6.24 Voltage Stabilisation

A rectifier with an appropriate filter serves as a good source of d.c. output. However, the major disadvantage of such a power supply is that the output voltage changes with the variations in the input voltage or load. Thus, if the input voltage increases, the d.c. output voltage of the rectifier also increases. Similarly, if the load current increases, the output voltage falls due to the voltage drop in the rectifying element, filter chokes, transformer winding etc. In many electronic applications, it is desired that the output voltage should remain constant regardless of the variations in the input voltage or load. In order to ensure this, a voltage stabilising device, called voltage stabiliser is used. Several stabilising circuits have been designed but only *zener diode* as a voltage stabiliser will be discussed.

6.25 Zener Diode

It has already been discussed that when the reverse bias on a crystal diode is increased, a critical voltage, called *breakdown voltage* is reached where the reverse current increases sharply to a high value. The breakdown region is the knee of the reverse characteristic as shown in Fig. 6.52. The satisfactory explanation of this breakdown of the junction was first given by the American scientist *C.* Zener. Therefore, the breakdown voltage is sometimes called *zener voltage* and the sudden increase in current is known as zener current.

The breakdown or zener voltage depends upon the amount of doping. If the diode is heavily doped, depletion layer will be thin and consequently the breakdown of the junction will occur at a lower reverse voltage. On the other hand, a lightly doped diode has a higher breakdown voltage. When an ordinary crystal diode is properly doped so that it has a sharp breakdown voltage, it is called a zener diode.

A properly doped crystal diode which has a sharp breakdown voltage is known as a **zener diode.**

