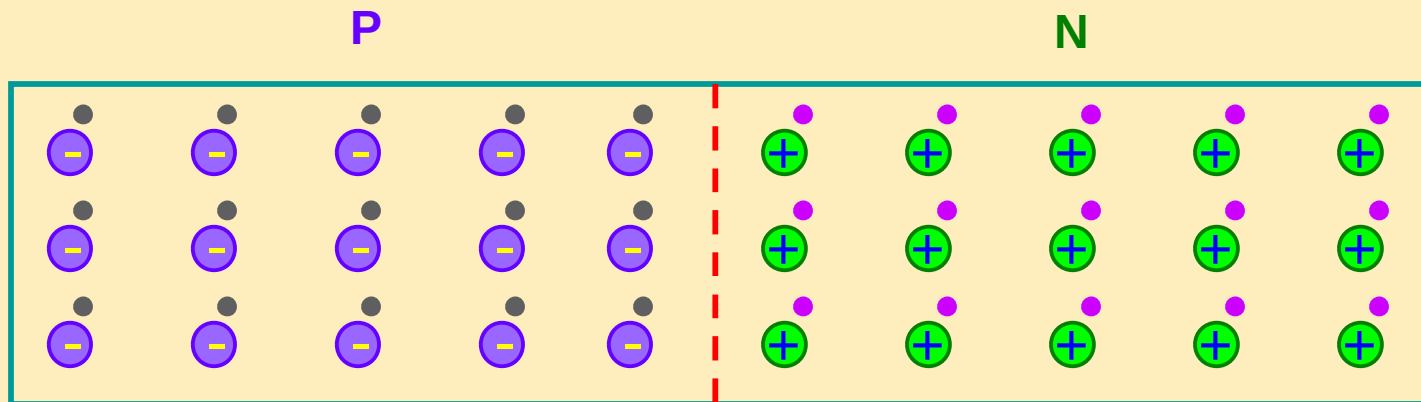


SOLIDS AND SEMICONDUCTOR DEVICES - II

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- 4. Diode Characteristics**
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PN Junction Diode:

When a P-type semiconductor is joined to a N-type semiconductor such that the crystal structure remains continuous at the boundary, the resulting arrangement is called a **PN junction diode** or a **semiconductor diode** or a **crystal diode**.



When a PN junction is formed, the P region has mobile holes (+) and immobile negatively charged ions.

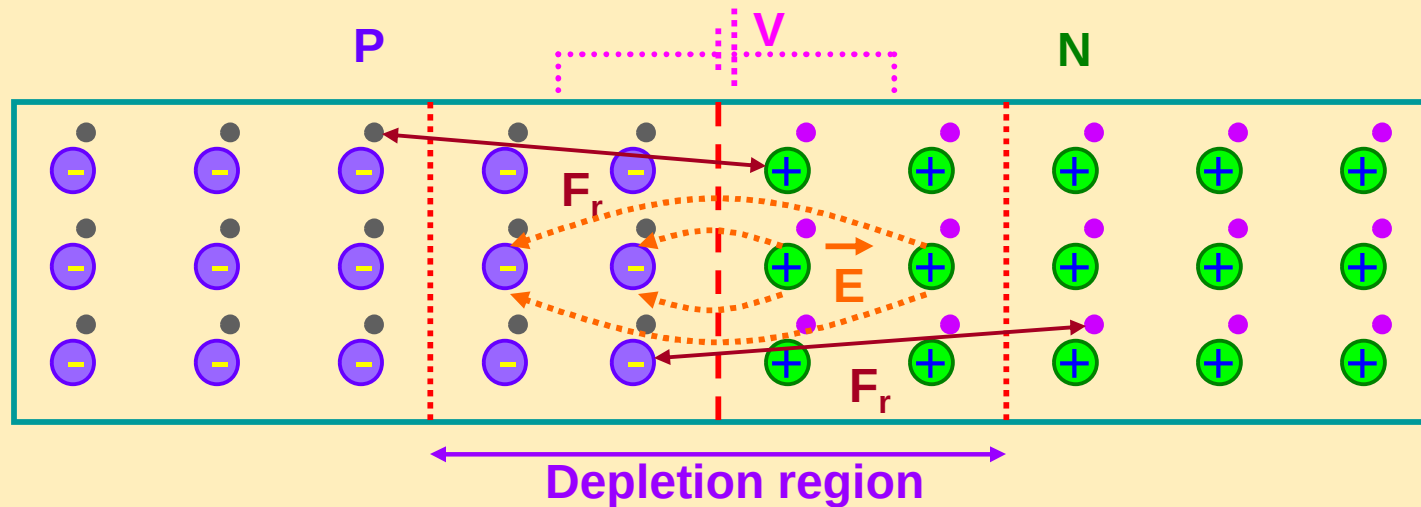
N region has mobile electrons (-) and immobile positively charged ions.

