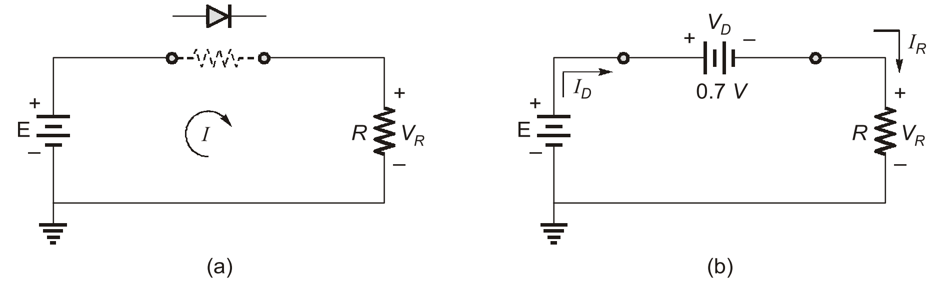


Figure : *Series diode circuit analysis in forward bias*

Following are the resulting voltage and current levels:

$$V_D = V_\gamma$$
$$V_R = E - V_\gamma \qquad \text{...(1.4)}$$
$$I_D = I_R = \frac{V_R}{R}$$

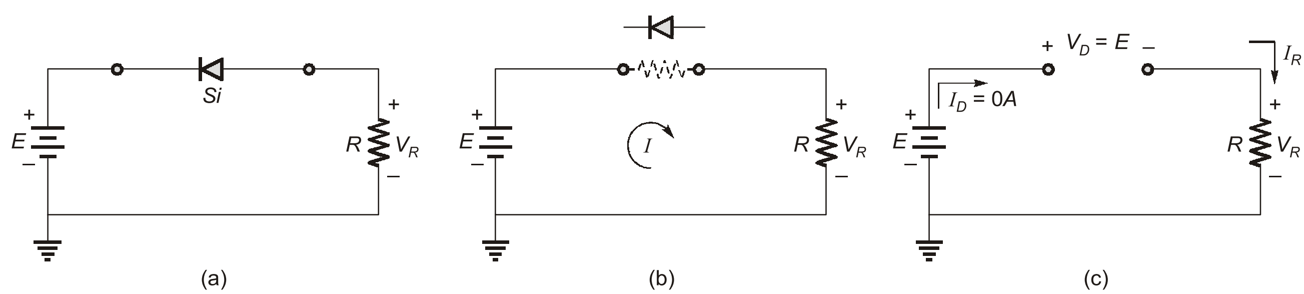


Figure : *Series diode circuit analysis in reverse bias*

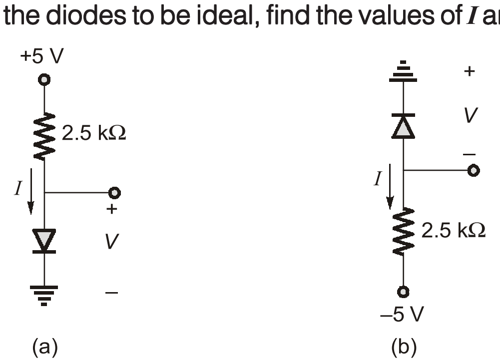
When reverse bias is applied to diode then mentally replace the diode with a resistive element as shown in Figure (b) will reveal that the resulting current direction does not match the arrow in the diode symbol. The diode is in the "off" state, resulting in the equivalent circuit of Figure (c). Due to the open circuit, the diode current is 0 A and the voltage across the resistor R is the following:

$$V_R = I_R R = I_D R = (0\text{ A})\ R = 0\text{ V}$$

The fact that V_R = 0 V will establish E volts across the open circuit defined by Kirchhoff's voltage law. Always keep in mind that under any circumstances i.e. either DC or AC—***Kirchhoff's voltage law must be satisfied!***

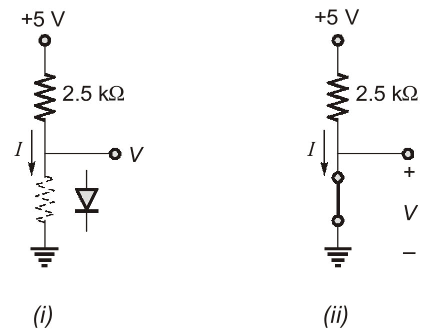
EXAMPLE : 1.1 [Single Branch Diode Circuits]

Assuming the diodes to be ideal, find the values of I and V in the circuits shown below:



Solution:

In Fig. (a) replacing the diode with a resistive element as shown below in ***Fig. (i)***:



The resulting direction of I is a match with the arrow in the diode symbol, hence the diode is in the "on" state. Now the network can be redrawn as shown in ***Fig. (ii)***.