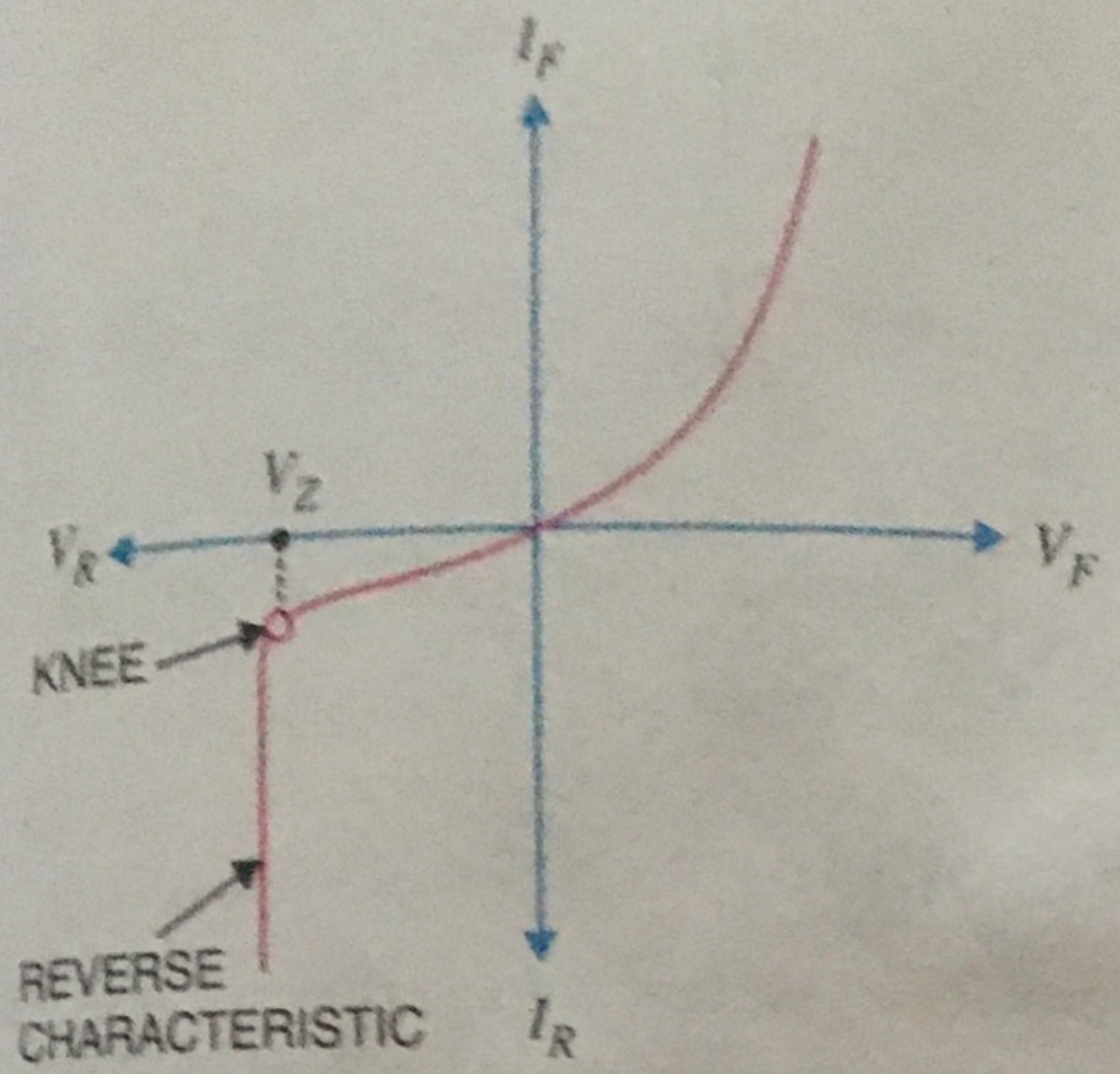


Fig. 6.52

Fig. 6.53 shows the symbol of a zener diode. It may be seen that it is just like an ordinary diode except that the bar is turned into z-shape. The following points may be noted about the zener diode:

(*i*) A zener diode is like an ordinary diode except that it is properly doped so as to have a sharp breakdown voltage.

(*ii*) A zener diode is always reverse connected *i.e.* it is always reverse biased.

(*iii*) A zener diode has sharp breakdown voltage, called zener voltage V_Z.

(*iv*) When forward biased, its characteristics are just those of ordinary diode.

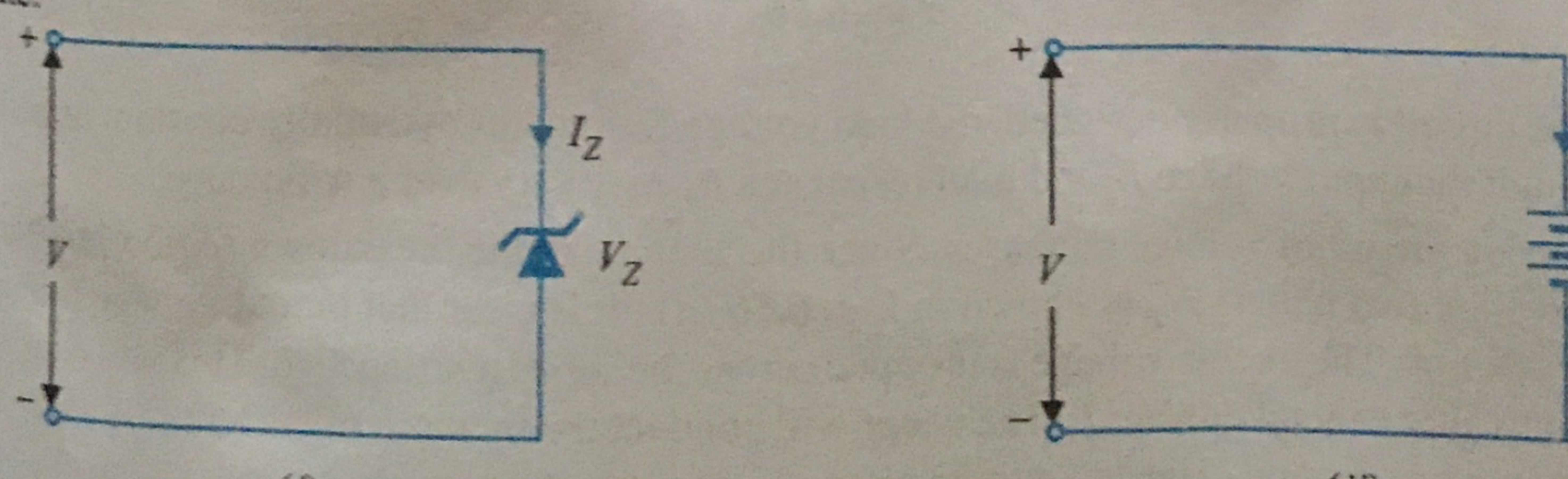
(*v*) The zener diode is not immediately burnt just because it has entered the *breakdown region. As long as the external circuit connected to the diode limits the diode current to less than *burn out* value, the diode will not burn out.