- Mobile Hole (Majority Carrier)
- Immobile Negative Impurity Ion
- Mobile Electron (Majority Carrier)
- Immobile Positive Impurity Ion

The whole arrangement is electrically neutral.

For simplicity, the minority charge carriers are not shown in the figure.

PN Junction Diode immediately after it is formed :



After the PN junction diode is formed –

- i) Holes from P region diffuse into N region due to difference in concentration.
- ii) Free electrons from N region diffuse into P region due to the same reason.
- iii) Holes and free electrons combine near the junction.
- iv) Each recombination eliminates an electron and a hole.
- v) The uncompensated negative immobile ions in the P region do not allow any more free electrons to diffuse from N region.
- vi) The uncompensated positive immobile ions in the N region do not allow any more holes to diffuse from P region.

vii) The positive donor ions in the N region and the negative acceptor ions in the P region are left uncompensated.

viii) The region containing the uncompensated acceptor and donor ions is called '**depletion region**' because this region is devoid of mobile charges.

Since the region is having only immobile charges, therefore, this region is also called '**space charge region**'.

ix) The N region is having higher potential than P region.

x) So, an electric field is set up as shown in the figure.

xi) The difference in potential between P and N regions across the junction makes it difficult for the holes and electrons to move across the junction. This acts as a barrier and hence called '**potential barrier**' or '**height of the barrier**'.

xii) The physical distance between one side and the other side of the barrier is called '**width of the barrier**'.

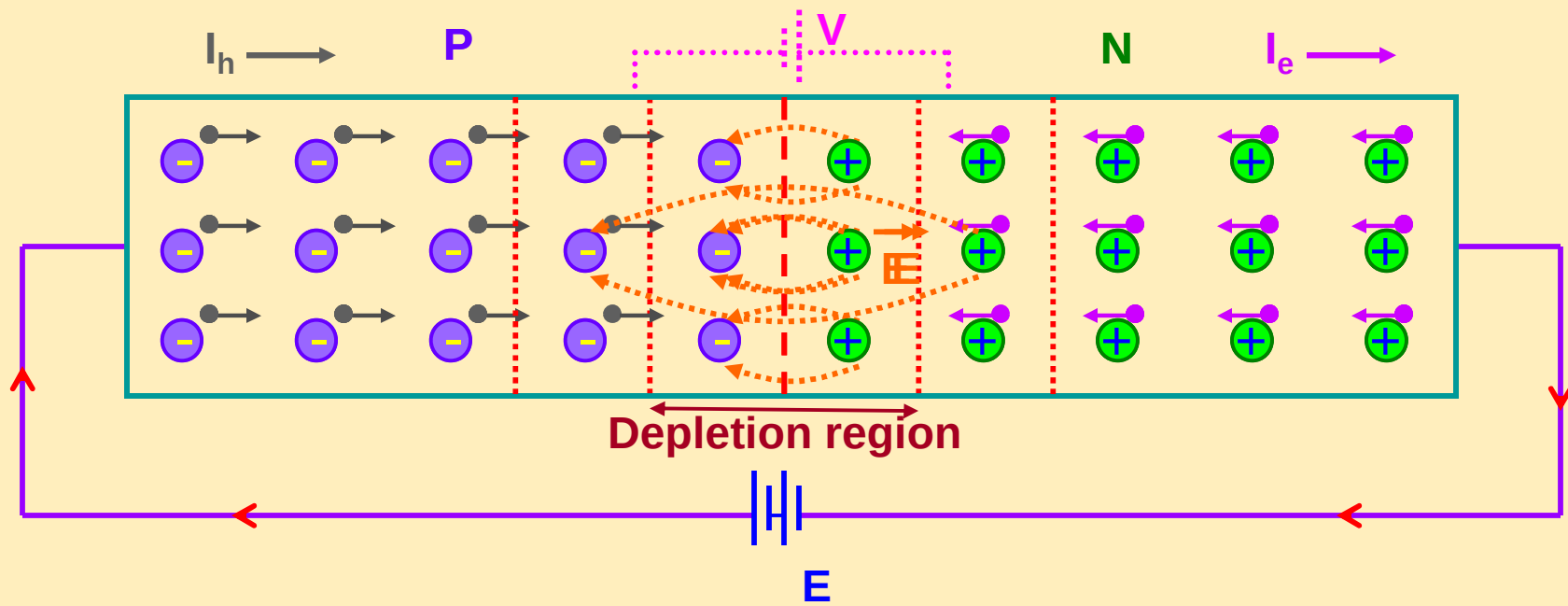
xiii) Potential barrier for Si is nearly 0.7 V and for Ge is 0.3 V.