The resulting voltage and current levels are the following:

$$V = 0\text{ V} \qquad [\text{as diode is ideal so } V_\gamma = 0\text{ V}]$$

and

$$I = \frac{5-0}{2.5\,k} = 2\text{ mA}$$

In Fig. (b) replacing the diode with a resistive element as shown below in ***Fig. (iii)***:

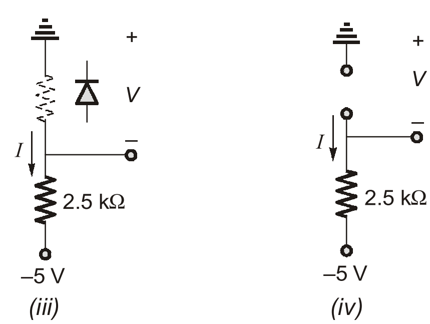


Fig. (iii) reveals that the resulting direction of current I does not match the arrow in the diode symbol. The diode is in the "off" state resulting in the equivalent circuit as shown in ***Fig. (iv)***:

Resulting current and voltage can be calculated as below:

$$I = 0\text{ A} \qquad [\text{Since diode is open circuit}]$$

Now applying KVL in the circuit

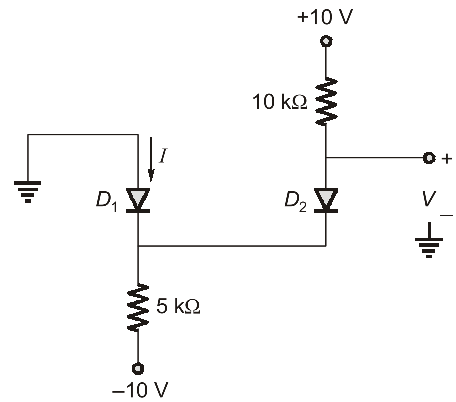
$$V + 2.5\,I - 5 = 0$$

$$\Rightarrow \quad V + 2.5 \times 0 - 5 = 0$$

$$\Rightarrow \quad V = 5\text{ V}$$

EXAMPLE : 1.2 [Multiple Branch Diode Circuit]

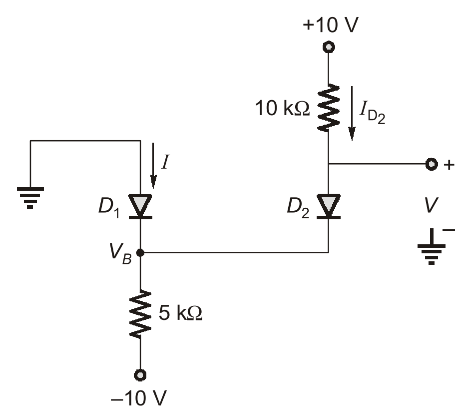
Assuming diodes to be ideal, find the values of I and V in the following circuit:



Solution:

NOTE: In such type of circuits it might not be obvious at first sight whether none, one, or both diodes are conducting. In such cases, we make a possible assumption, proceed with the analysis, and check whether we end up with a consistent solution.

For this circuit, we shall assume that both diodes are conducting. It follow that $V_B = 0$ and $V = 0$. The current through D_2 can now be determined from



$$I_{D_2} = \frac{10-0}{10k} = 1\text{mA}$$

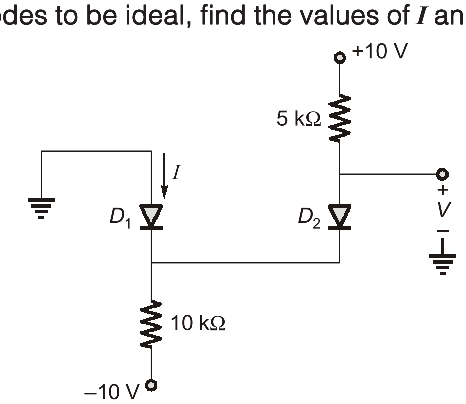
Writing a node equation at B,

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

$\Rightarrow$ $$I = +1\text{ mA}$$

Thus D_1 is conducting as originally assumed and the final result is $I = 1$ mA and $V = 0$ V.

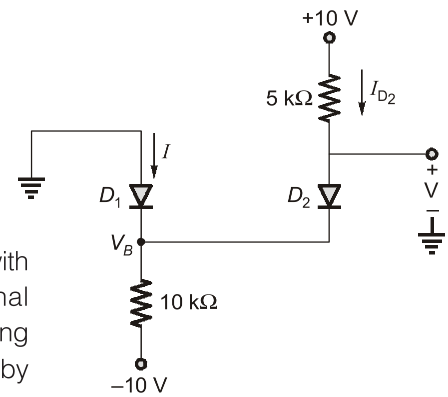
EXAMPLE : 1.3 Assuming diodes to be ideal, find the values of I and V in the following circuit:



Solution :

If we assume that both diodes are conducting then $V_B = 0$ V and $V = 0$ V. The current in D_2 is obtained from

$$I_{D_2} = \frac{10-0}{5k} = 2\,\text{mA}$$



The node equation at B is

$$I + 2\,\text{mA} = \frac{0-(-10)}{10\,k}$$

$$\Rightarrow \quad I = -1\text{ mA}$$

$I = -1$ mA, is not possible as I does not match with arrow direction of the diode D_1 so our original assumption is not correct. We start again, assuming that D_1 is off and D_2 is on. The current I_{D_2} is given by

$$I_{D_2} = \frac{10-(-10)}{10\,k+5\,k} = 1.33\text{ mA}$$

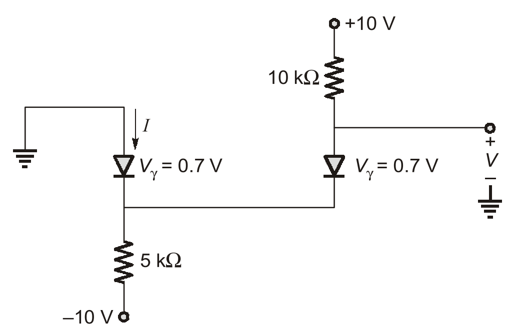
and the voltage at node B is, $\quad V_B = -10 + 10\text{ k} \times 1.33\text{ mA} = +3.3$ V

Thus D_1 is reverse biased as assumed, and the final result is I = **0 A** and V = **3.3 V**.