Fig. 6.53

6.26 Equivalent Circuit of Zener Diode

The analysis of circuits using zener diodes can be made quite easily by replacing the zener diode by its equivalent circuit.

(*i*) **"On" state.** When reverse voltage across a zener diode is equal to or more than break down voltage V_Z, the current increases very sharply. In this region, the curve is almost vertical. It means that voltage across zener diode is constant at V_Z even though the current through it changes. Therefore, in the breakdown region, an **ideal zener diode can be represented by a battery of voltage V_Z as shown in Fig. 6.54 (*ii*). Under such conditions, the zener diode is said to be in the "ON" state.



(*i*)
$V \geq V_Z$

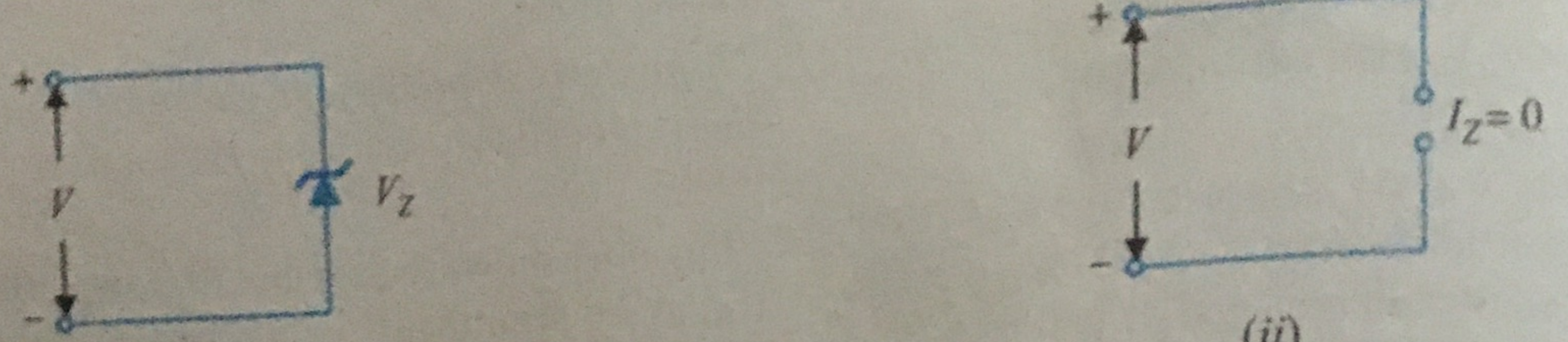
(*ii*)
Equivalent circuit of zener for "on" state

Fig. 6.54

(*ii*) **"OFF" state.** When the reverse voltage across the zener diode is less than V_Z but greater than 0 V, the zener diode is in the "OFF" state. Under such conditions, the zener diode can be represented by an open-circuit as shown in Fig. 6.55 (*ii*).

* The current is limited only by both external resistance and the power dissipation of zener diode.

** This assumption is fairly reasonable as the impedance of zener diode is quite small in the breakdown region.



(i)

$V_Z > V > 0$

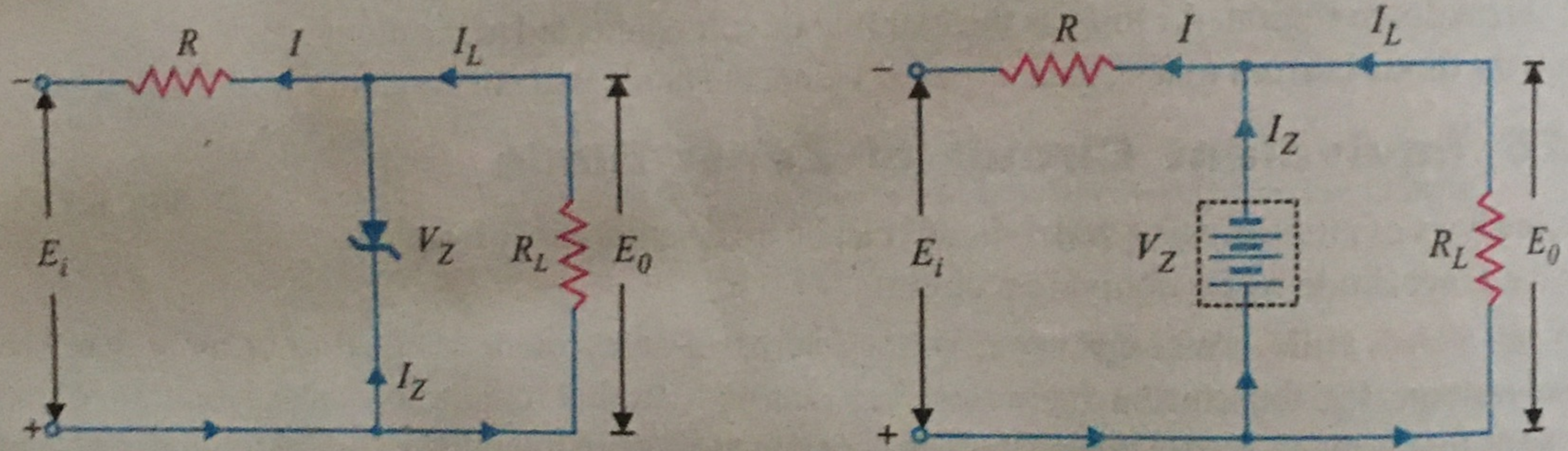
(ii)