xiv) The potential barrier opposes the motion of the majority carriers.

xv) However, a few majority carriers with high kinetic energy manage to overcome the barrier and cross the junction.

ix) Potential barrier helps the movement of minority carriers.

Forward Bias:



When the positive terminal of the battery is connected to P-region and negative terminal is connected to N-region, then the PN junction diode is said to be forward-biased.

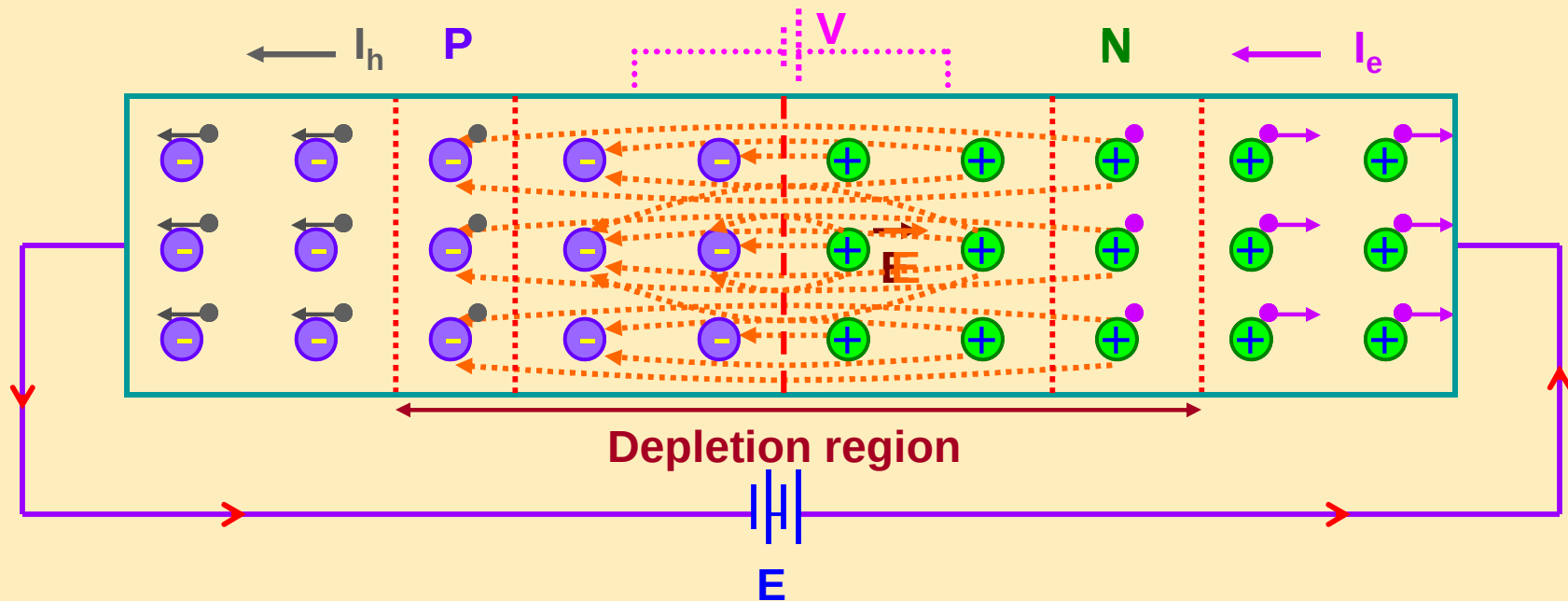
- i) Holes in P-region are repelled by +ve terminal of the battery and the free electrons are repelled by -ve terminal of the battery.
- ii) So, some holes and free electrons enter into the depletion region.
- iii) The potential barrier and the width of the depletion region decrease.
- iv) Therefore, a large number of majority carriers diffuse across the junction.
- v) Hole current and electronic current are in the same direction and add up.

