BME2312 - Analog Electronics

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LECTURE 4

Semiconductor Diodes

Why do we need Semiconductors?

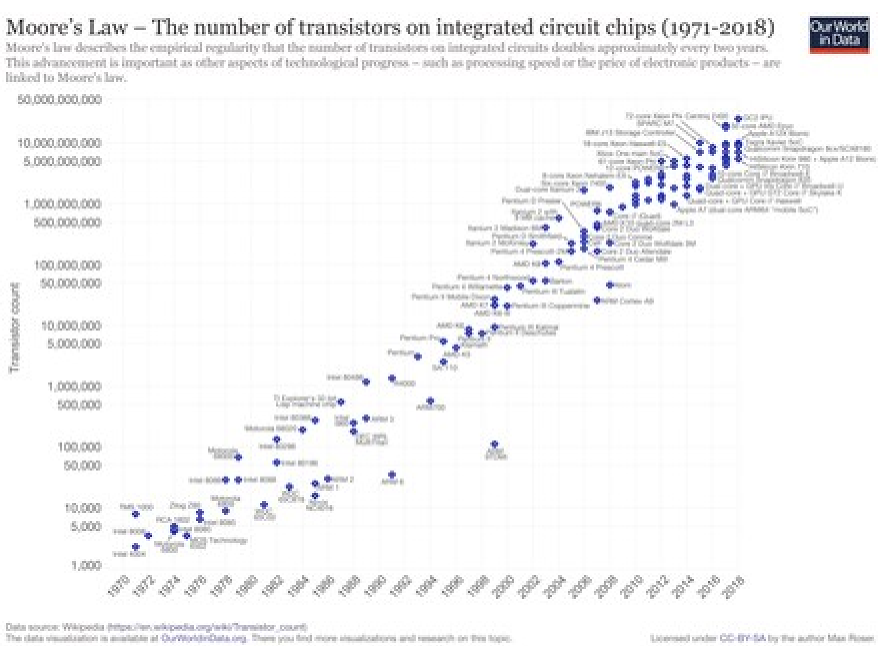
An old hard-drive (5 MB)

Recent Technology (32 GB)

Semiconductors

Conductors Semiconductors Insulators

Semiconductors are a special class of elements having a conductivity between that of a good conductor and that of an insulator.



In 1965, Dr. Gordon E. Moore presented a paper predicting that the transistor count in a single IC chip would double every two years.

How Semiconductors are used?

Basic unit of a computer

Switch
Not mechanically controlled,
Electricity is used

How Semiconductors are used?

We need circuit elements that will allow current in only one direction

Vacuum tubes are used in old times.

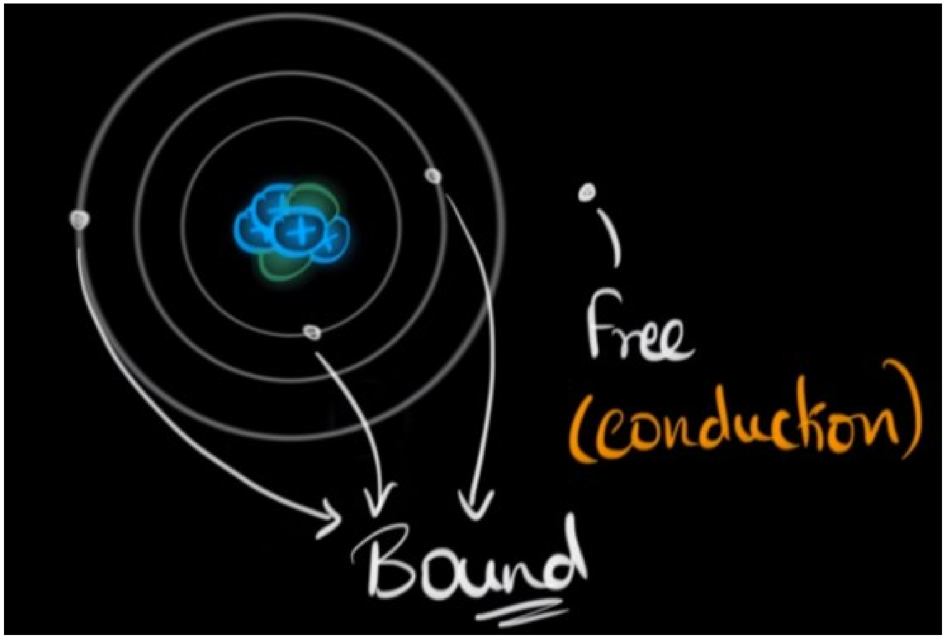
- You need to heat them up for working.
- Very large size.
- Consume huge power.
- Hard to manufacture.

