ELL100: INTRODUCTION TO ELECTRICAL ENGG.

Lecture 21: Semiconductor Basics and p-n junctions

Instructor: Debanjan Bhowmik

Reference: Chenming Hu's 'Modern Semiconductor Devices for Integrated Circuits' (*only read the relevant parts of Chap. 1, 2, and 4 qualitatively, don't go into the math*)

Conduction in Solids

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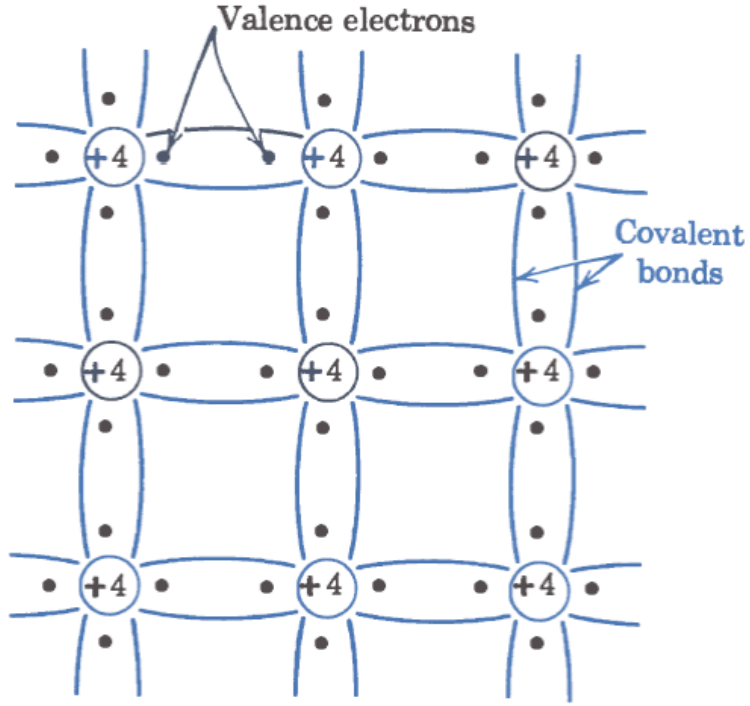
- Depending on availability of free electrons, solids can be categorized into :
    - Conductors : large number of mobile charge carriers.
    - Insulators : Practically no free charge carriers.
    - Semiconductors : Conductivity intermediate of conductors and insulators.

Semiconductors

- Two important semiconductors in electronics : Silicon and Germanium.
- They have 4 valence electrons.



Semiconductors

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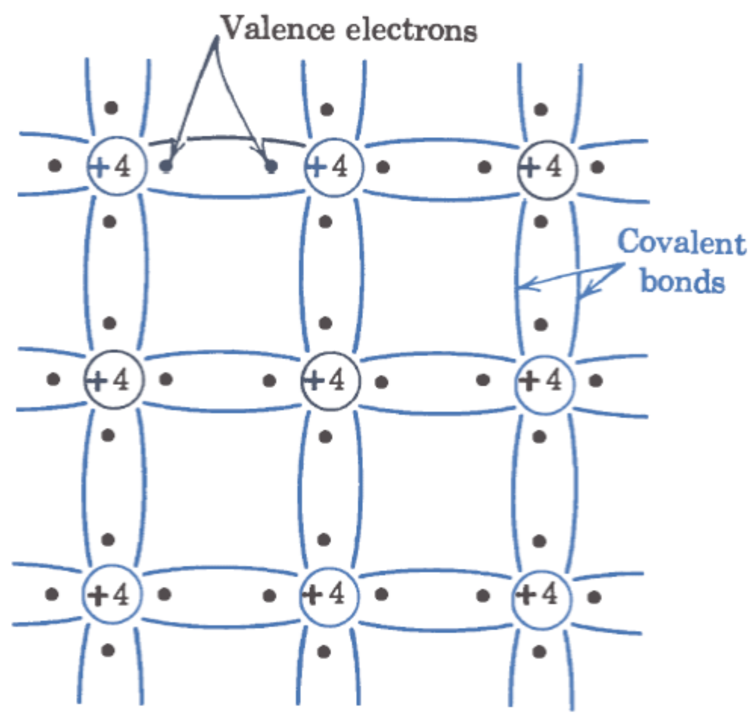
- At room temperature, few electrons gain enough thermal energy to get into conduction band (free electrons).



Semiconductors

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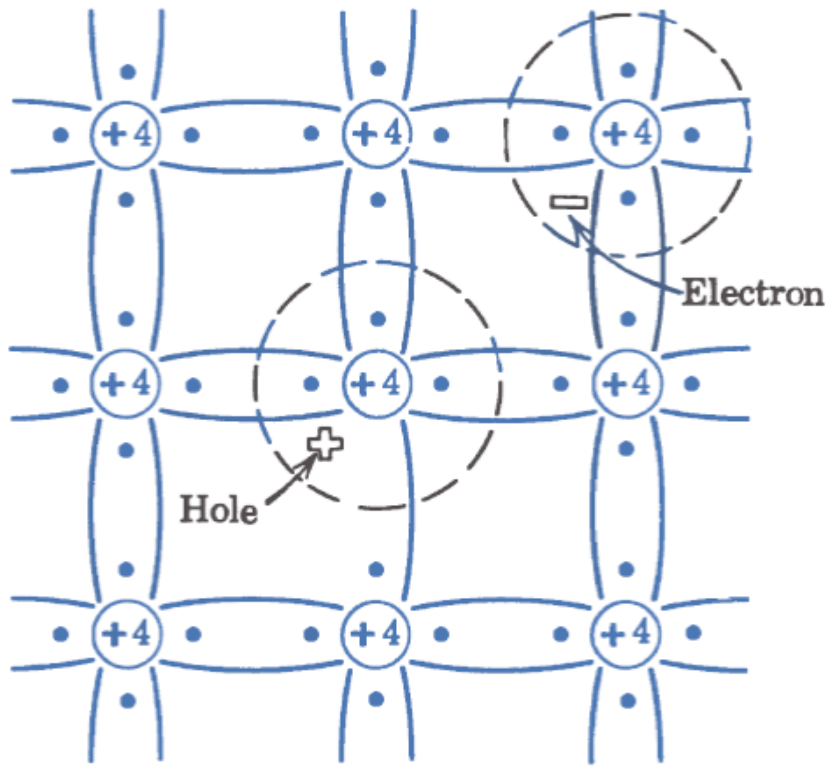
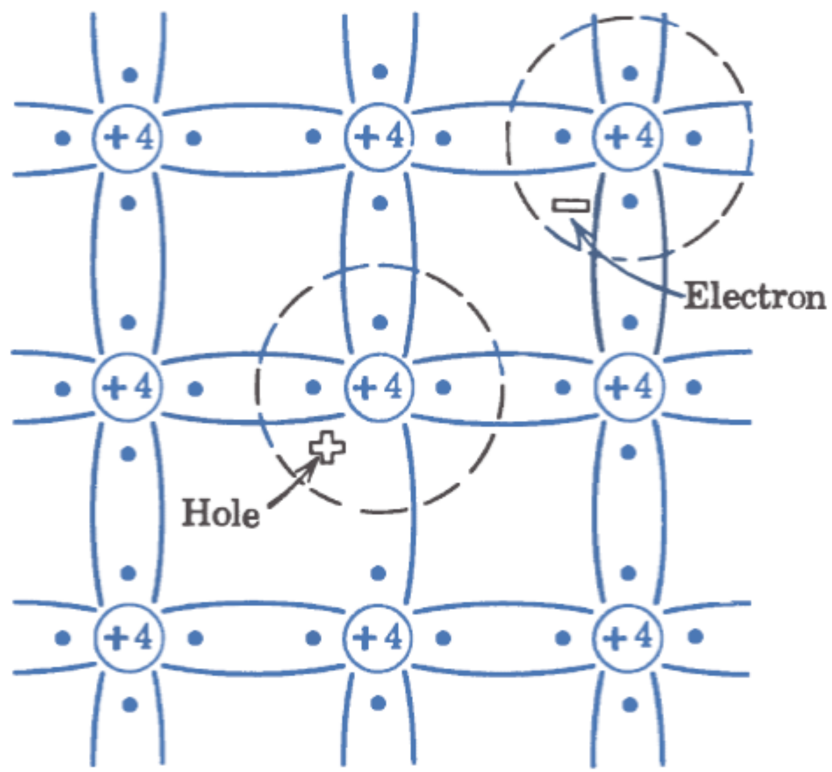