- v) Once they cross the junction, the holes in N-region and the electrons in P-region become minority carriers of charge and constitute minority current.
- vi) For each electron – hole recombination, an electron from the negative terminal of the battery enters the N-region and then drifts towards the junction.

In the P-region, near the positive terminal of the battery, an electron breaks covalent bond in the crystal and thus a hole is created. The hole drifts towards the junction and the electron enters the positive terminal of the battery.

- vii) Thus, the current in the external circuit is due to movement of electrons, current in P-region is due to movement of holes and current in N-region is due to movement of electrons.
- viii) If the applied potential is increased, the potential barrier further decreases. As a result, a large number of majority carriers diffuse through the junction and a larger current flows.

Reverse Bias:

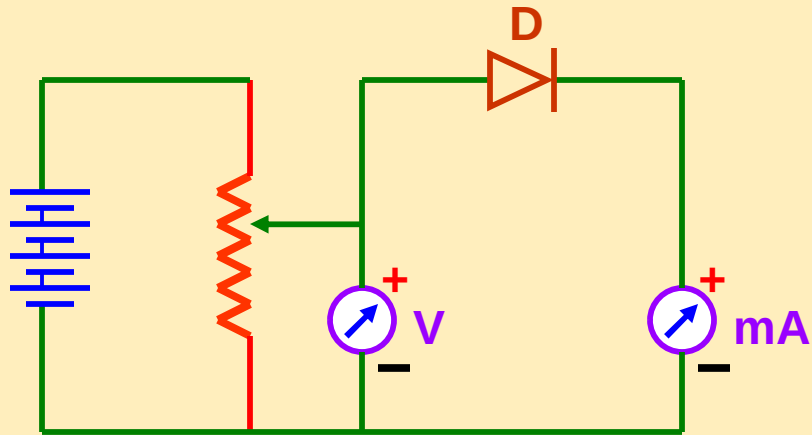


When the negative terminal of the battery is connected to P-region and positive terminal is connected to N-region, then the PN junction diode is said to be reverse-biased.