Equivalent circuit of zener for "off" state

Fig. 6.55

6.27 Zener Diode as Voltage Stabiliser

A zener diode can be used as a voltage regulator to provide a constant voltage from a source whose voltage may vary over sufficient range. The circuit arrangement is shown in Fig. 6.56 (*i*). The zener diode of zener voltage V_Z is reverse connected across the load R_L across which constant output is desired. The series resistance R absorbs the output voltage fluctuations so as to maintain constant voltage across the load. It may be noted that the zener will maintain a constant voltage V_Z (= E_0) across the load so long as the input voltage does not fall below V_Z.



(i)

(ii)

Fig. 6.56

When the circuit is properly designed, the load voltage E_0 remains essentially constant (equal to V_Z) even though the input voltage E_i and load resistance R_L may vary over a wide range.

(*i*) Suppose the input voltage increases. Since the zener is in the breakdown region, the zener diode is equivalent to a battery V_Z as shown in Fig. 6.56 (*ii*). It is clear that output voltage remains constant at V_Z (= E_0). The excess voltage is dropped across the series resistance R. This will cause an increase in the value of total current I. The zener will conduct the increase of current in I while the load current remains constant. Hence, output voltage E_0 remains constant irrespective of the changes in the input voltage E_i.

(*ii*) Now suppose that input voltage is constant but the load resistance R_L decreases. This will cause an increase in load current. The extra current cannot come from the source because drop in R (and hence source current I) will not change as the zener is within its regulating range. The additional load current will come from a decrease in zener current I_Z. Consequently, the output voltage stays at constant value.

$$\text{Voltage drop across } R = E_i - E_0$$

$$\text{Current through } R,\ I = I_Z + I_L$$

Applying Ohm's law, we have,

$$R = \frac{E_i - E_0}{I_Z + I_L}$$

6.28 Solving Zener Diode Circuits

The analysis of zener diode circuits is quite similar to that applied to the analysis of semiconductor diodes. The first step is to determine the state of zener diode *i.e.*, whether the zener is in the "on" state or "off" state. Next, the zener is replaced by its appropriate model. Finally, the unknown quantities are determined from the resulting circuit.

1. **E_i and R_L fixed.** This is the simplest case and is shown in Fig. 6.57 (*i*). Here the applied voltage E_i as well as load R_L is fixed. The first step is to find the state of zener diode. This can be determined by removing the zener from the circuit and calculating the voltage V across the resulting open-circuit as shown in Fig. 6.57 (*ii*).

