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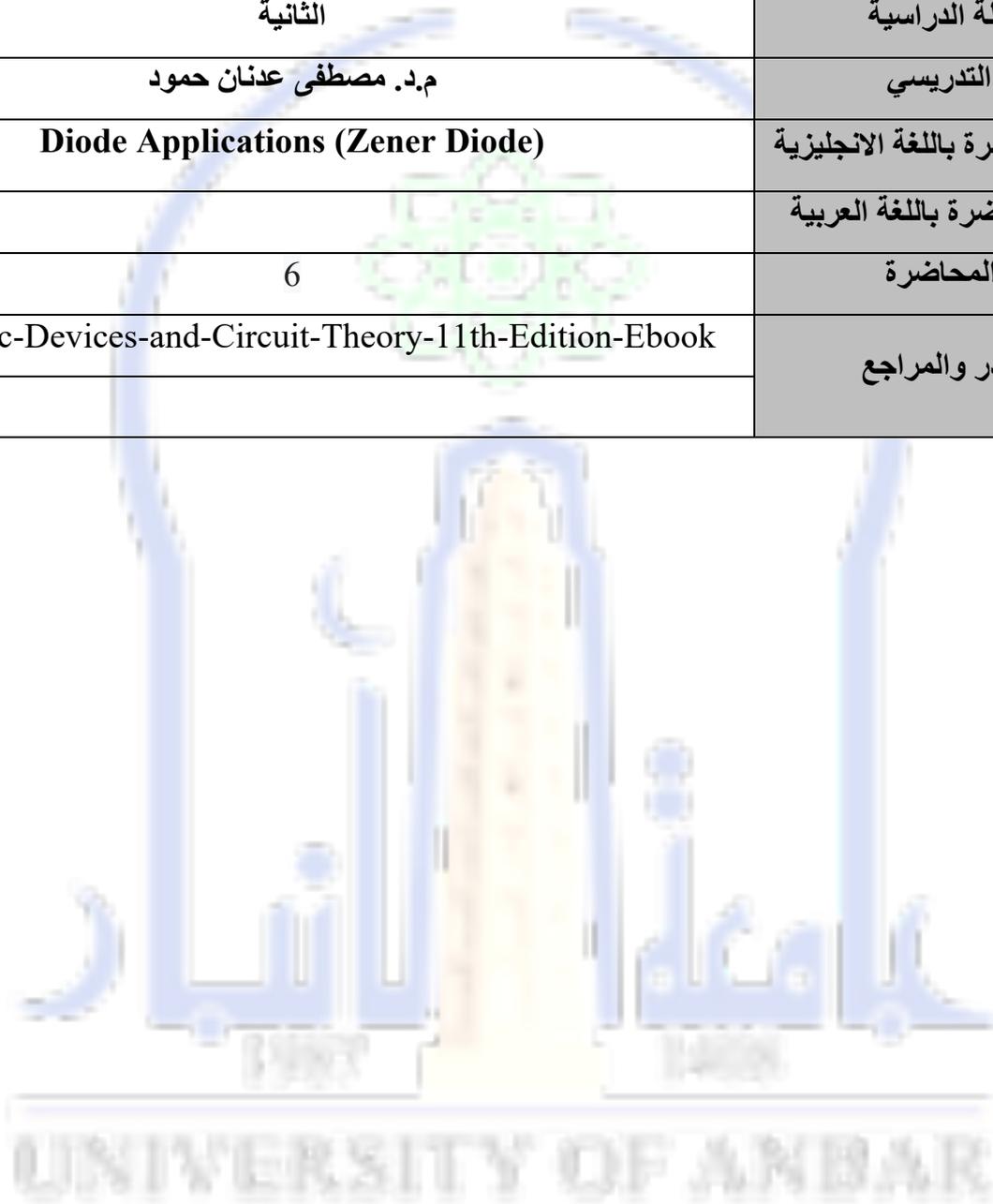
Lecture 6