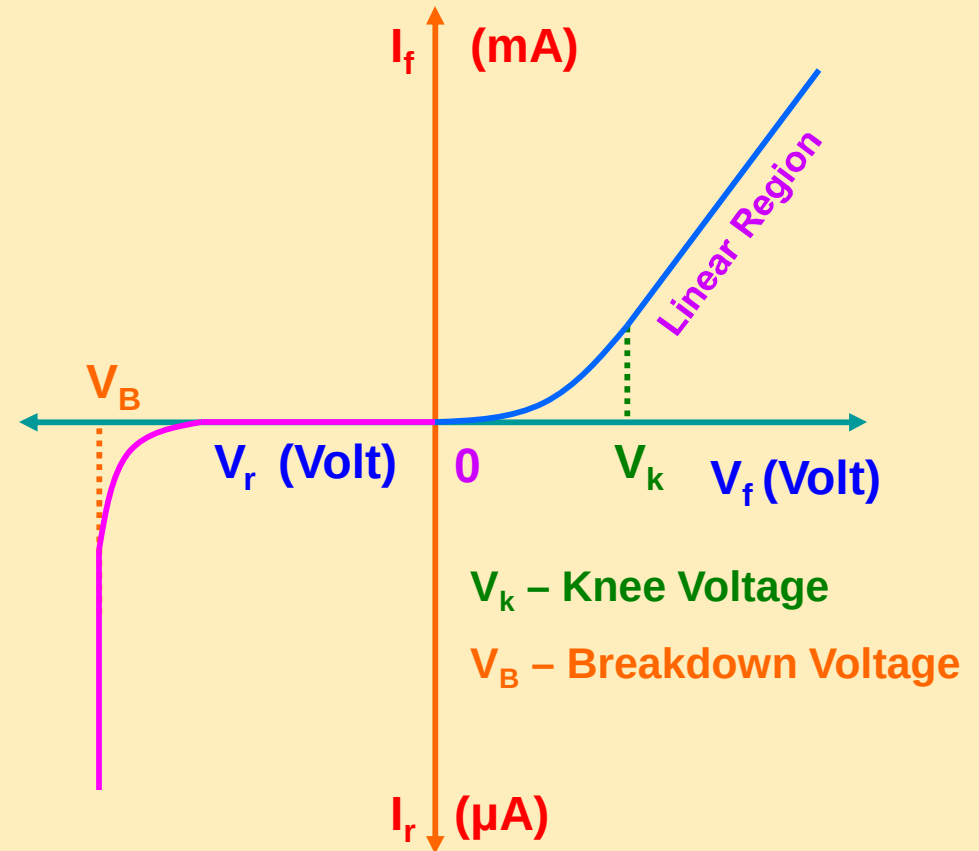
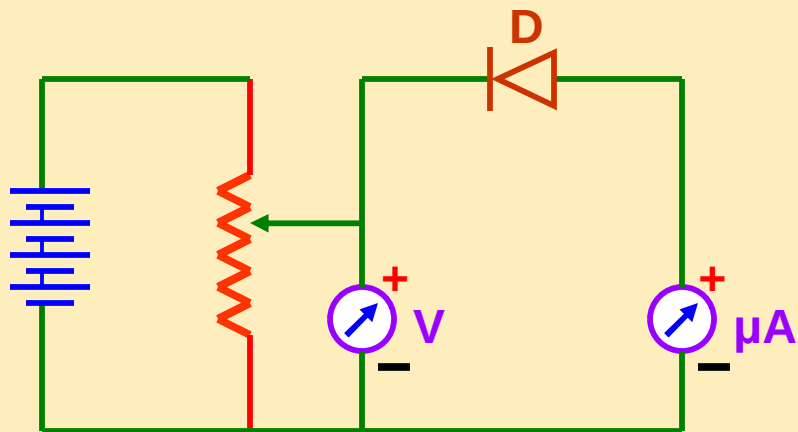
- i) Holes in P-region are attracted by -ve terminal of the battery and the free electrons are attracted by +ve terminal of the battery.
- ii) Thus, the majority carriers are pulled away from the junction.
- iii) The potential barrier and the width of the depletion region increase.
- iv) Therefore, it becomes more difficult for majority carriers diffuse across the junction.

- v) But the potential barrier helps the movement of the minority carriers. As soon as the minority carriers are generated, they are swept away by the potential barrier.
- vi) At a given temperature, the rate of generation of minority carriers is constant.
- vii) So, the resulting current is constant irrespective of the applied voltage. For this reason, this current is called 'reverse saturation current'.
- viii) Since the number of minority carriers is small, therefore, this current is small and is in the order of 10^{-9} A in silicon diode and 10^{-6} A in germanium diode.
- ix) The reverse – biased PN junction diode has an effective capacitance called 'transition or depletion capacitance'. P and N regions act as the plates of the capacitor and the depletion region acts as a dielectric medium.

Diode Characteristics: Forward Bias:



Reverse Bias:



Resistance of a Diode:

i) Static or DC Resistance $R_{d.c} = V / I$

ii) Dynamic or AC Resistance

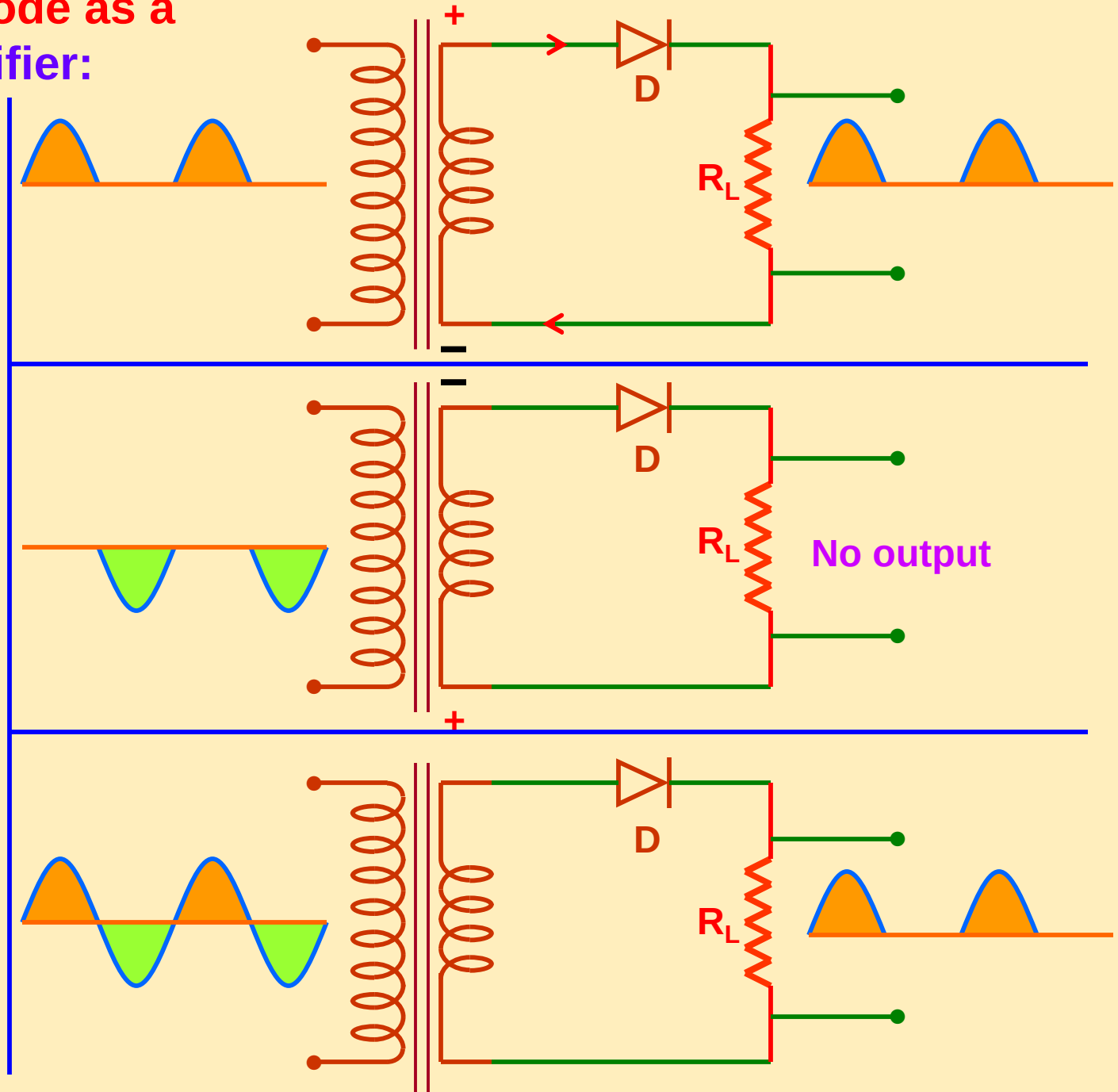
$$R_{a.c} = \Delta V / \Delta I$$

PN Junction Diode as a Half Wave Rectifier:

The process of converting alternating current into direct current is called '**rectification**'.

The device used for rectification is called '**rectifier**'.

The PN junction diode offers low resistance in forward bias and high resistance in reverse bias.