$$V = E_0 = \frac{R_L E_i}{R + R_L}$$

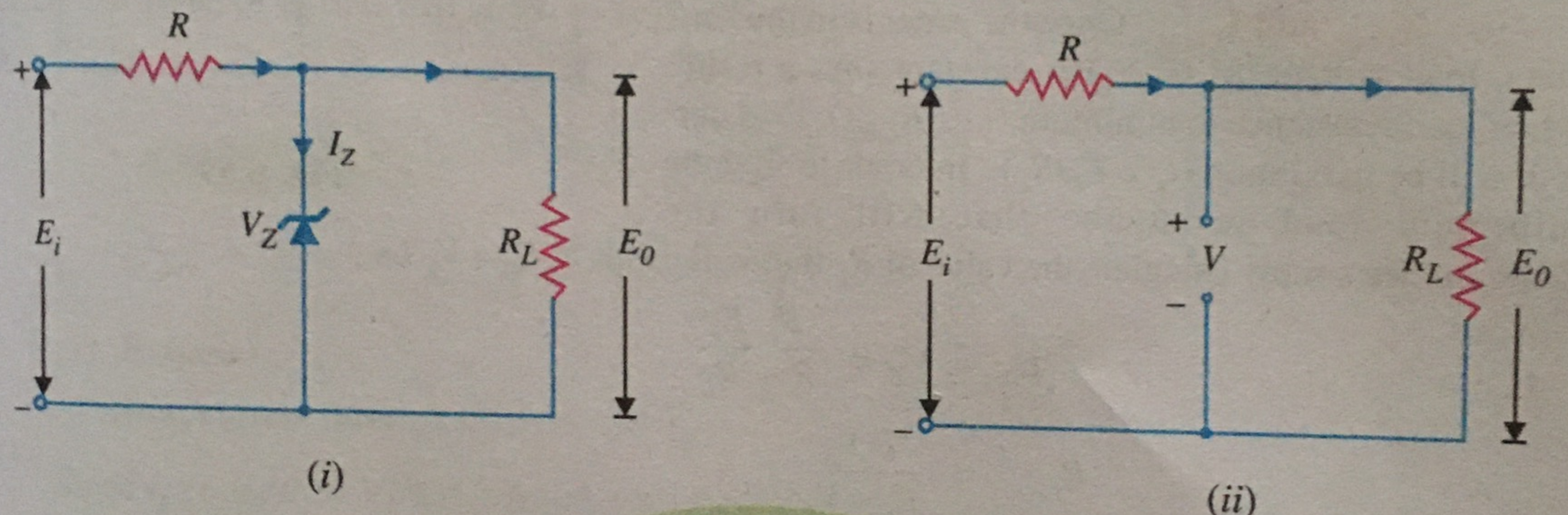
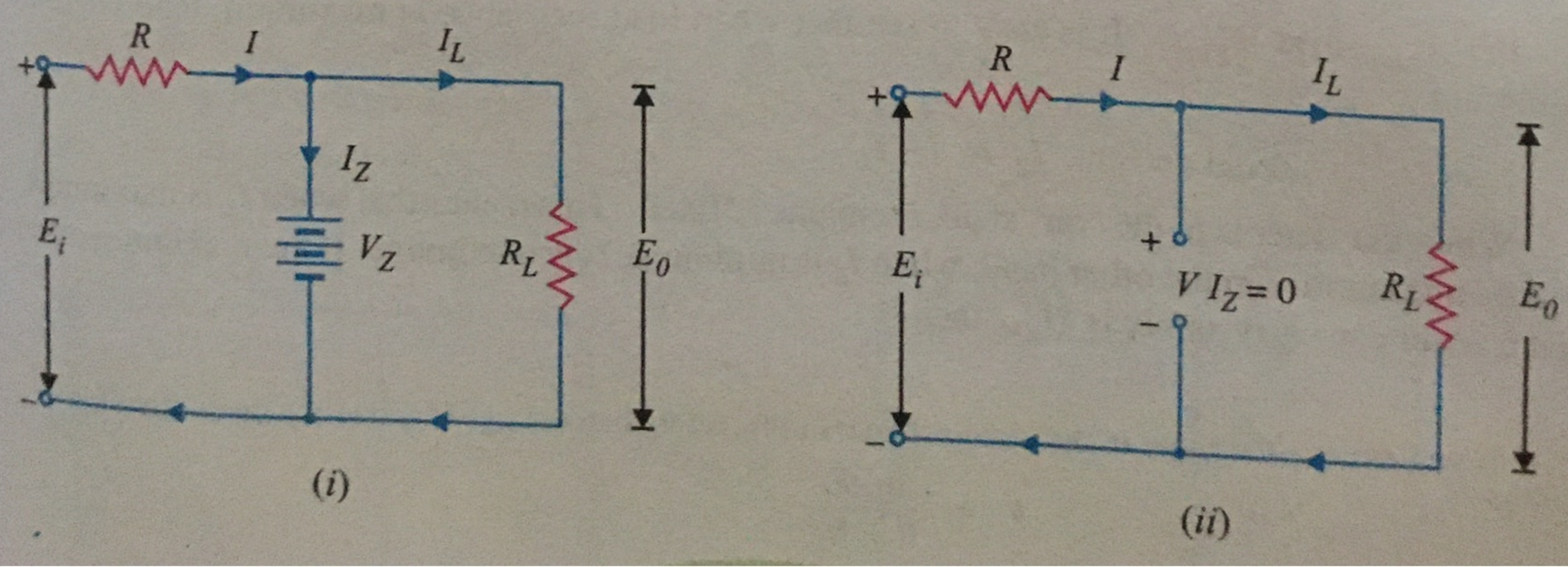