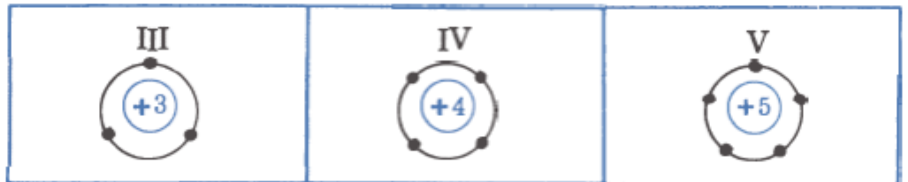
Semiconductors

- At room temperature, few electrons gain enough thermal energy to get into conduction band (free electrons).
- Where there was an electron, there is a 'hole' left now.
  - Region with free electron has net -ve charge
  - Region with hole has net +ve charge
- Both contribute to conduction



Doping

- The conductivity of a Si/Ge semiconductor can be altered by adding **impurity** element from the third of fifth column of periodic table.

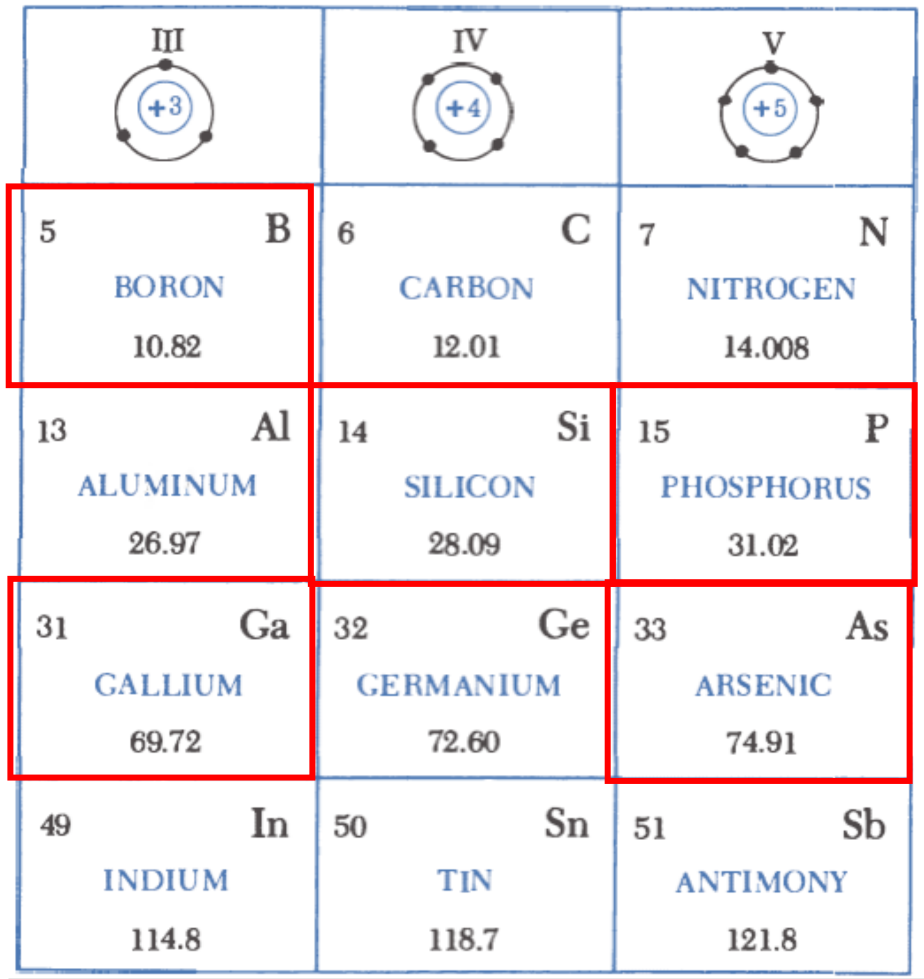


III	IV	V
5 B BORON 10.82	6 C CARBON 12.01	7 N NITROGEN 14.008
13 Al ALUMINUM 26.97	14 Si SILICON 28.09	15 P PHOSPHORUS 31.02
31 Ga GALLIUM 69.72	32 Ge GERMANIUM 72.60	33 As ARSENIC 74.91
49 In INDIUM 114.8	50 Sn TIN 118.7	51 Sb ANTIMONY 121.8

Doping

- The conductivity of a Si/Ge semiconductor can be altered by adding **impurity** element from the third of fifth column of periodic table.
- Typical choices : For Silicon
  - Boron, Gallium (trivalent),
  - Phosphorus, Arsenic (Pentavalent)
- A semiconductor without doping

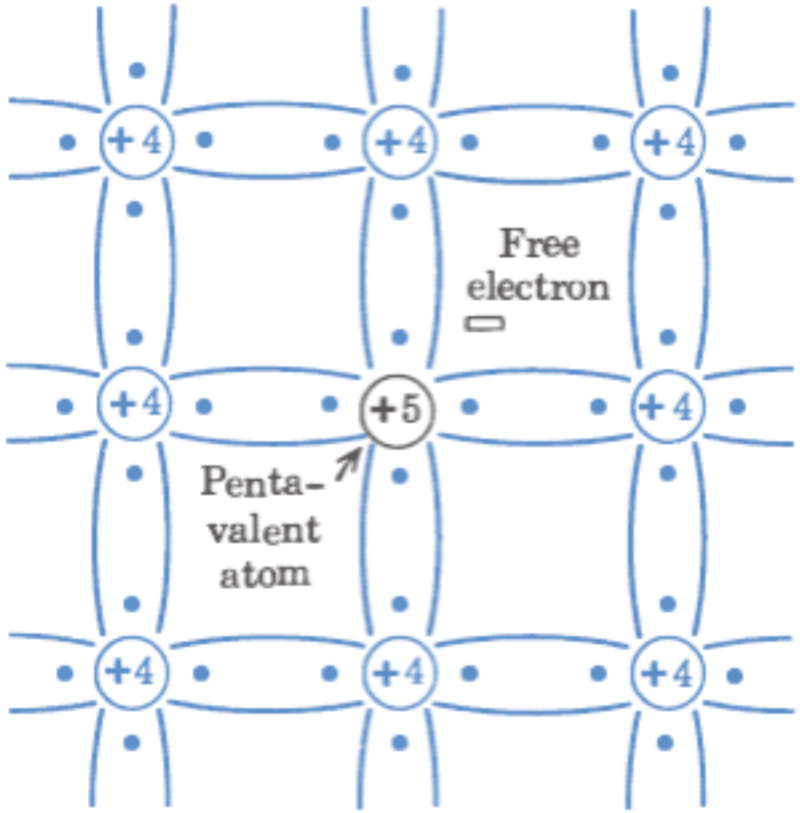
Is called intrinsic/pure



Doping – Pentavalent (n-type)

- When a pentavalent atom replaces Si atom in crystal.
- There is an excess free electron

Which can go into conduction band (with little thermal energy).