EXAMPLE : 1.4

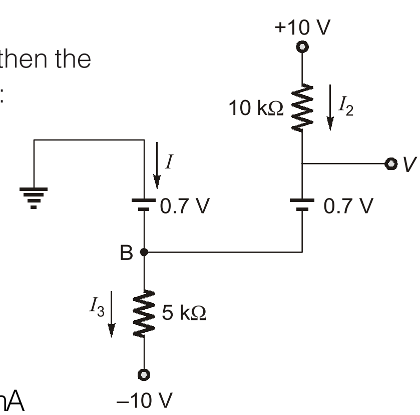
[Practical diode circuit]

Find I and V for the circuit shown below:



Solution :

We shall assume that D_1 and D_2 are forward bias then the equivalent circuit can be redrawn as shown below:



So, voltage at node B is

$$V_B = -0.7\text{ V}$$

and $\quad V = 0.7 + V_B = 0.7 - 0.7 = 0$ V

Hence, I_2 can be calculated as

$$I_2 = \frac{10-0}{10\,k} = 1\,\text{mA}$$

Now applying KCL at node B

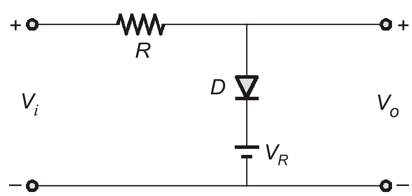
$$I_3 = \frac{0.7-(-10)}{5\,k\Omega} = 1.86\,\text{mA}$$

$$I = I_3 - I_2 = 1.86\text{ mA} - 1\text{ mA} = 0.86\text{ mA}$$

Thus D_1 is conducting as originally assumed and the final result is I = **0.86 mA** and V = **0 V**.

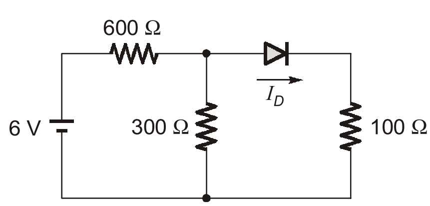
OBJECTIVE BRAIN TEASERS

Q.1 In the circuit shown below the input v_i has positive and negative swings and v_o is the output then



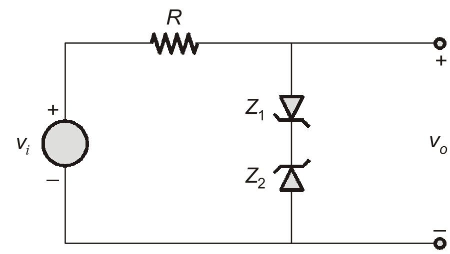
(a) $v_o = 0$ for negative v_i
(b) $v_o = V_R$ for positive v_i
(c) $v_o = V_R$ for $v_i > V_R$
(d) $v_o = V_R$ for all v_i

Q.2 In the *Si* diode circuit shown below, a diode current of 6.7 mA is flowing.



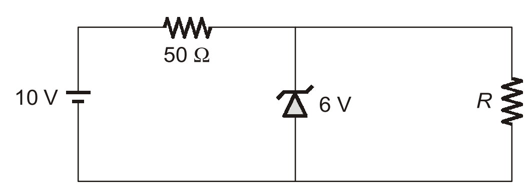
Assuming diode is ideal one. Its forward resistance and cut-in voltage are
(a) 2 Ω, 0.7 V (b) 0 Ω, 0.7 V
(c) 0 Ω, 0 V (d) 4 Ω, 0 V

Q.3 In the circuit shown below the Zener voltage $V_{Z_1} = V_{Z_2} = 5$ volts, $V_\gamma = 0.6$ V, v_o is the output then



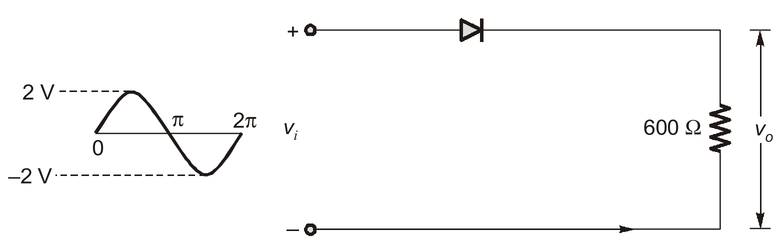
(a) For $|v_i| \le 5.6$ volts, $v_o = v_i$
(b) For $|v_i| \le 10$ volts, $v_o = v_i$
(c) For $|v_i| > 5.6$ volts, $v_o = v_i$
(d) $v_o = 5.6$ volts for all v_i

Q.4 The 6 V Zener diode shown in figure has zero Zener resistance and a knee current of 5 mA. The minimum value of R so that the voltage across it does not fall below 6 V is

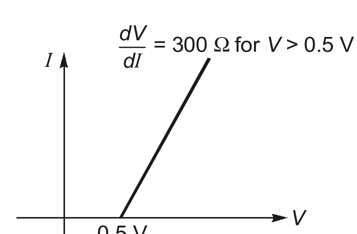


(a) 1200 Ω (b) 80 Ω
(c) 50 Ω (d) 10 Ω

Q.5 Consider the circuit shown in Figure (I). If the diode used here has the V-I characteristic as in Figure (II), then the output waveform v_o is