Diode Applications

6.1 ZENER DIODE

The analysis of networks employing Zener diodes is quite similar to the analysis of semiconductor diodes. First the state of the diode must be determined, followed by a substitution of the appropriate model and a determination of the other unknown quantities of the network. Figure 1 reviews the approximate equivalent circuits for each region of a Zener diode.
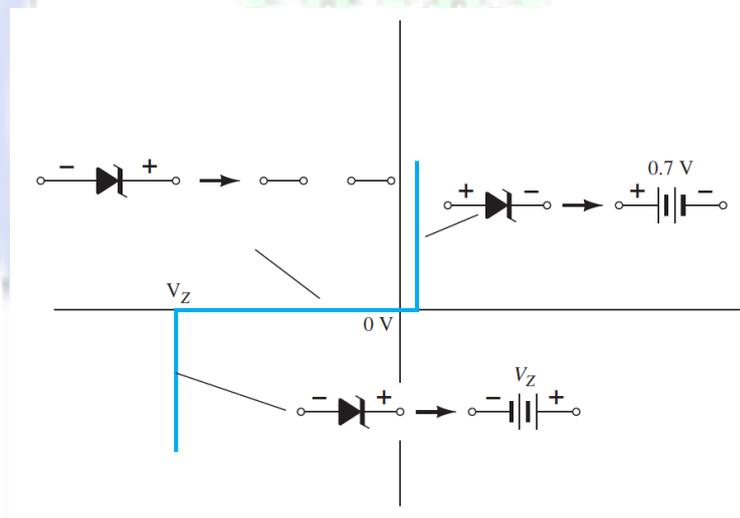

Figure 1: Approximate equivalent circuits for the Zener diode in the three possible regions of application.

The first two examples will demonstrate how a Zener diode can be used to establish reference voltage levels and act as a *protection device*.
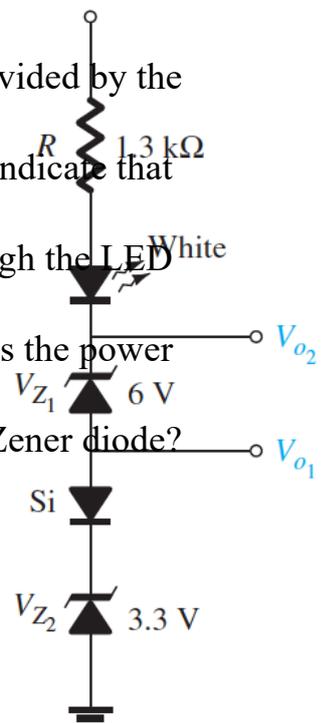
EXAMPLE 1: Determine the reference voltages provided by the network of Figure 2 ,which uses a white LED to indicate that the power is on. What is the level of current through the LED and the power delivered by the supply? How does the power absorbed by the LED compare to that of the 6-V Zener diode?

Solution: First we have to check that there is sufficient applied voltage to turn on all the series diode elements. **The white LED will have a drop of about 4 V** across it, the 6-V and 3.3-V Zener diodes have a total of 9.3 V, and the forward-biased silicon diode has 0.7 V, for a total of 14 V. The applied 40 V is then sufficient to turn on all the elements and, one hopes, establish a proper operating current.

Note that the silicon diode was used to create a reference voltage of 4 V because

$$V_{o_1} = V_{Z_2} + V_K = 3.3\text{ V} + 0.7\text{ V} = \textbf{4.0 V}$$

Combining the voltage of the 6-V Zener diode with the 4 V results in

$$V_{o_2} = V_{o_1} + V_{Z_1} = 4\text{ V} + 6\text{ V} = \textbf{10 V}$$

Finally, the 4 V across the white LED will leave a voltage of 40 V – 14 V = 26 V across the resistor, and

$$I_R = I_{\text{LED}} = \frac{V_R}{R} = \frac{40\text{ V} - V_{o_2} - V_{\text{LED}}}{1.3\text{ k}\Omega} = \frac{40\text{ V} - 10\text{ V} - 4\text{ V}}{1.3\text{ k}\Omega} = \frac{26\text{ V}}{1.3\text{ k}\Omega} = \textbf{20 mA}$$

which should establish the proper brightness for the LED.