Doping – Pentavalent (n-type)

- When a pentavalent atom replaces Si atom in crystal.
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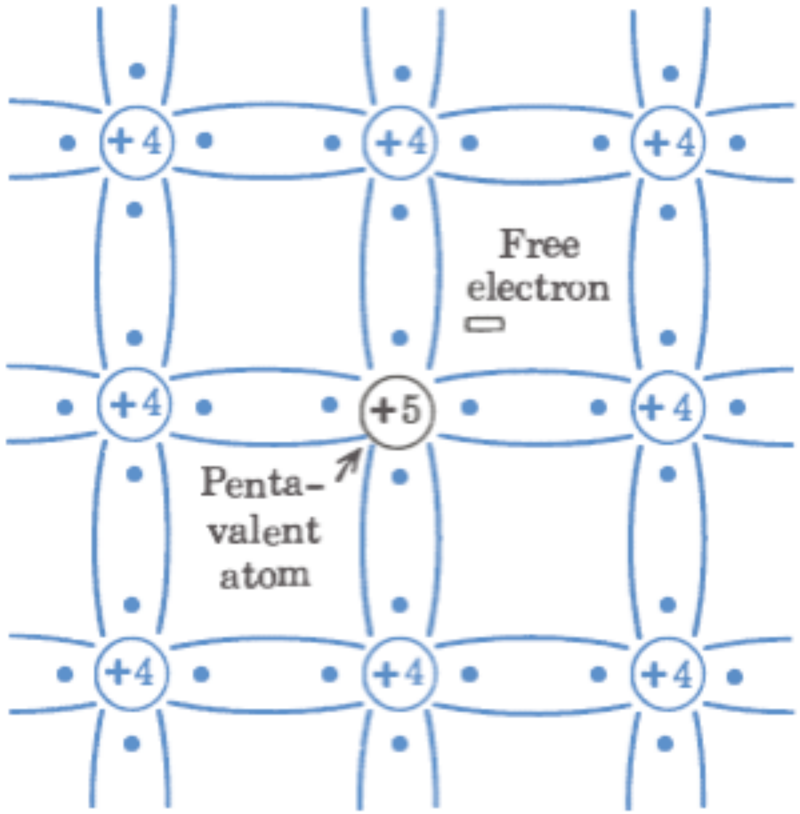
- Resulting material has negative

Charge carriers in electrically
neutral material

n-type semiconductor

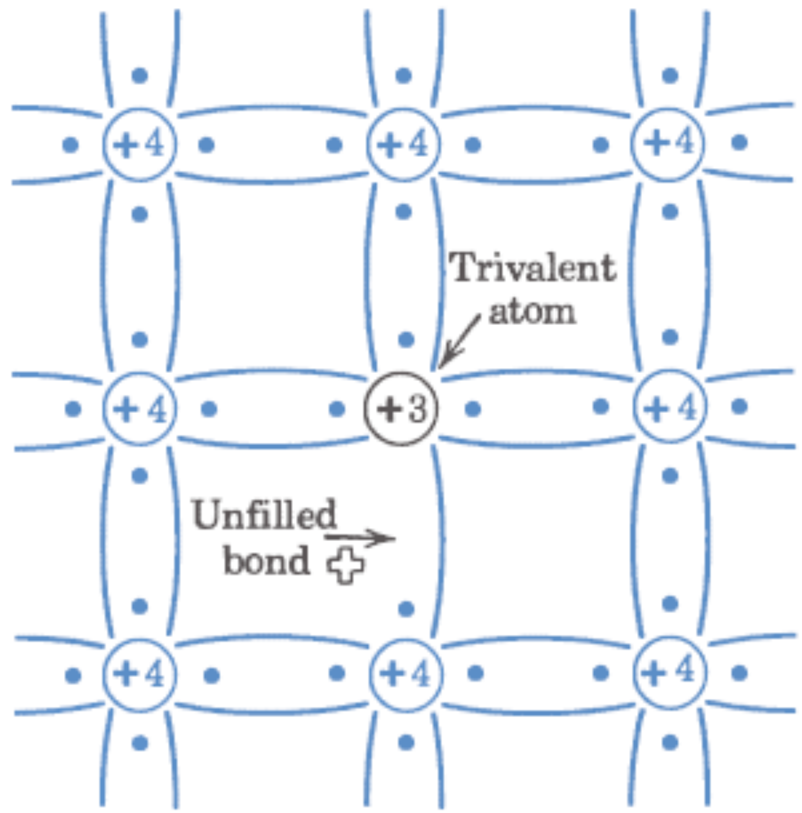


Doping – Trivalent (p-type)

- When a trivalent atom replaces Si atom in crystal.
- There only 3 valence electrons are available instead of 4.
- If the remaining unfilled covalent

Is filled from neighbouring atom,

There is a ‘hole’ created.



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- When a trivalent atom replaces Si atom in crystal.
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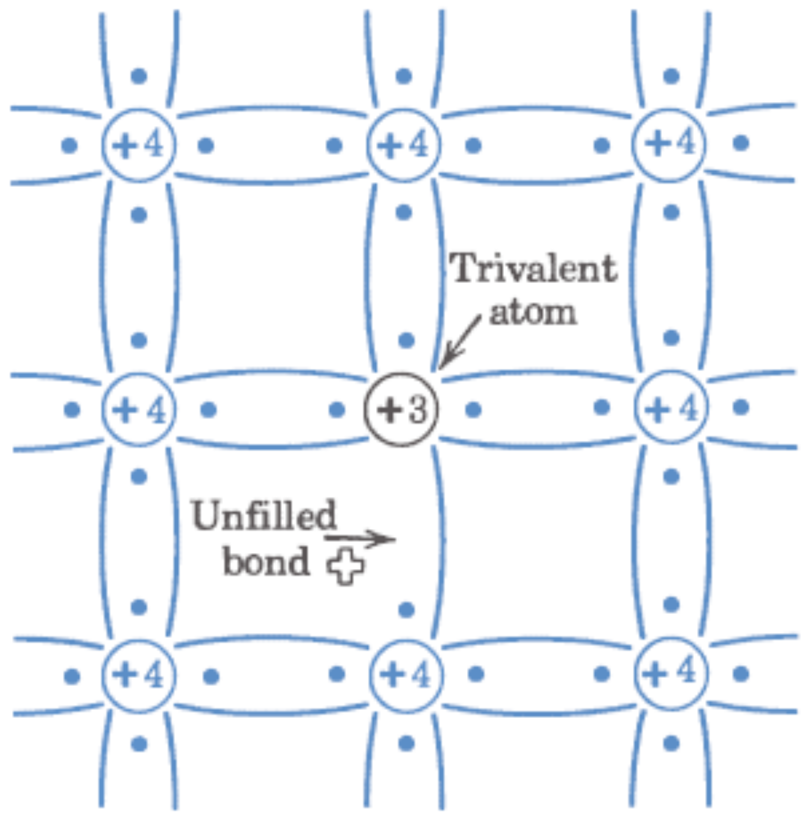
- Resulting material has positive

Charge carriers in electrically

neutral material (effectively)

p-type semiconductor



Junction Diodes

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- But, if a p-type region placed close to an n-type region, there is difference in carrier concentration.