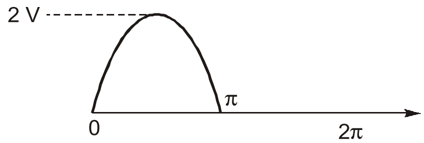


(I)

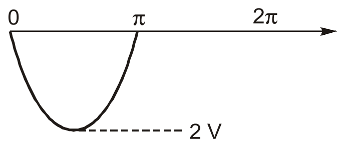


(II)

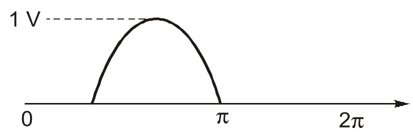
(a)



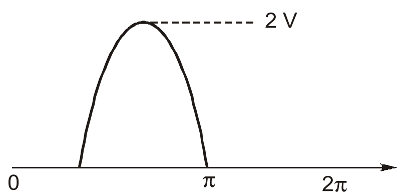
(b)



(c)



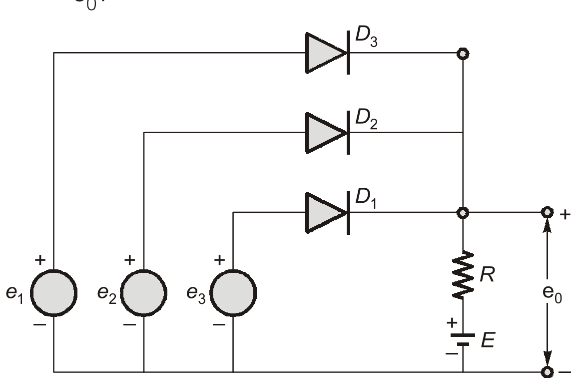
(d)



Q.6 A diode is very useful for rectifier circuits due to its

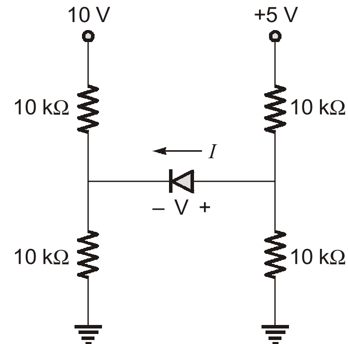
(a) ability to conduct current only in one direction
(b) ability to given current in both direction
(c) zero resistance in both direction
(d) none of these

Q.7 In the circuit shown below, if $e_1 = 2$ V, $e_2 = 5$ V, $e_3 = 1$ V and $E = 2$ V, then which one of the diodes will be conducting and what will be the e_0?



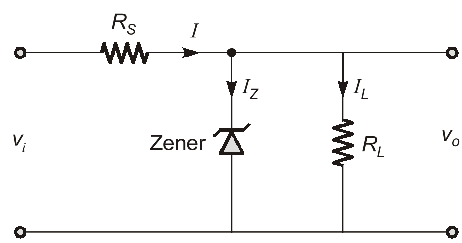
(a) D_3 : 1 V
(b) D_1 : 2 V
(c) D_2 : 5 V
(d) D_1 : 5 V

Q.8 Assuming diode in the circuit is ideal one. Find the current and voltage shown in the figure.



(a) 0 mA, 2 V
(b) 0 mA, –2.5 V
(c) 1 mA, 2 V
(d) 1 mA, 2.5 V

Q.9 Consider the following statements regarding the circuit given in the figure, where the output voltage is constant:



1. $v_i >$ the voltage at which the Zener breaks down.
2. $I_L <$ the difference between I and I_Z, the current at which the Zener breaks down.
3. $R_S <$ the Zener nominal resistance.

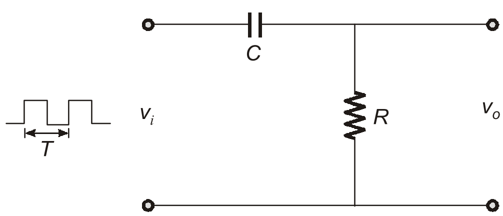
Of these statements:

(a) 1, 2 and 3 are correct
(b) 1 and 2 are correct
(c) 2 and 3 are correct
(d) 1 and 3 are correct

Q.10 The ideal characteristics of a voltage stabilizer is

(a) constant output voltage with low internal resistance
(b) constant output current with low internal resistance
(c) constant output voltage with high internal resistance
(d) constant internal resistance with variable output voltage

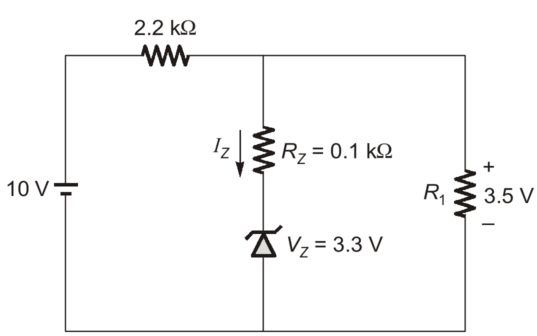
Q.11 For the circuit given below, consider the following statements:



1. The output v_o will consist of a positive and a negative spike $RC << T/2$.
2. The output v_o will be similar to v_i if $RC >> T/2$.
3. The output pulse will have a higher rise time if RC is made progressively smaller than T.