The power delivered by the supply is simply the product of the supply voltage and current drain as follows:

$$P_s = EI_s = EI_R = (40\text{ V})(20\text{ mA}) = \textbf{800 mW}$$

The power absorbed by the LED is

$$P_{\text{LED}} = V_{\text{LED}}I_{\text{LED}} = (4\text{ V})(20\text{ mA}) = \textbf{80 mW}$$

and the power absorbed by the 6-V Zener diode is

$$P_Z = V_Z I_Z = (6\text{ V})(20\text{ mA}) = \textbf{120 mW}$$

The power absorbed by the Zener diode exceeds that of the LED by 40 mW.

The use of the Zener diode as a regulator is so common that three conditions surrounding the analysis of the basic Zener regulator are considered. The analysis provides an excellent opportunity to become better acquainted with the response of the Zener diode to different operating conditions. The basic configuration appears in Fig. 2.112 . The analysis is first for fixed quantities, followed by a fixed supply voltage and a variable load, and finally a fixed load and a variable supply.
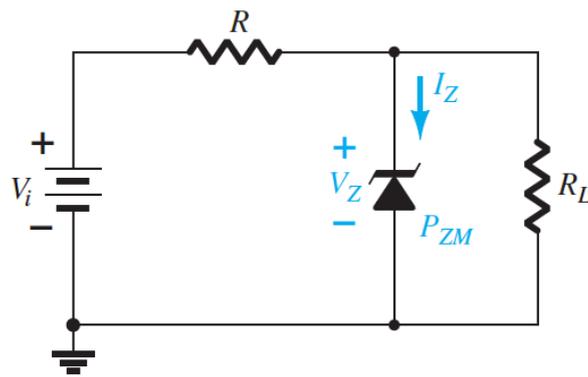

FIG. 2.112
Basic Zener regulator.

V$_i$ and R Fixed

The simplest of Zener diode regulator networks appears in Fig. 2.112. The applied dc voltage is fixed, as is the load resistor. The analysis can fundamentally be broken down into two steps.

1. *Determine the state of the Zener diode by removing it from the network and calculating the voltage across the resulting open circuit.*

Applying step 1 to the network of Fig. 2.112 results in the network of Fig. 2.113, where an application of the voltage divider rule results in

$$V = V_L = \frac{R_L V_i}{R + R_L} \qquad (2.16)$$

If $V \geq V_Z$, the Zener diode is on, and the appropriate equivalent model can be substituted. If $V < V_Z$, the diode is off, and the open-circuit equivalence is substituted.

2. *Substitute the appropriate equivalent circuit and solve for the desired unknowns.*