Junction Diodes

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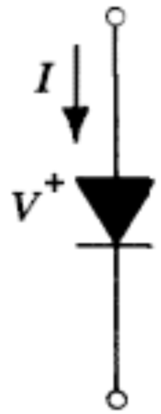
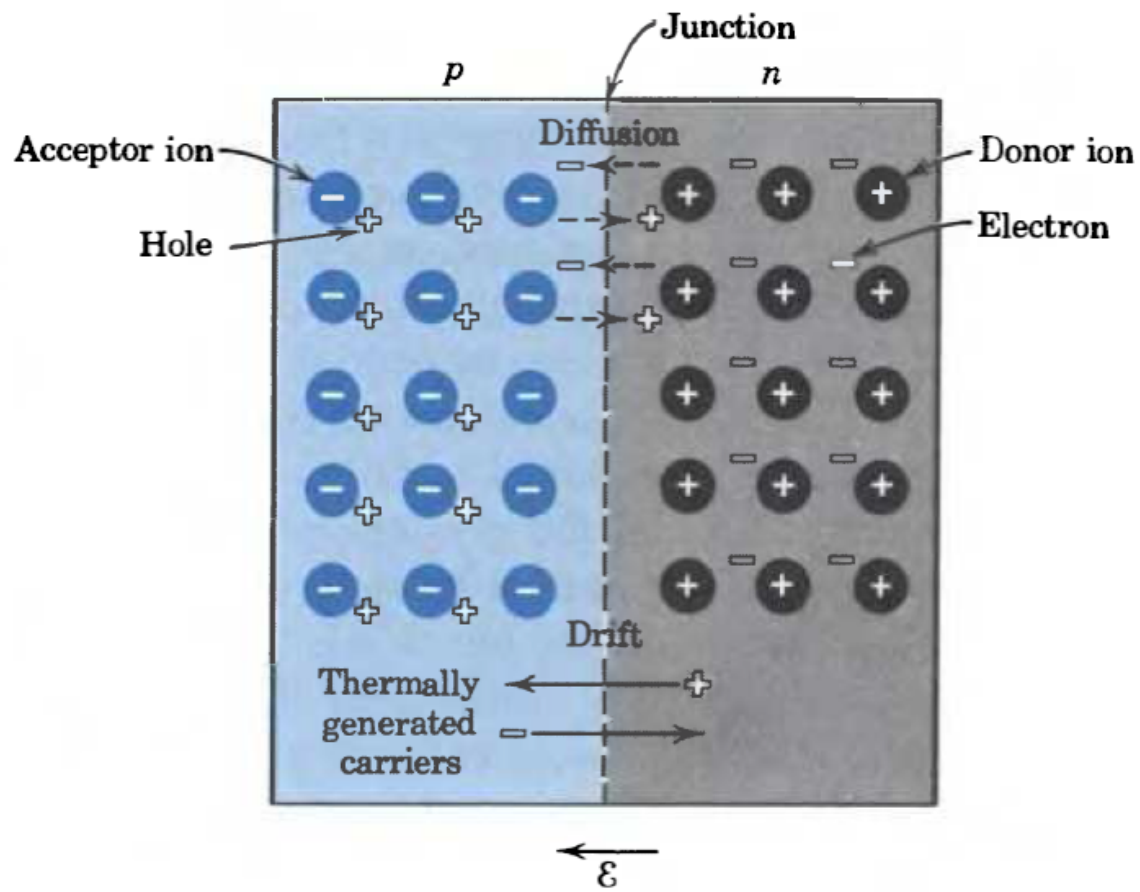
- But, if a p-type region placed close to an n-type region, there is difference in carrier concentration.
- Current flows preferentiall

In one direction.

- This device is a

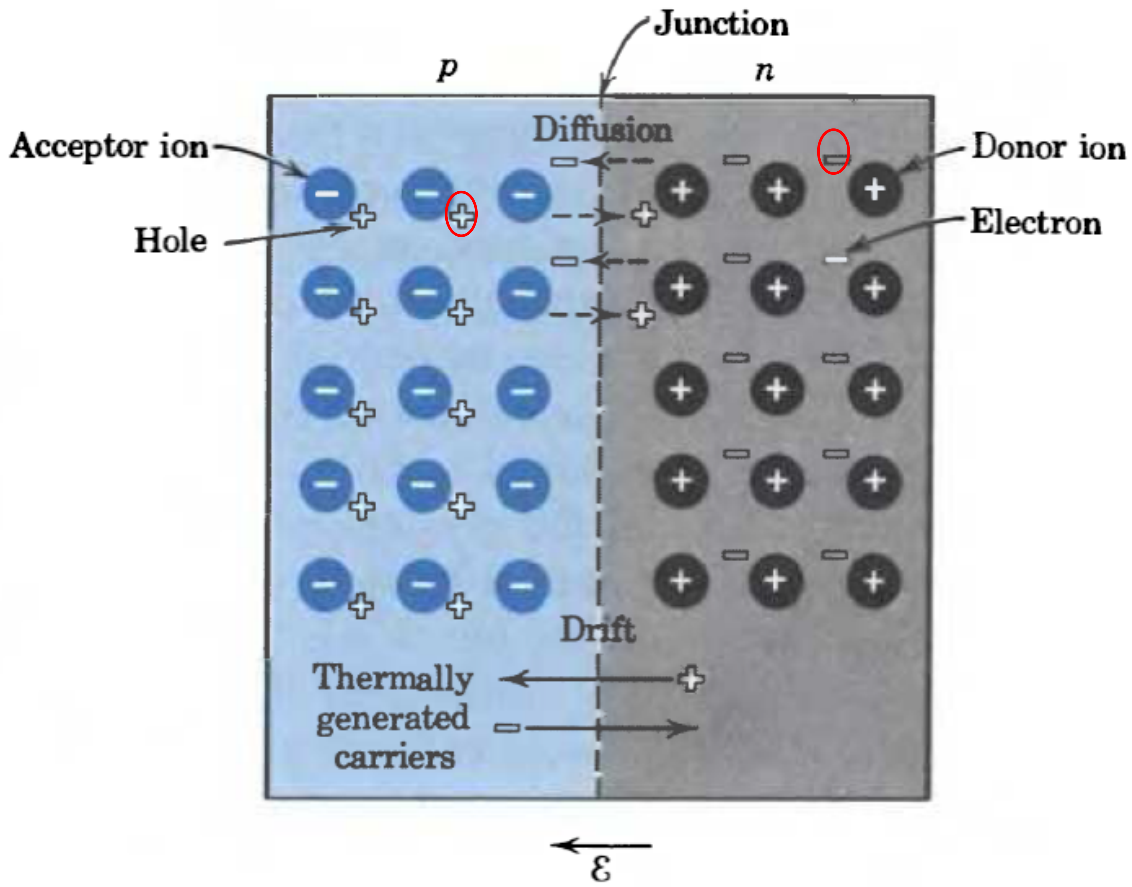
Semiconductor diode.





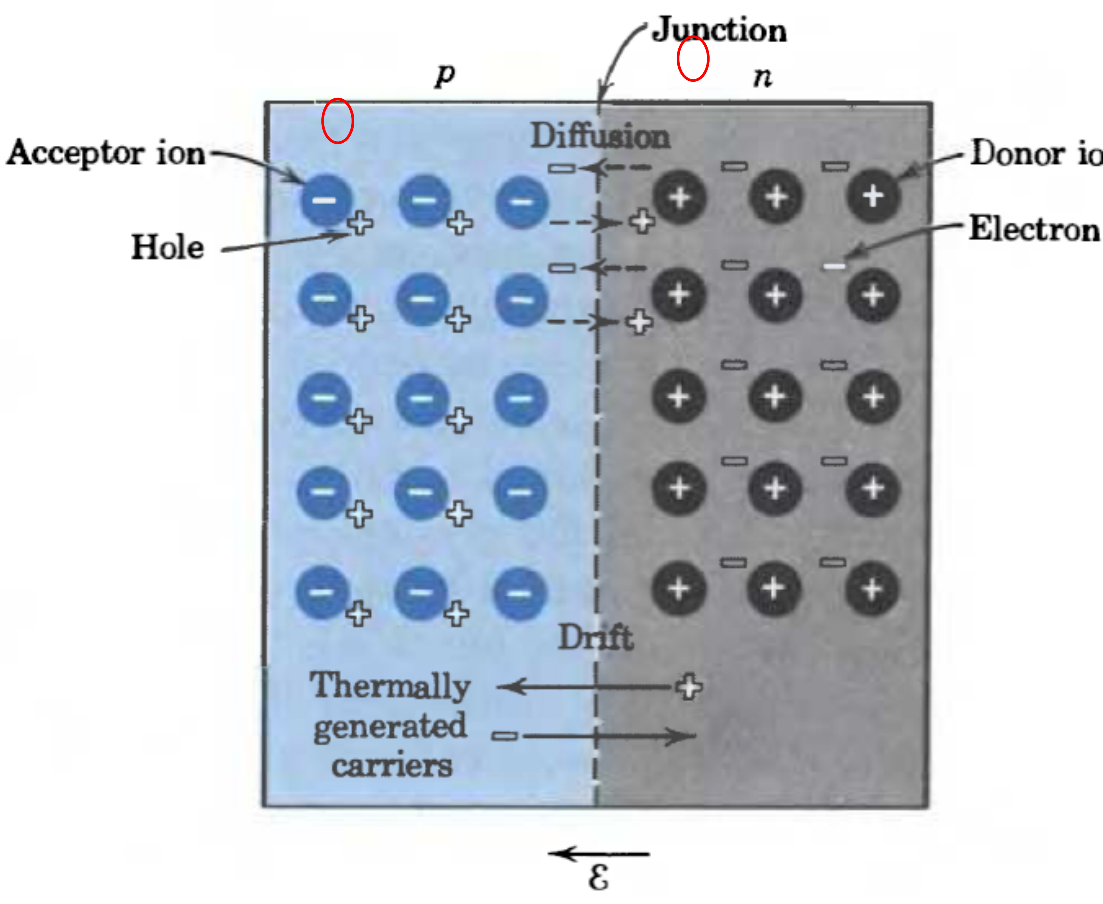
pn-Junction Behaviour

- Majority carriers : Main cause of flow of current in a region. (hole in p, electron in n)
-