Of these statements:
(a) 1, 2 and 3 are correct
(b) 1 and 2 are correct
(c) 2 and 3 are correct
(d) 1 and 3 are correct

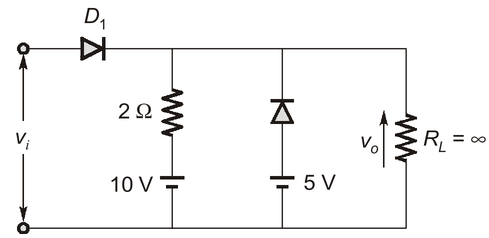
Q.12 The current through the Zener diode in figure is

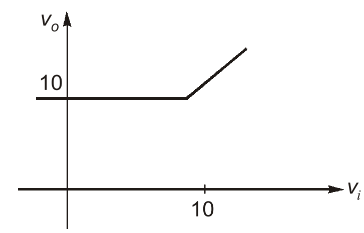


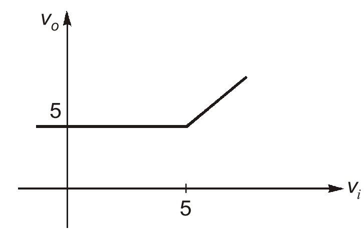
(a) 33 mA (b) 3.3 mA
(c) 2 mA (d) 0 mA

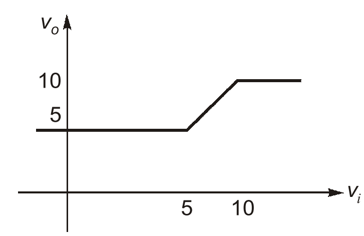
Q.13 A forward biased Zener diode behaves as a
(a) tunnel diode
(b) Schottky diode
(c) no diode properties
(d) ordinary diode

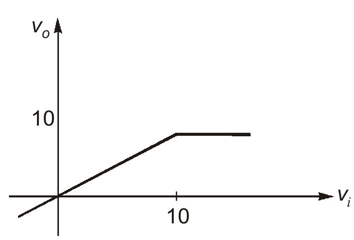
Q.14 Assuming that diodes D_1 and D_2 of the circuit shown in figure to be ideal, the transfer characteristics of the circuit will be



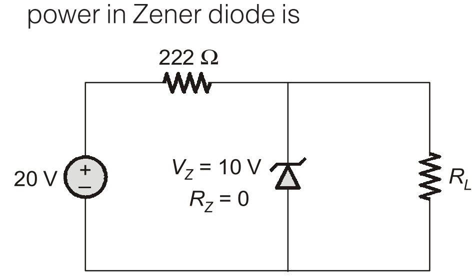
(a)


(b)


(c)


(d)


Q.15 In the voltage regulator circuit shown below the power rating of Zener diode is 400 mW. The value of R_L that will establish maximum power in Zener diode is



(a) 5 kΩ (b) 2 kΩ
(c) 10 kΩ (d) 8 kΩ

ANSWER KEY

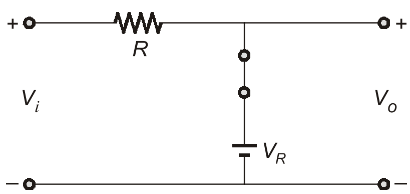
1. (c)	**2.** (c)	**3.** (a)	**4.** (b)	**5.** (c)
6. (a)	**7.** (c)	**8.** (b)	**9.** (b)	**10.** (a)
11. (b)	**12.** (c)	**13.** (d)	**14.** (a)	**15.** (b)

HINTS & EXPLANATIONS

1. (c)

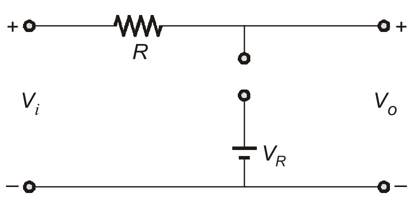
The given circuit is a positive clipper.

For $V_i > V_R$, the diode is forward biased and acts as short-circuit.



$$V_o = V_R$$

For $V_i < V_R$, diode is reverse-biased and acts as open-circuit.

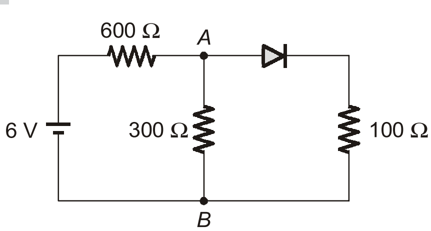


$$V_o = V_i$$

Hence, $V_o = \begin{cases} V_R \text{ for } V_i \geq V_R \\ V_i \text{ for } V_i < V_R \end{cases}$

Hence, option (c) is correct.