Fig. 6.57

If $V \geq V_Z$, the zener diode is in the "on" state and its equivalent model can be substituted as shown in Fig. 6.58 (*i*). If $V < V_Z$, the diode is in the "off" state as shown in Fig. 6.58 (*ii*).

(*i*) **On state.** Referring to circuit shown in Fig. 6.58 (*i*),

$$E_0 = V_Z$$



$$I_Z = I - I_L \quad \text{where } I_L = \frac{E_0}{R_L} \text{ and } I = \frac{E_i - E_0}{R}$$

Power dissipated in zener, $P_Z = V_Z I_Z$

(ii) **Off state.** Referring to the circuit shown in Fig. 6.58 (ii),

$$I = I_L \quad \text{and} \quad I_Z = 0$$

$$V_R = E_i - E_0 \quad \text{and} \quad V = E_0 \quad (V < V_Z)$$

$$\therefore \quad P_Z = V I_Z = V(0) = 0$$

2. **Fixed E_i and Variable R_L.** This case is shown in Fig. 6.59. Here the applied voltage (E_i) is fixed while load resistance R_L (and hence load current I_L) changes. Note that there is a definite range of R_L values (and hence I_L values) which will ensure the zener diode to be in "on" state. Let us calculate that range of values.

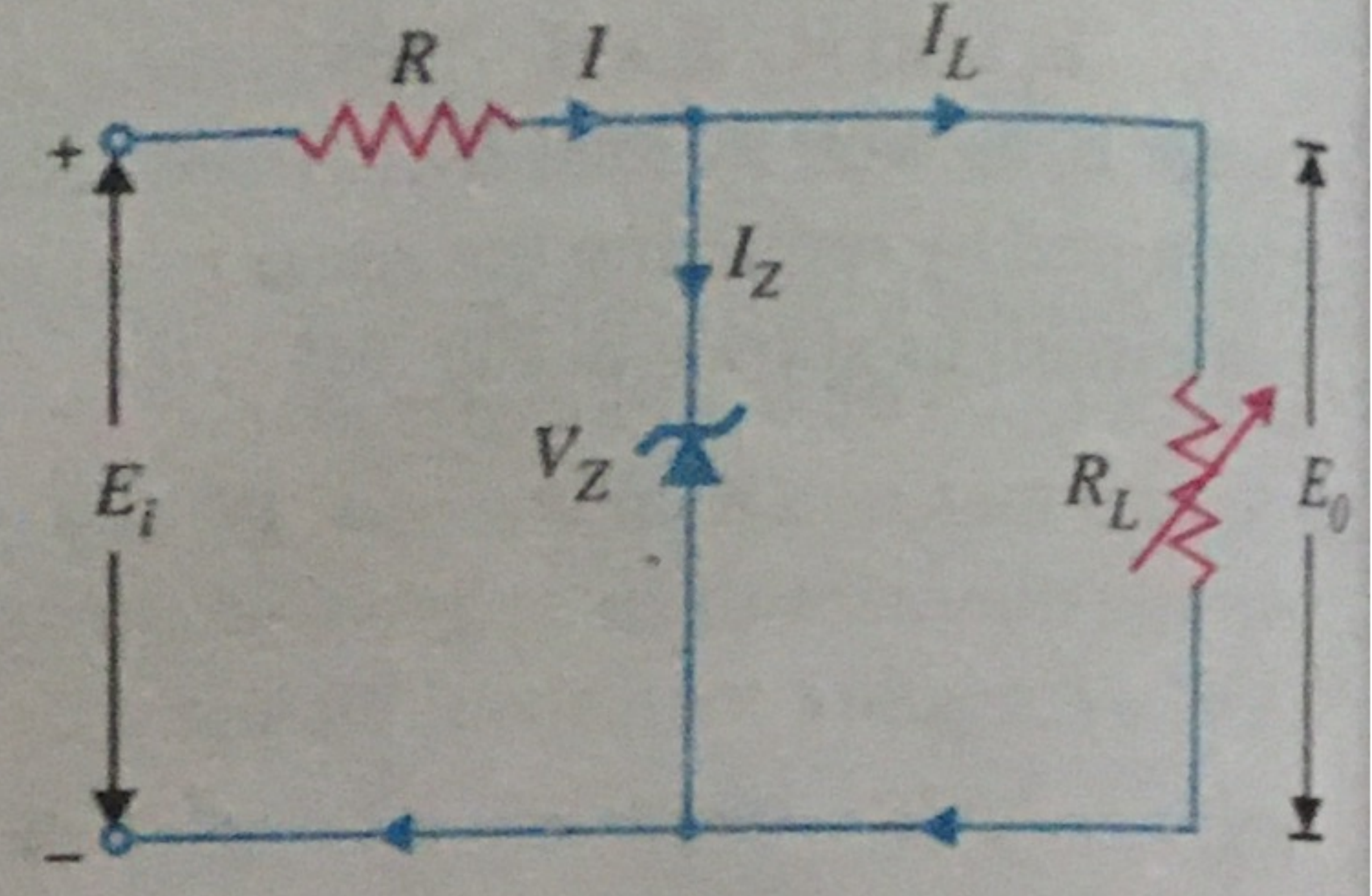


Fig. 6.59

(i) **R_{Lmin} and I_{Lmax}.** Once the zener is in the "on" state, load voltage E_0 (= V_Z) is constant. As a result, when load resistance is minimum (*i.e.*, R_{Lmin}), load current will be maximum ($I_L = E_0/R_L$). In order to find the minimum load resistance that will turn the zener on, we simply calculate the value of R_L that will result in $E_0 = V_Z$ *i.e.*,

$$E_0 = V_Z = \frac{{}^*R_L E_i}{R + R_L}$$

$$\therefore \quad R_{Lmin} = \frac{R V_Z}{E_i - V_Z} \quad \text{...(i)}$$