For the network of Fig. 2.112, the "on" state will result in the equivalent network of Fig. 2.114. Since voltages across parallel elements must be the same, we find that
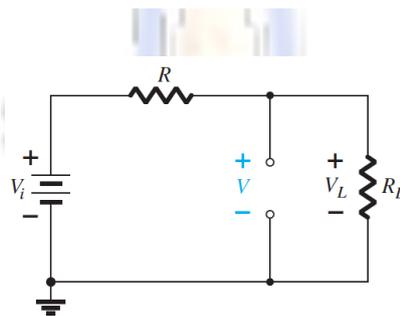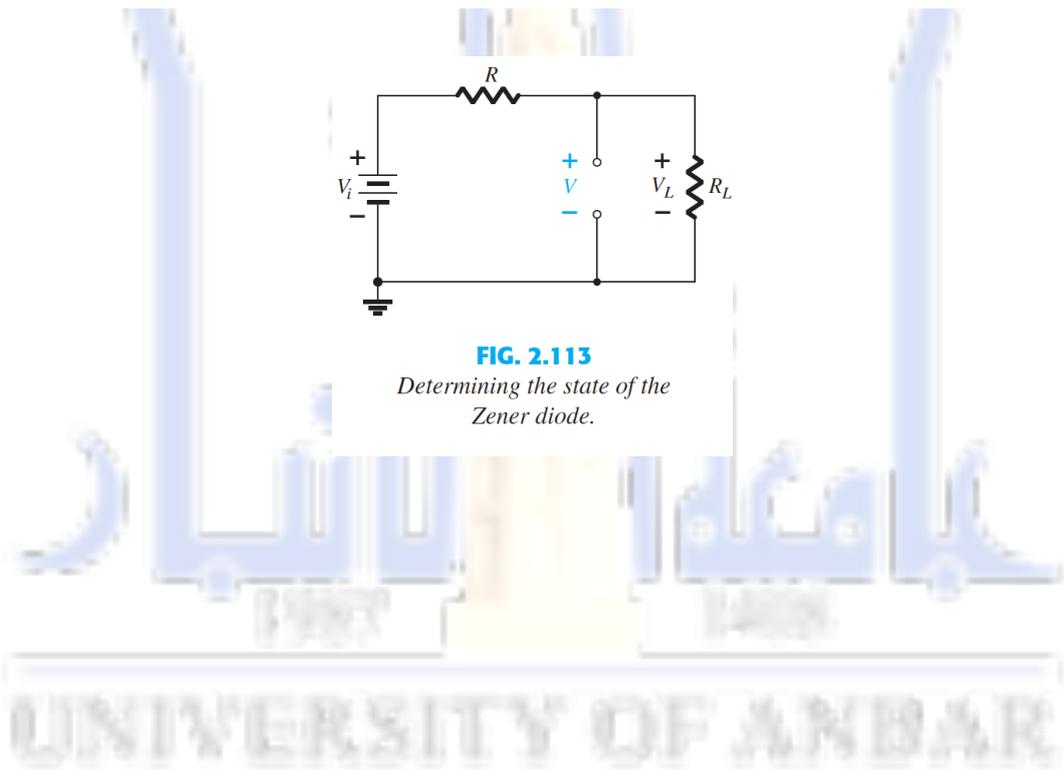
$$V_L = V_Z \qquad (2.17)$$

FIG. 2.113
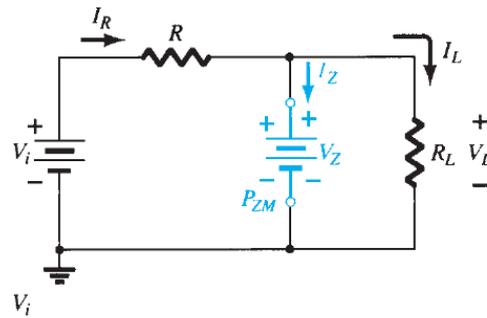*Determining the state of the Zener diode.*

FIG. 2.114
Substituting the Zener equivalent for the
"on" situation.

The Zener diode current must be determined by an application of Kirchhoff's current law. That is,

$$I_R = I_Z + I_L$$

and

$$\boxed{I_Z = I_R - I_L}$$

(2.18)

where

$$I_L = \frac{V_L}{R_L} \quad \text{and} \quad I_R = \frac{V_R}{R} = \frac{V_i - V_L}{R}$$

The power dissipated by the Zener diode is determined by

$$\boxed{P_Z = V_Z I_Z}$$

(2.19)

that must be less than the P_{ZM} specified for the device.

Before continuing, it is particularly important to realize that the first step was employed only to determine the *state of the Zener diode*. If the Zener diode is in the "on" state, the voltage across the diode is not V volts. When the system is turned on, the Zener diode will turn on as soon as the voltage across the Zener diode is V_Z volts. It will then "lock in" at this level and never reach the higher level of V volts.