2. (c)

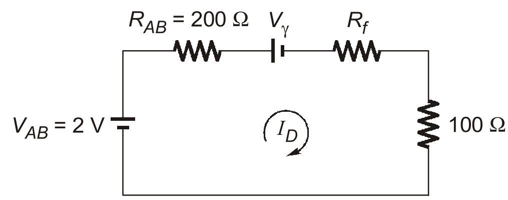


Calculating Thevenin equivalent across terminals *A-B*,

$$V_{AB} = \frac{6 \times 300}{300 + 600} = 2 \text{ V}$$

$$R_{AB} = \frac{600 \times 300}{600 + 300} = 200\ \Omega$$

Since, the diode is forward-biased, the equivalent circuit can be drawn as below:



$$I_D = \frac{V_{AB} - V_\gamma}{200 + R_f + 100}$$

where, V_γ is the cut-in voltage and R_f is the forward resistance of diode,

$$6.7 \times 10^{-3} = \frac{2 - V_\gamma}{300 + R_f}$$

The above condition is satisfied for option (c):

$$V_\gamma = 0 \text{ and } R_f = 0$$

3. (a)

For $V_i > V_\gamma + V_{Z_1} = 5.6$ V, Zener diode Z_1 will be forward-bias and Z_2 will be in break-down region. Hence,

$$V_o = V_\gamma + V_{Z_1} = 5.6 \text{ V}; \text{ for } V_i > 5.6 \text{ V}$$

For $V_i < -V_\gamma - V_{Z_2} = -5.6$ V, Z_2 will be forward-bias and Z_1 will be in break-down region. Hence,

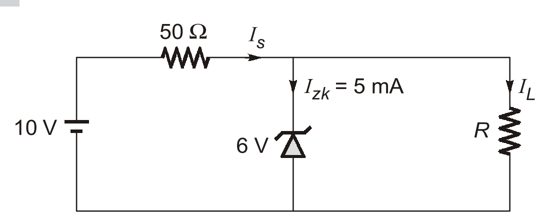
$$V_o = -V_\gamma - V_{Z_2} = -5.6 \text{ V}; \text{ for } V_i < -5.6 \text{ V}$$

For $-5.6 \text{ V} \leq V_i \leq 5.6$ V, the reverse-biased Zener diode is not in break-down region and hence, doesn't conduct current

$$V_o = V_i \text{ for } -5.6 \leq V_i \leq 5.6 \text{ V}$$

$$V_o = V_i \text{ for } |V_i| \leq 5.6 \text{ V}$$

4. (b)



In the above regulator circuit,

$$I_s = \frac{10-6}{50} = 0.08 \text{ A} = 80 \text{ mA}$$

When the minimum current (knee current passes through the diode), then maximum current passes through load resistance R. Hence,

$$I_{L\,(\max)} = I_s - I_{zk}$$

$$I_{L\,(\max)} = 80 \text{ mA} - 5 \text{ mA}$$

$$\frac{6}{R_{s\,(\min)}} = 75 \times 10^{-3}$$

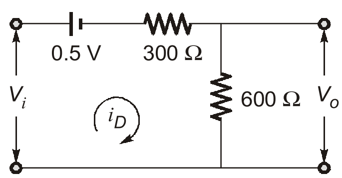
$$\Rightarrow \quad R_{s\,(\min)} = 80\ \Omega$$

5. (c)

From the given V-I characteristics of diode,

$$V_\gamma = 0.5 \text{ V},\ R_f = 300\ \Omega$$

In the given circuit, diode is forward-biased for $V_i > 0.5$ V. Hence, the equivalent circuit can be drawn as below:



$$i_D = \frac{V_i - 0.5}{900} \text{ A}$$

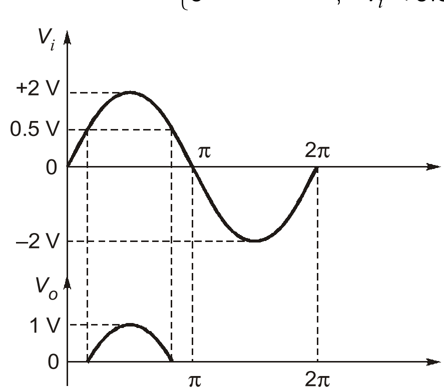
$$V_o = 600 i_D = 600\left(\frac{V_i - 0.5}{900}\right)$$

$$V_o = \frac{2}{3}(V_i - 0.5)$$

For $V_i < 0.5$ V, diode is reverse-biased and acts as open-circuit. Hence,

$$V_o = 0$$

$$V_o = \begin{cases} \frac{2}{3}(V_i - 0.5) & ; \text{ for } V_i > 0.5 \text{ V} \\ 0 & ; V_i < 0.5 \text{ V} \end{cases}$$



6. (a)

The diodes allows the current only in one direction and block the current flow into the other. The above property of diode is used to convert bidirectional voltage into undirectional voltage in a rectifier.

7. (c)

If either of diodes D_1 or D_3 is conducting, then D_2 will also conduct and two voltages will try to superimpose at e_o which is violation of Kirchhoff's law.

When diode D_2 conducts, $e_o = 5$ V and both the diodes D_1 and D_3 are reverse-biased. Hence,

D_2 conducts : $e_o = 5$ V

8. (b)

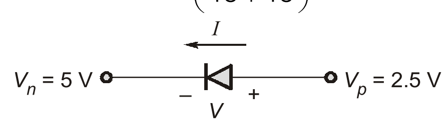
Using the voltage division rule,

Voltage on n-side of diode,

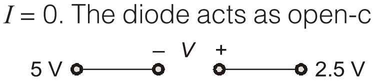
$$V_n = 10\left(\frac{10}{10+10}\right) = 5 \text{ V}$$

Voltage on p-side of diode,

$$V_p = 5\left(\frac{10}{10+10}\right) = 2.5 \text{ V}$$

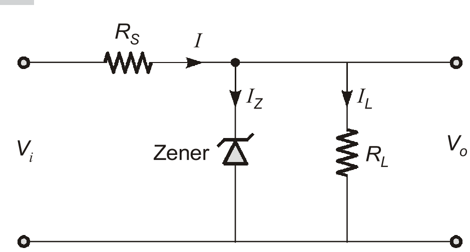


Since, $V_n > V_p$. Hence, the diode is reverse-biased and $I = 0$. The diode acts as open-circuit.



$$\therefore \quad V = 2.5 - 5 = -2.5 \text{ V}$$

9. (b)



1. $V_i = V_Z + IR_S$. Hence, $V_i > V_Z$.
   Therefore, statement 1 is correct.
2. We have, $I = I_Z + I_L$
   Here, $I_{L(\max)} = I - I_{zk}$, where I_{zk} is the current at which Zener break-down.