This is the minimum value of load resistance that will ensure that zener is in the "on" state. Any value of load resistance less than this value will result in a voltage E_0 across the load less than V_Z and the zener will be in the "off" state.

Clearly ; $$I_{Lmax} = \frac{E_0}{R_{Lmin}} = \frac{V_Z}{R_{Lmin}}$$

(ii) **I_{Lmin} and R_{Lmax}.** It is easy to see that when load resistance is maximum, load current is minimum.

Now, Zener current, $I_Z = I - I_L$

When the zener is in the "on" state, I remains **fixed. This means that when I_L is maximum, I_Z will be minimum. On the other hand, when I_L is minimum, I_Z is maximum. If the maximum current that a zener can carry safely is †I_{ZM}, then,

* If you remove the zener in the circuit shown in Fig. 6.59, then voltage V across the open-circuit is

$$V = \frac{R_L E_i}{R + R_L}$$

The zener will be turned on when $V = V_Z$.

** Voltage across R, $V_R = E_i - E_0$ and $I = V_R/R$. As E_i and E_0 are fixed, I remains the same.

† Max. power dissipation in zener, $P_{ZM} = V_Z I_{ZM}$

$$I_{Lmin} = I - I_{ZM}$$

and $$R_{Lmax} = \frac{E_0}{I_{Lmin}} = \frac{V_Z}{I_{Lmin}}$$

If the load resistance exceeds this limiting value, the current through zener will exceed I_{ZM} and the device may burn out.

3. Fixed R_L and Variable E_i. This case is shown in Fig. 6.60. Here the load resistance R_L is fixed while the applied voltage (E_i) changes. Note that there is a definite range of E_i values that will ensure that zener diode is in the "on" state. Let us calculate that range of values.