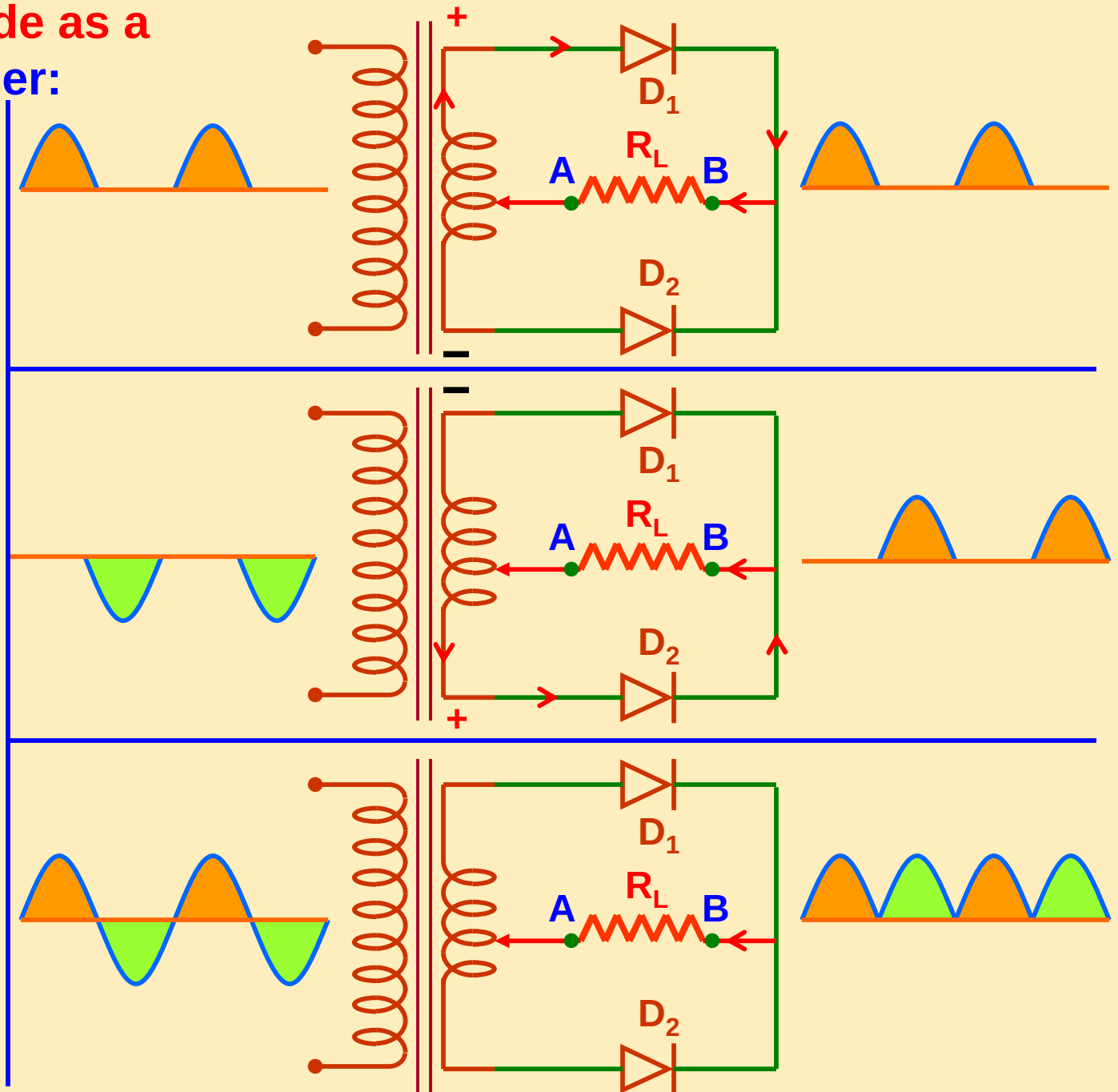


PN Junction Diode as a Full Wave Rectifier:

When the diode rectifies whole of the AC wave, it is called 'full wave rectifier'.

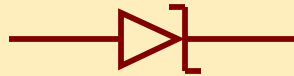
During the positive half cycle of the input ac signal, the diode D_1 conducts and current is through **BA**.

During the negative half cycle, the diode D_2 conducts and current is through **BA**.