Today we can use semiconductor technology for implementing switches.

731 million transistors in a package

FIG. 1.2
Intel® Core™ i7 Extreme Edition Processor.

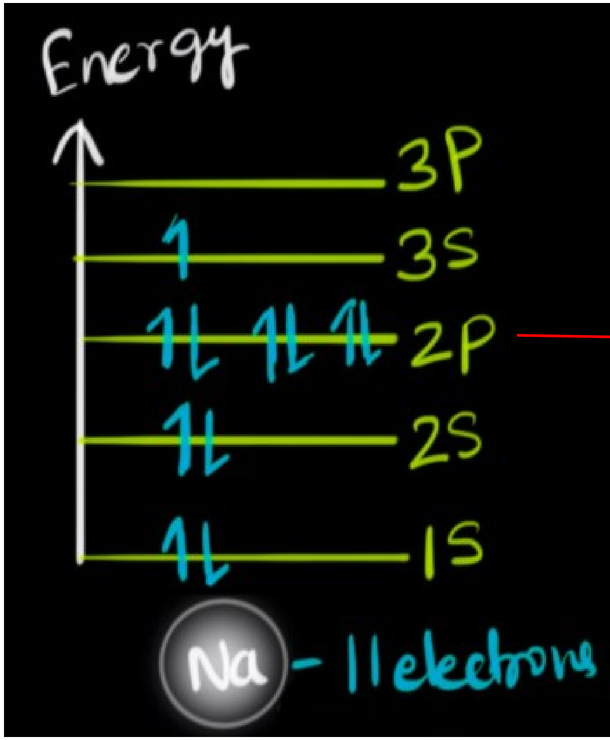
Semiconductor Material Properties



Materials	Free e^-
CONDUCT	A LOT
SEMICOND	V few
INSULAT	$\simeq 0$

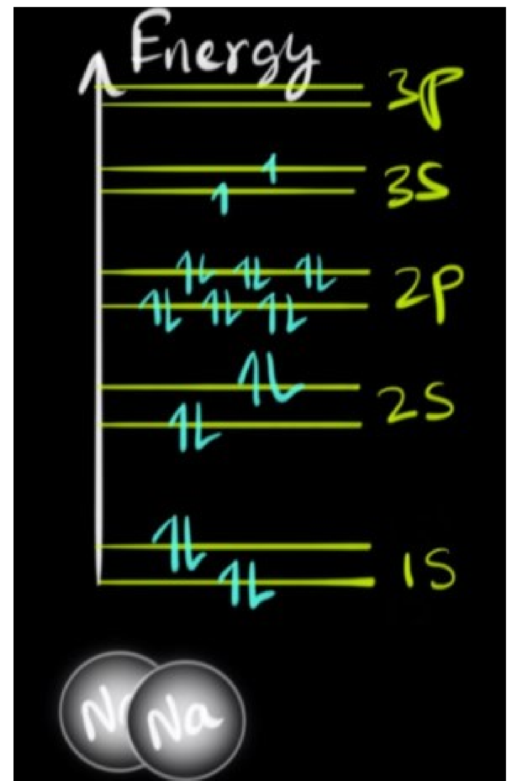
In order to understand semiconductor material behaviour, we need to look at energy levels of electrons