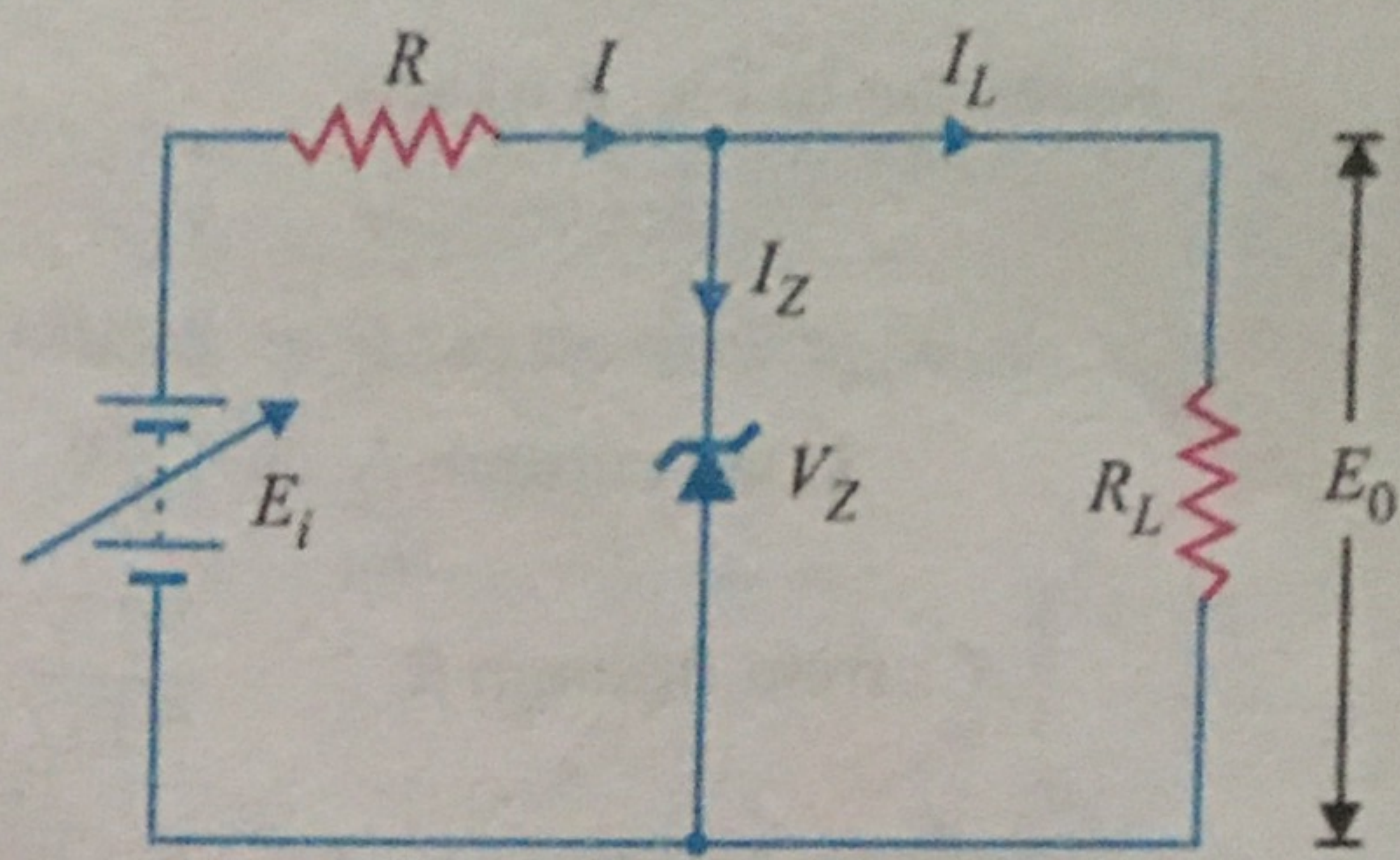


Fig. 6.60

***(i)* E$_i$ *(min)*.** To determine the minimum applied voltage that will turn the zener on, simply calculate the value of E_i that will result in load voltage $E_0 = V_Z$ *i.e.*,

$$E_0 = V_Z = \frac{R_L\, E_i}{R + R_L}$$

$$\therefore \quad E_{i\,(min)} = \frac{(R + R_L)\, V_Z}{R_L}$$

(ii)* E$_i$ *(max)

Now, current through R, $I = I_Z + I_L$

Since $I_L\ (= E_0/R_L = V_Z/R_L)$ is fixed, the value of I will be maximum when zener current is maximum *i.e.*,

$$I_{max} = I_{ZM} + I_L$$

Now $$E_i = I\,R + E_0$$

Since $E_0\ (= V_Z)$ is constant, the input voltage will be maximum when I is maximum.

$$\therefore \quad E_{i\,(max)} = I_{max}\, R + V_Z$$