$I_{L(\min)} = I - I_{z(\max)}$

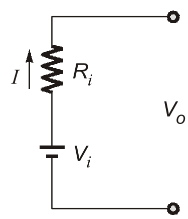
Therefore, $I_L < I - I_{zk}$

Hence, statement 2 is correct.

3. The Zener nominal resistance is very small and less than the resistance R_s. Hence, statement 3 is incorrect.

10. (a)

Voltage stabilizer must provide a constant output voltage.



$$V_o = V_i - IR_i$$

For $V_o \simeq V_i$, R_i should be very low.

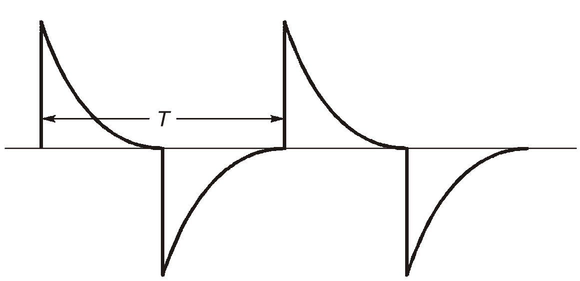
Hence, the voltage stabilizer must have constant output voltage with low internal resistance.

11. (b)

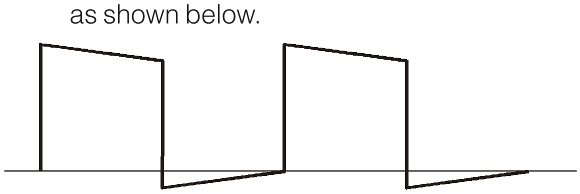
$$V_o = V_i - V_c$$

where V_c is the voltage across the capacitor.

(i) If $RC << T/2$, the capacitor charges and discharges very rapidly. The output waveform consists of positive and negative spikes as shown below.



(ii) If $RC >> T/2$, the capacitor charges and discharges very slowly and V_o resembles V_i as shown below.



(iii) If RC is made progressively smaller than T, time constant will be small and capacitor will charge rapidly leading to a lower rise time.

Hence, only statements 1 and 2 are correct.

12. (c)

We have, $V_o = V_z + I_z R_z$

$$3.5 = 3.3 + I_z(0.1 \times 10^3)$$

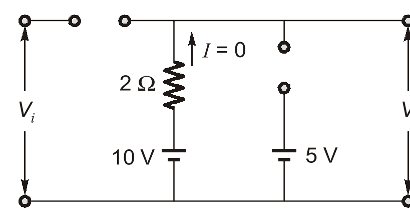
$$I_z = \frac{0.2}{0.1 \times 10^3} = 2 \text{ mA}$$

13. (d)

Zener diodes acts like normal p-n junction diodes under forward biased condition.

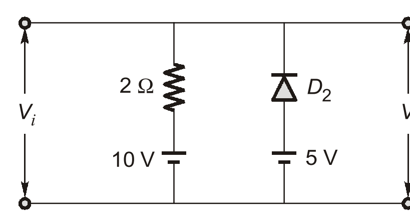
14. (a)

For $V_i < 10$ V, both the diodes are reverse-biased.



$$V_0 = 10 \text{ V}$$

For $V_i > 10$ V, diode D_1 is forward-biased and the equivalent circuit is as drawn below:

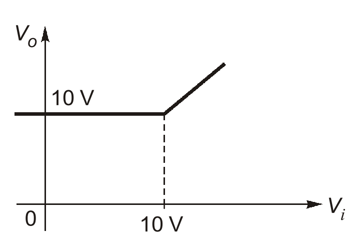


Diode D_2 is reverse biased as

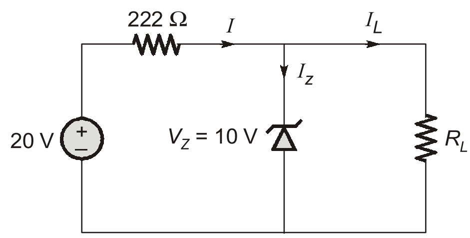
$$V_n > V_p$$

Hence; $V_0 = V_i$

Transfer characteristics:



15. (b)



$$I = \frac{20 - V_z}{222} = \frac{20-10}{222}$$

$\therefore$ $$I = 0.045 \text{ A} = 45 \text{ mA}$$

For the Zener diode,

$$P_{D(max)} = 400 \text{ mW}$$

$$\Rightarrow I_{z(max)} \cdot V_z = 400 \text{ mW}$$

$$I_{z(max)} = 40 \text{ mA}$$

We have, $I = I_{z(max)} + I_L$

$$\Rightarrow 45 \text{ mA} = 40 \text{ mA} + \frac{V_z}{R_L}$$

$$\Rightarrow 5 \times 10^{-3} = \frac{10}{R_L}$$

$$\Rightarrow R_L = 2 \text{ k}\Omega$$

CONVENTIONAL BRAIN TEASERS

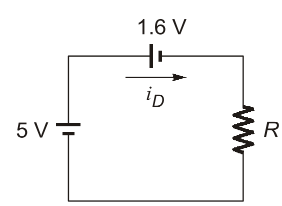
Q.1 A light-emitting diode (LED) has a greater forward voltage drop than that of common signal diode. A typical LED can be modeled as a constant forward voltage drop v_D = 1.6 V. Its luminous intensity I_v varies directly with forward current and is described by $I_v = 40 i_D$ millicandela (mcd).