EXAMPLE 2.26

a. For the Zener diode network of Fig. 2.115, determine V_L, V_R, I_Z, and P_Z.
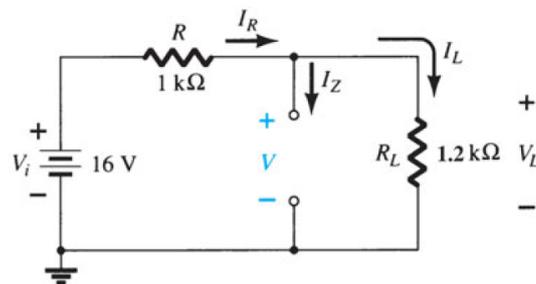b. Repeat part (a) with $R_L = 3 \text{ k}\Omega$.
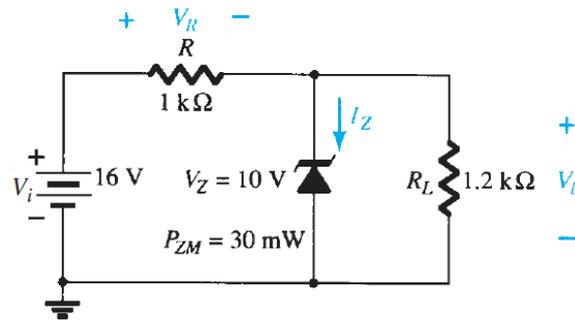
FIG. 2.115
Zener diode regulator for Example 2.26.

Solution:

a. Following the suggested procedure, we redraw the network as shown in Fig. 2.116.
Applying Eq. (2.16) gives

$$V = \frac{R_L V_i}{R + R_L} = \frac{1.2 \text{ k}\Omega(16 \text{ V})}{1 \text{ k}\Omega + 1.2 \text{ k}\Omega} = 8.73 \text{ V}$$

FIG. 2.116
Determining V for the regulator of Fig. 2.115.

Since $V = 8.73$ V is less than $V_Z = 10$ V, the diode is in the "off" state, as shown on the characteristics of Fig. 2.117. Substituting the open-circuit equivalent results in the same network as in Fig. 2.116, where we find that

$$V_L = V = \mathbf{8.73\ V}$$
$$V_R = V_i - V_L = 16\ V - 8.73\ V = \mathbf{7.27\ V}$$
$$I_Z = \mathbf{0\ A}$$

and
$$P_Z = V_Z I_Z = V_Z(0\ A) = \mathbf{0\ W}$$

b. Applying Eq. (2.16) results in

$$V = \frac{R_L V_i}{R + R_L} = \frac{3\ k\Omega(16\ V)}{1\ k\Omega + 3\ k\Omega} = 12\ V$$

Since $V = 12$ V is greater than $V_Z = 10$ V, the diode is in the "on" state and the network of Fig. 2.118 results. Applying Eq. (2.17) yields

$$V_L = V_Z = \mathbf{10\ V}$$

and
$$V_R = V_i - V_L = 16\ V - 10\ V = \mathbf{6\ V}$$

with
$$I_L = \frac{V_L}{R_L} = \frac{10\ V}{3\ k\Omega} = 3.33\ mA$$

and
$$I_R = \frac{V_R}{R} = \frac{6\ V}{1\ k\Omega} = 6\ mA$$

so that
$$I_Z = I_R - I_L\ [\text{Eq. (2.18)}]$$
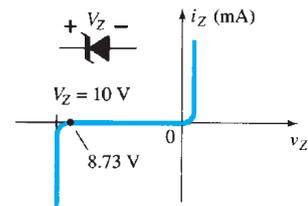$$= 6\ mA - 3.33\ mA$$
$$= \mathbf{2.67\ mA}$$

FIG. 2.117
Resulting operating point for the network of Fig. 2.115.

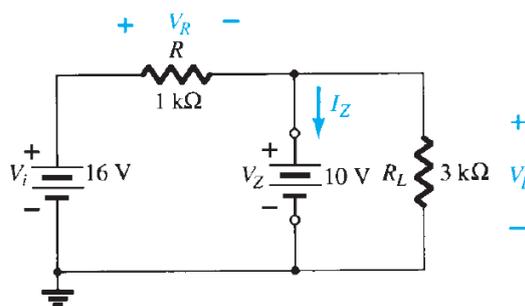**FIG. 2.118**
Network of Fig. 2.115 in the "on" state.

The power dissipated is

$$P_Z = V_Z I_Z = (10\ V)(2.67\ mA) = \mathbf{26.7\ mW}$$

which is less than the specified $P_{ZM} = 30$ mW.