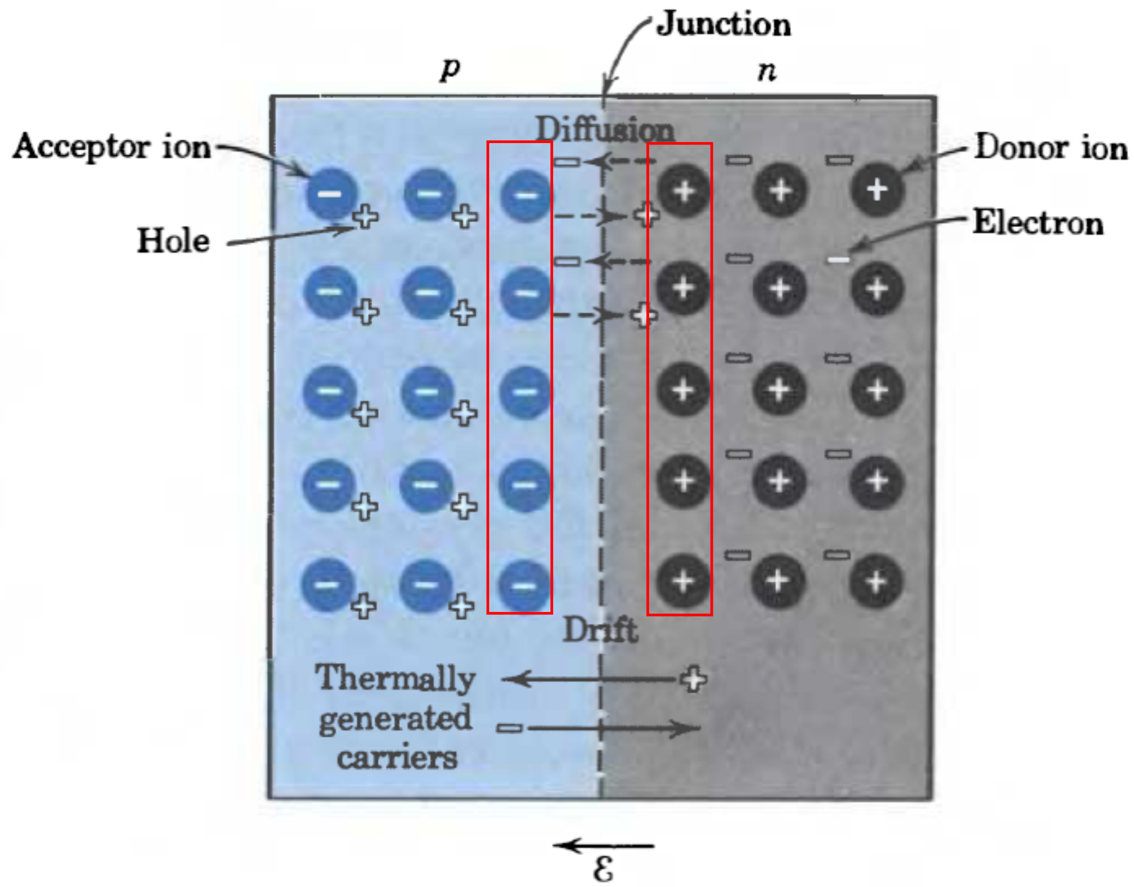
pn-Junction Behaviour

- Majority carriers : Main cause of flow of current in a region. (hole in p, electron in n)
- Because of the concentration gradient, the majority carriers diffuse across the junction and recombine.



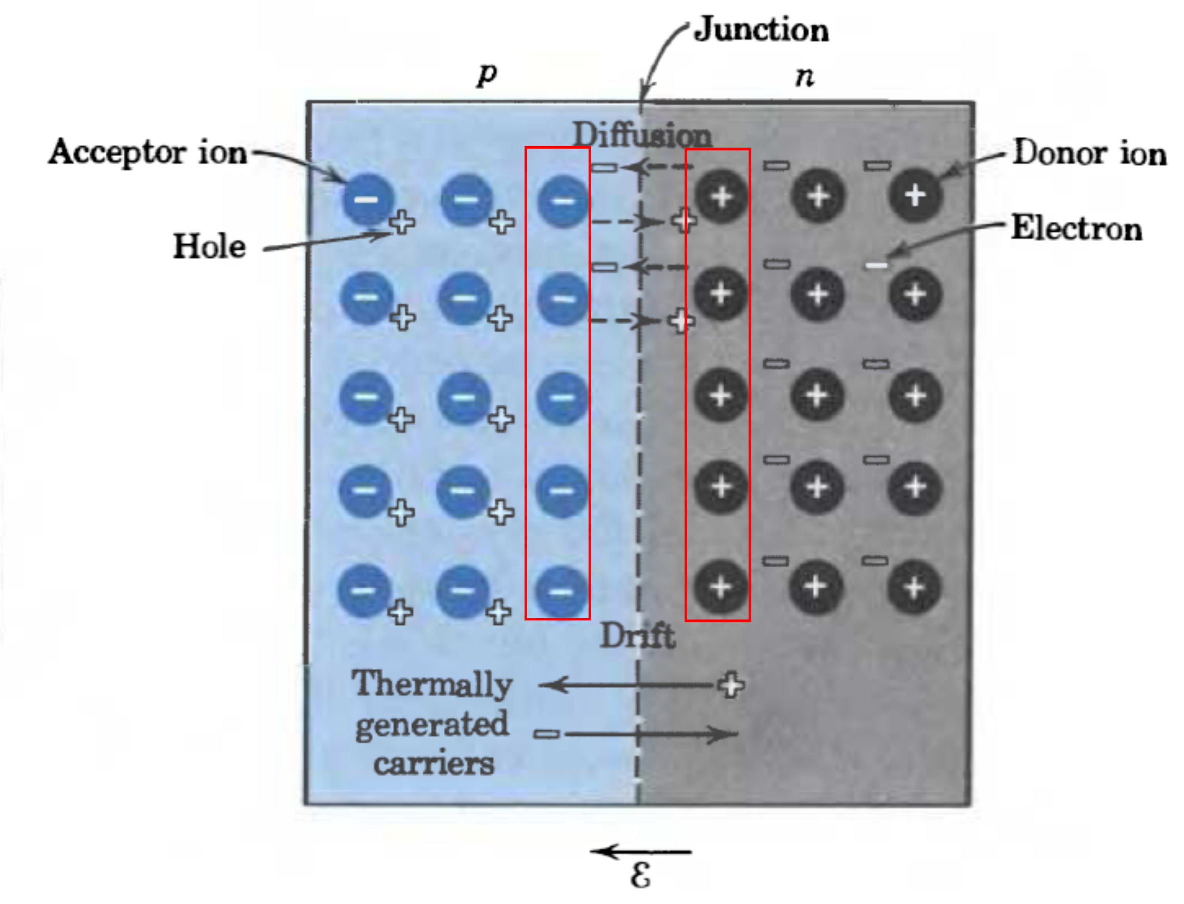
pn-Junction Behaviour

- Diffusion uncovers bound –ve charges in p region (and +ve charge in n region)