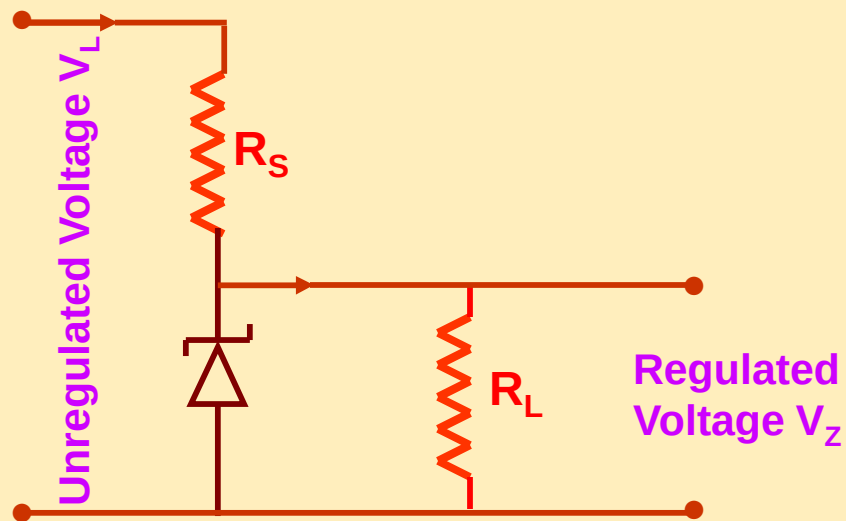
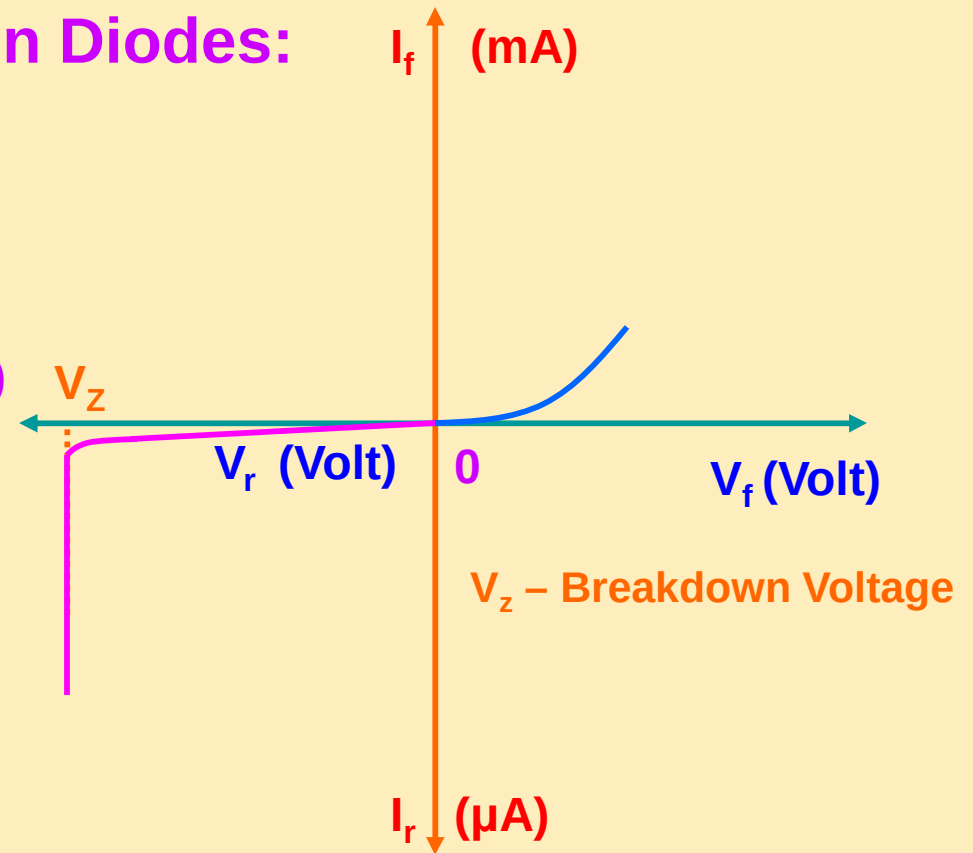


Special Purpose p-n Junction Diodes:

Zener Diode



- Heavily doped
- Depletion Region is $< 10^{-6}$ m
- Electric Field is very high (5×10^6 V/m)
- Reverse biased
- Internal Field emission or field ionisation



Zener Diode as a Voltage Regulator