A series circuit consists of a LED, a current-limiting resistor R, and a 5-V DC source V_s. Find the value of R such that the luminous intensity is 1 mcd.

1. (Sol.)

With a 5 V DC source, LED is forward-biased and can be modelled as a constant forward voltage drop V_D = 1.6 V. The equivalent circuit can be drawn as below:

$\therefore$ $$i_D = \frac{5-1.6}{R}$$



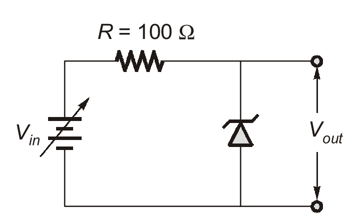
The luminous intensity, I_V is defined as

$$I_V = 40 i_D (mcd)$$

$$\Rightarrow 1\ mcd = 40\left(\frac{5-1.6}{R}\right)$$

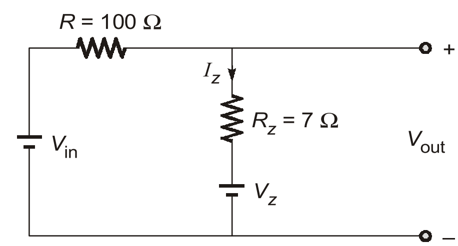
$$\Rightarrow R = 136\ \Omega$$

Q.2 Determine the maximum and the minimum input voltages that can be regulated by the Zener diode of circuit shown in figure. Take V_{out} = 5.1 V, at I_z = 49 mA, I_{zk} = 1 mA, R_z = 7 Ω at I_z power dissipation = 1 Watt.



2. (Sol.)

The equivalent circuit with Zener diode in breakdown region can be drawn as below:



Given: $V_{out} = 5.1$ V at $I_z = 49$ mA

At $I_{zk} = 1$ mA, the output voltage is

$$V_{out} = 5.1\text{ V} - (I_z - I_{zk})\, R_z$$
$$V_{out} = 5.1 - (49 - 1) \times 7 \times 10^{-3}$$
$$V_{out} = 4.76\text{ V}$$

Hence, the minimum voltage that can be regulated is

$$V_{in\,(min)} = I_{zk} \times R + V_{out}$$
$$V_{in\,(min)} = 1 \times 10^{-3} \times 100 + 4.76 = 4.86\text{ V}$$

To find the maximum input voltage, we first calculate the maximum Zener current. For power dissipation of 1 Watt,

$$I_{z(max)} = \frac{P_{D(max)}}{V_z} = \frac{1\text{ W}}{5.1\text{ V}} = 196\text{ mA}$$

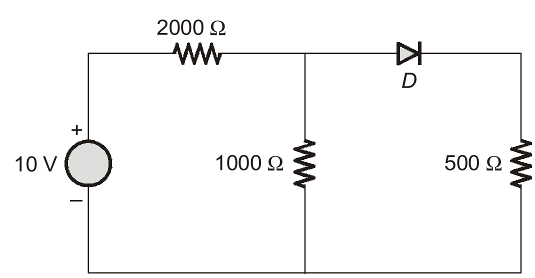
At $I_{z\,(max)}$, the output voltage is

$$V'_{out} = 5.1\text{ V} + (I_{z(max)} - I_z)\, R_z$$
$$V'_{out} = 5.1 + (196 - 49) \times 7 = 5.1 + 1.03 = 6.13\text{ V}$$

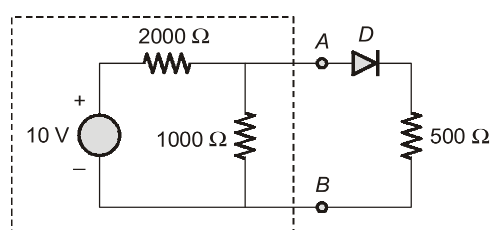
Hence, the maximum output voltage that can be regulated is

$$V_{in\,(max)} = I_{z(max)} \cdot R + V'_{out} = 196 \times 10^{-3} \times 100 + 6.13 = 25.73\text{ V}$$

Q.3 In the circuit shown below, the diode has a forward resistance $R_f = 15\ \Omega$ and a cut-in voltage $V_\gamma = 0.5$ V. Determine the current in the diode.



3. (Sol.)



Calculating the Thevenin voltage and resistance across the terminals *AB*, we get,

$$V_{Th} = 10 \times \left(\frac{1000}{1000 + 2000}\right) = \frac{10}{3}\text{ V}$$

$$R_{Th} = 1000\ \Omega \,\|\, 2000\ \Omega = \frac{1000 \times 2000}{1000 + 2000} = \frac{2000}{3}\ \Omega$$