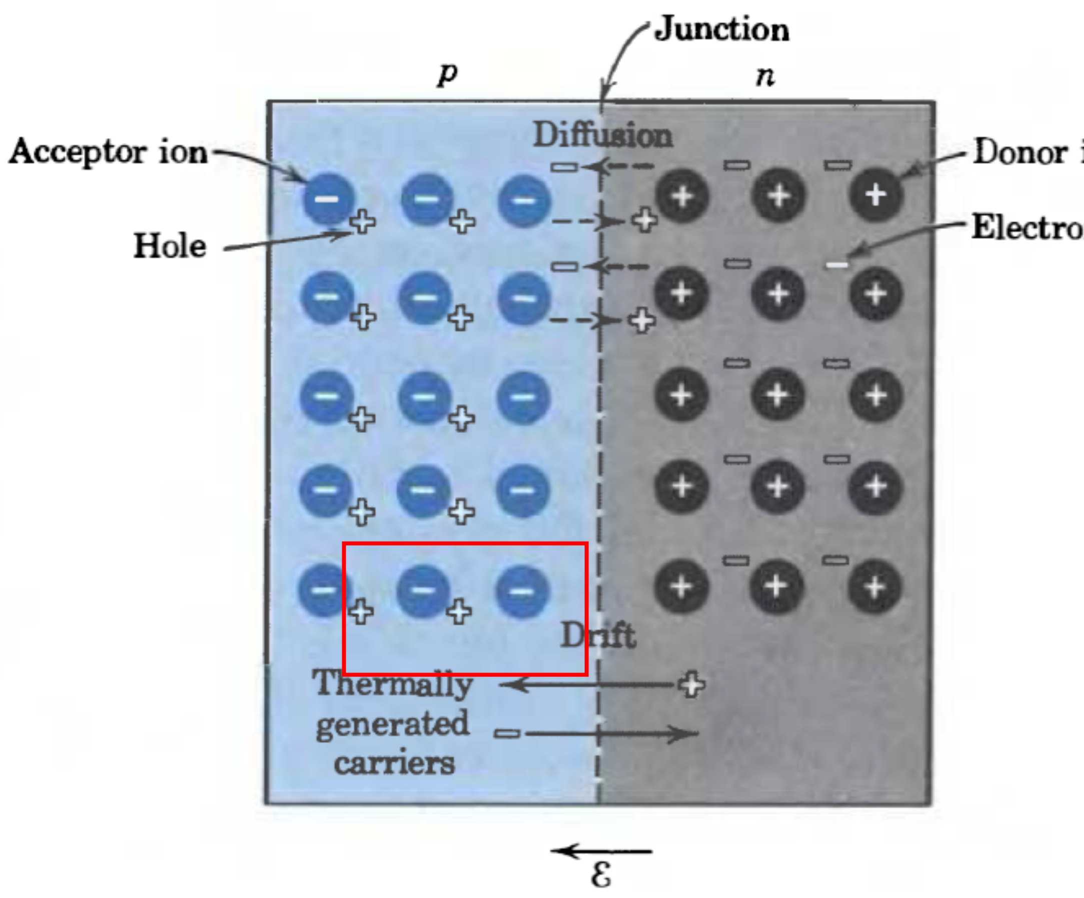
pn-Junction Behaviour

- Diffusion uncovers bound –ve charges in p region (and +ve charge in n region)
- This region where the bound charges are uncovered is depletion region.
  (depleted of majority carriers
An electric field ε is created a
depletion region



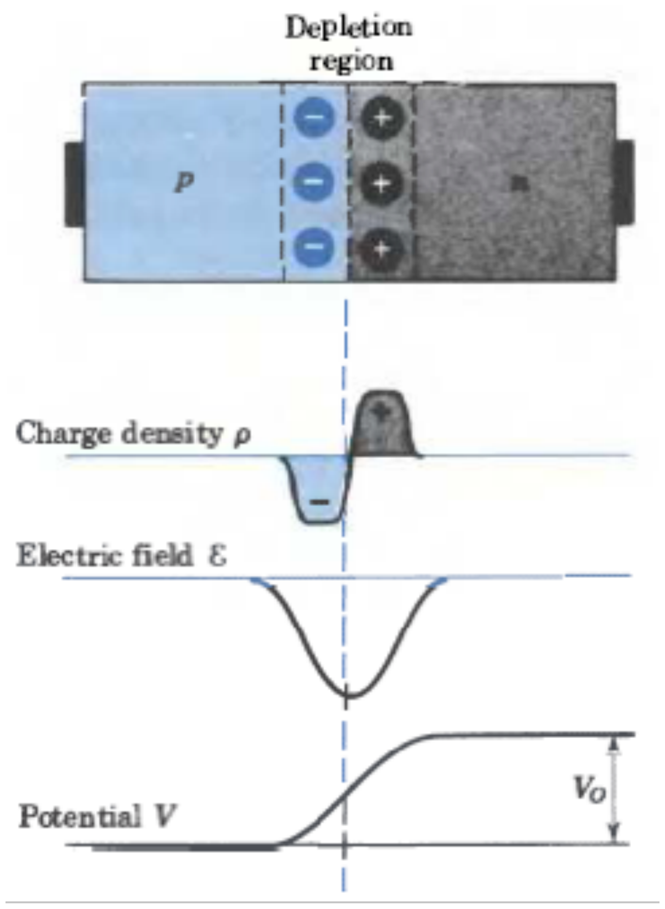
pn-Junction Behaviour

- Diffusion uncovers bound –ve charges in p region (and +ve charge in n region)
- This region where the bound charges are uncovered is depletion region.
  (depleted of majority carriers)
- The minority carriers drift due to thermal energy



pn-Junction – Open Circuit

- There is a charge build up only in the transition region.



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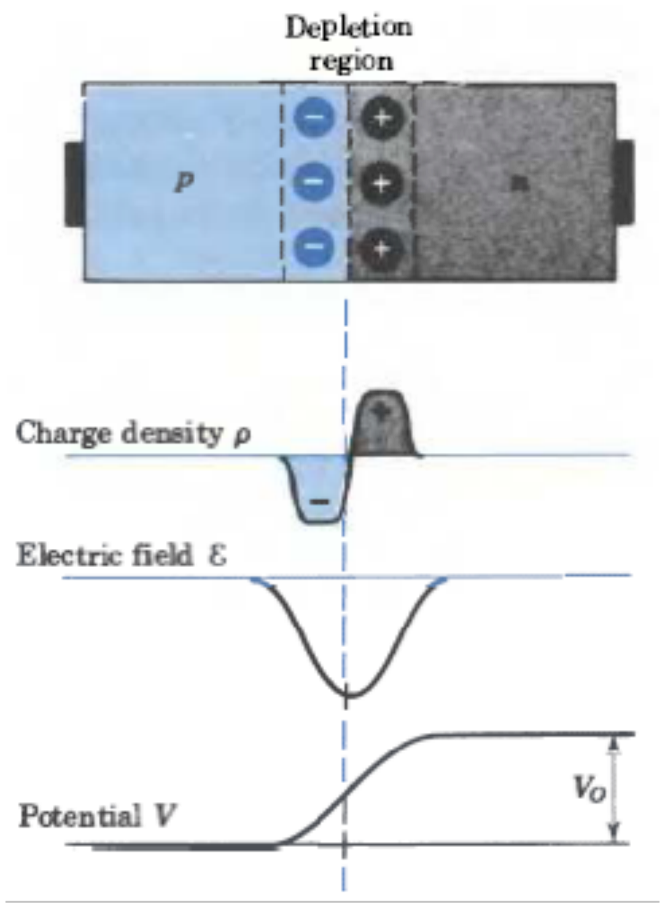
- There is a charge build up only in the transition region.
- Creates an electric field and then a “potential hill” V0.



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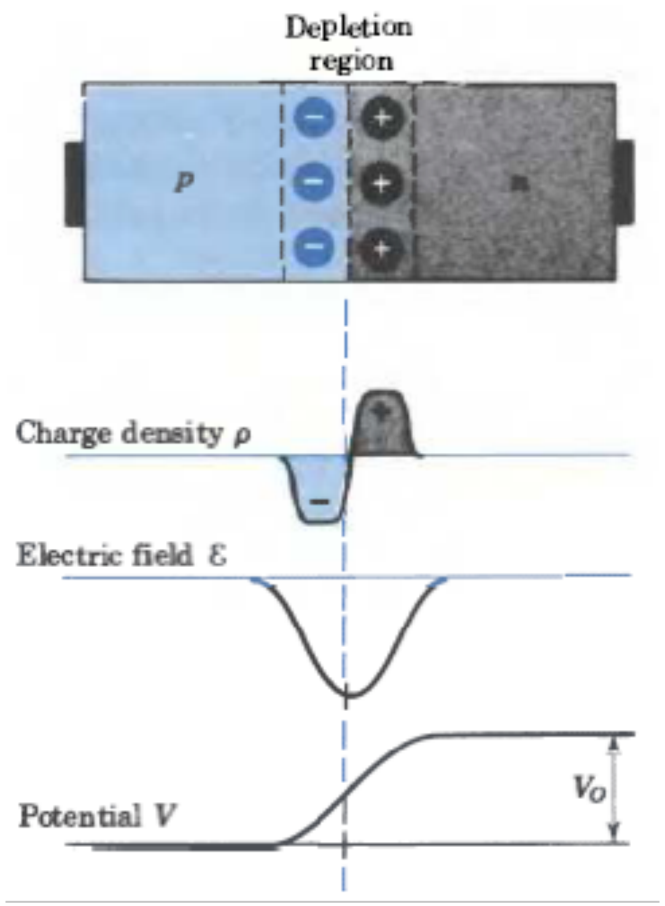

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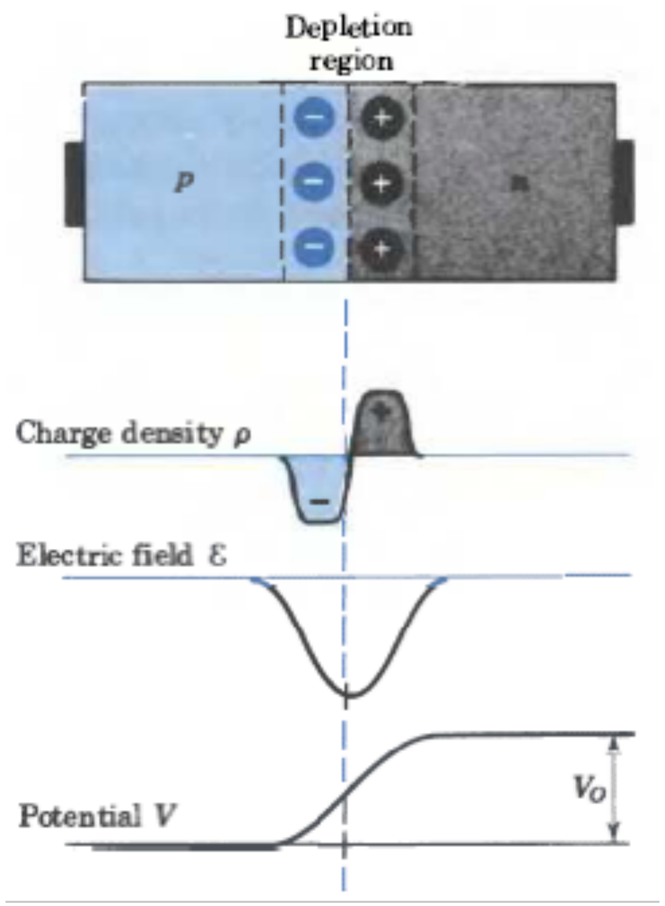
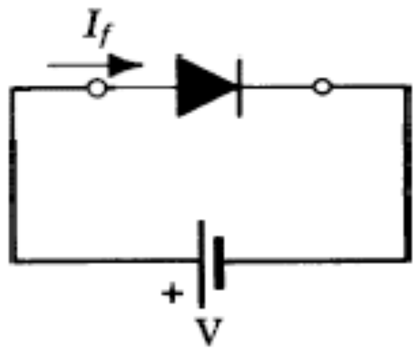
- There is a charge build up only in the transition region.
- Creates an electric field and then a “potential hill” V0.
- Potential hill OPPOSES diffusion and ENCOURAGES drift.
- This potential (Contact Potential) is the ‘barrier’ required to balance diffusion and drift.
- Vo = few tenths of a volt.



pn-Junction – Forward Bias

- Forward bias : Connecting of external source (V) with p-type at higher potential than n-type.



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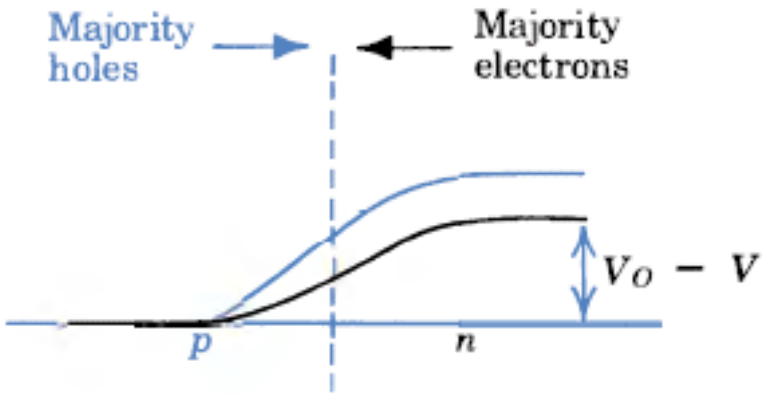
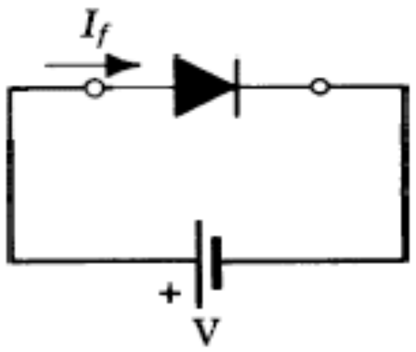
- The external potential effectively reduces the barrier potential to V0-V.





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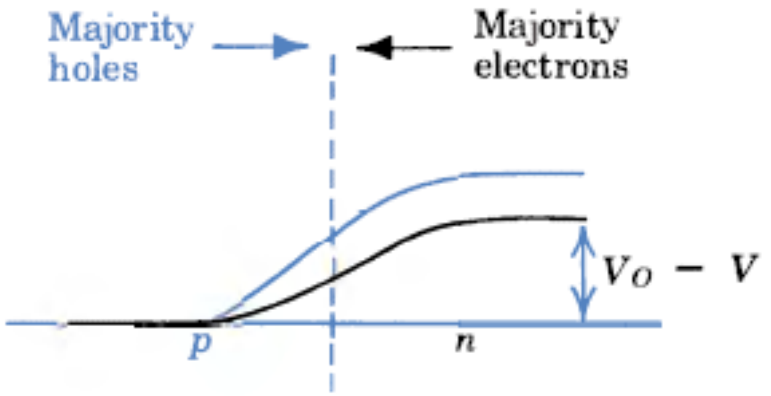
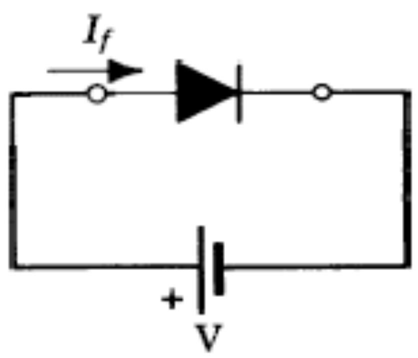
- Forward bias : Connecting of external source (V) with p-type at higher potential than n-type.
- The external potential effectively reduces the barrier potential to V0-V.
- The process is very sensitive to barrier voltage and a large increase in current occurs for a small decrease in barrier potential. (Exponential Relation)





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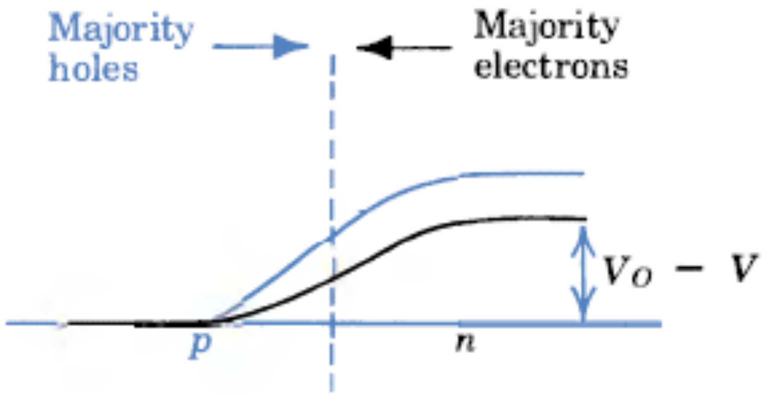
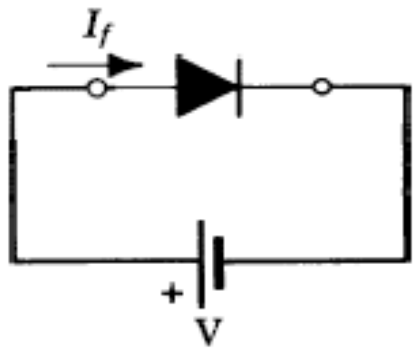
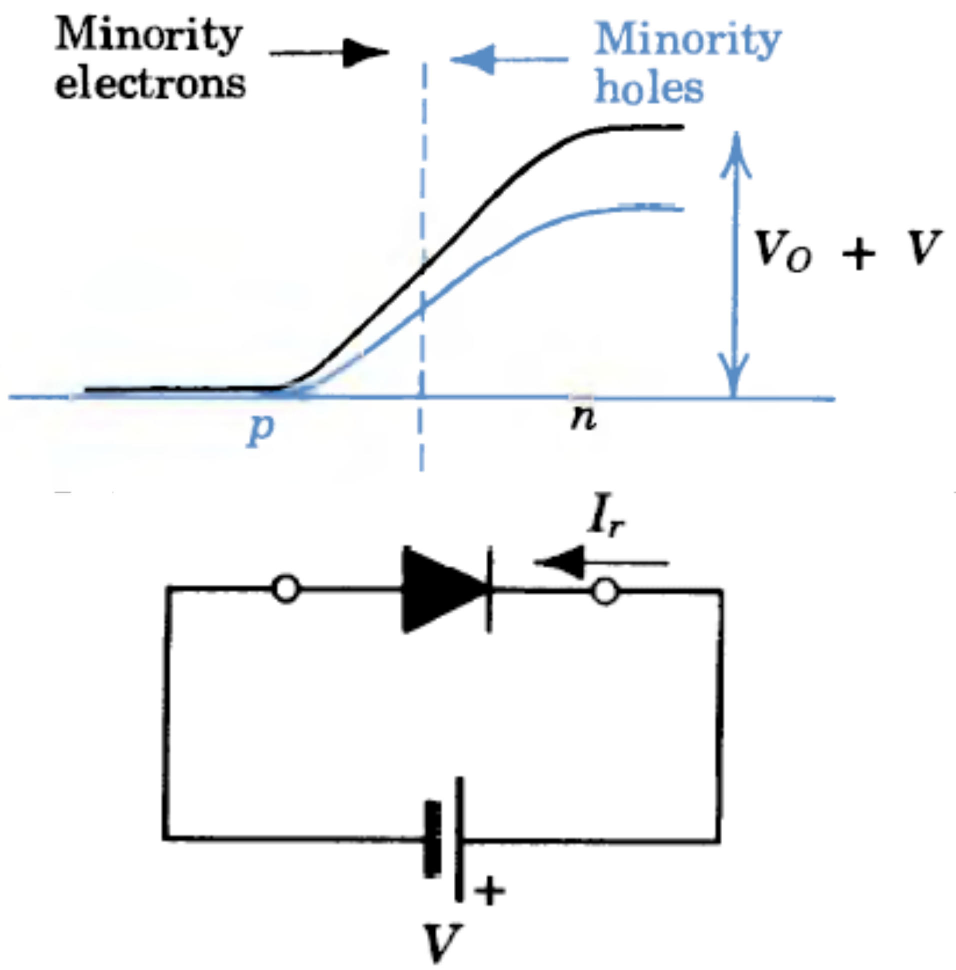
- Process is sustained by supply of electrons in n region and removal from p region, by ext. battery





pn-Junction – Reverse Bias

- Reverse Bias : p junction is connected to a lower potential than n junction.



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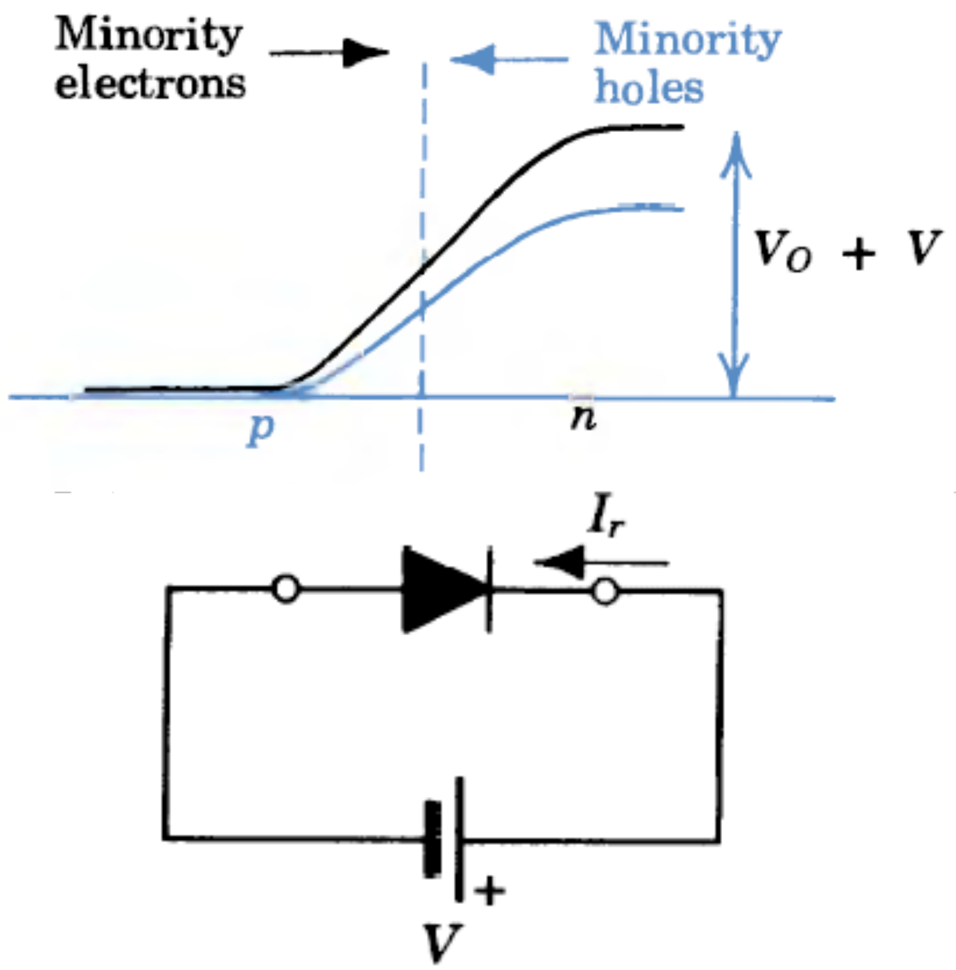
- With reverse bias the potential barrier increases.
  - Probability of current by majority carriers decreases exponentially.



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- With reverse bias the potential barrier increases.
  - Probability of current by majority carriers decreases exponentially.
- Small amount of reverse bias current due to minority carrier drift.
  - I_r is independent of V