Energy Levels



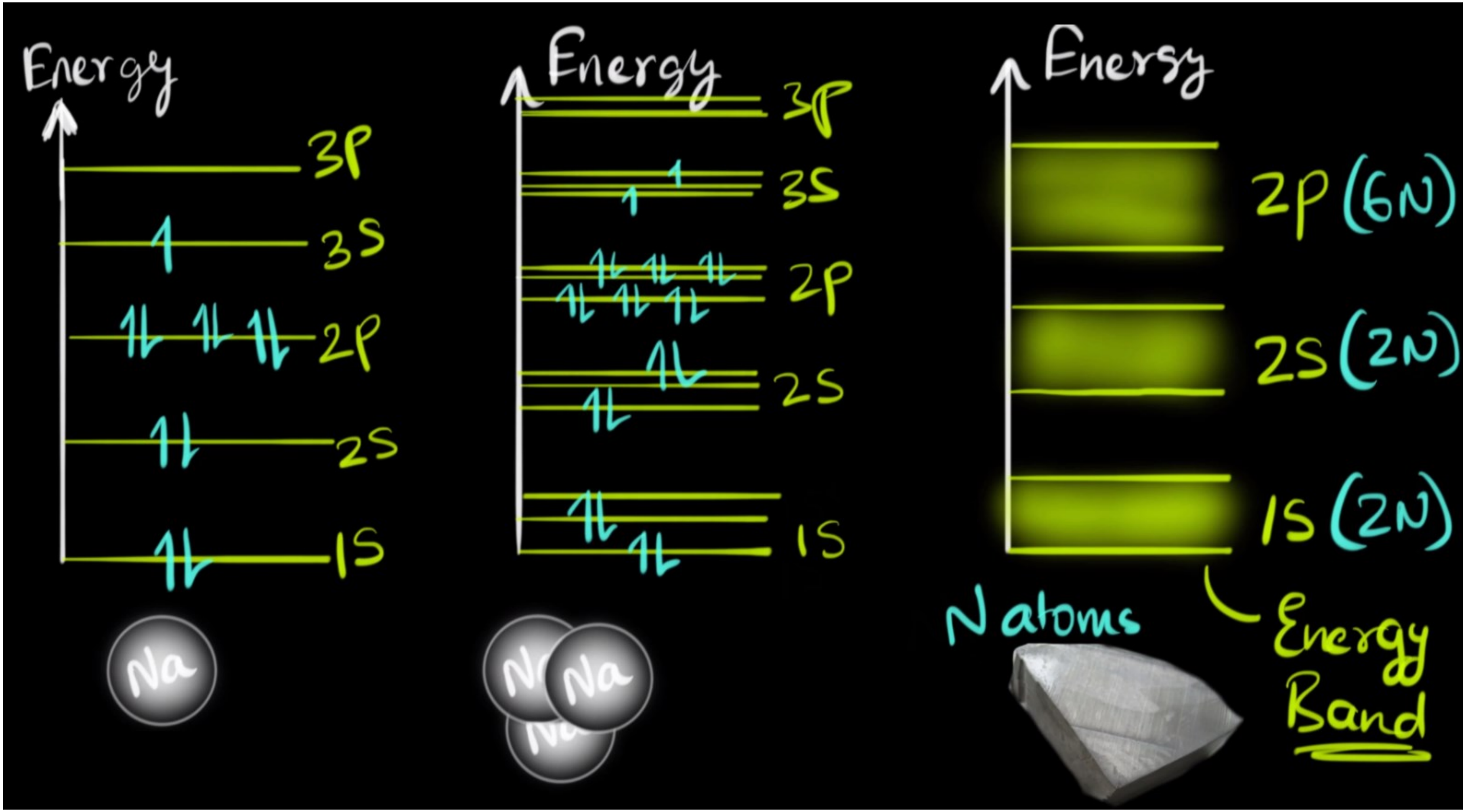
The Pauli Exclusion Principle states that, no two electrons can have identical energies.

3 different orbitals, not same energy

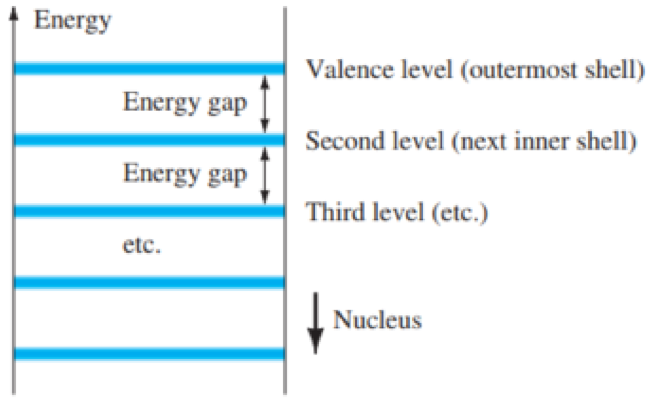


If we have two atoms

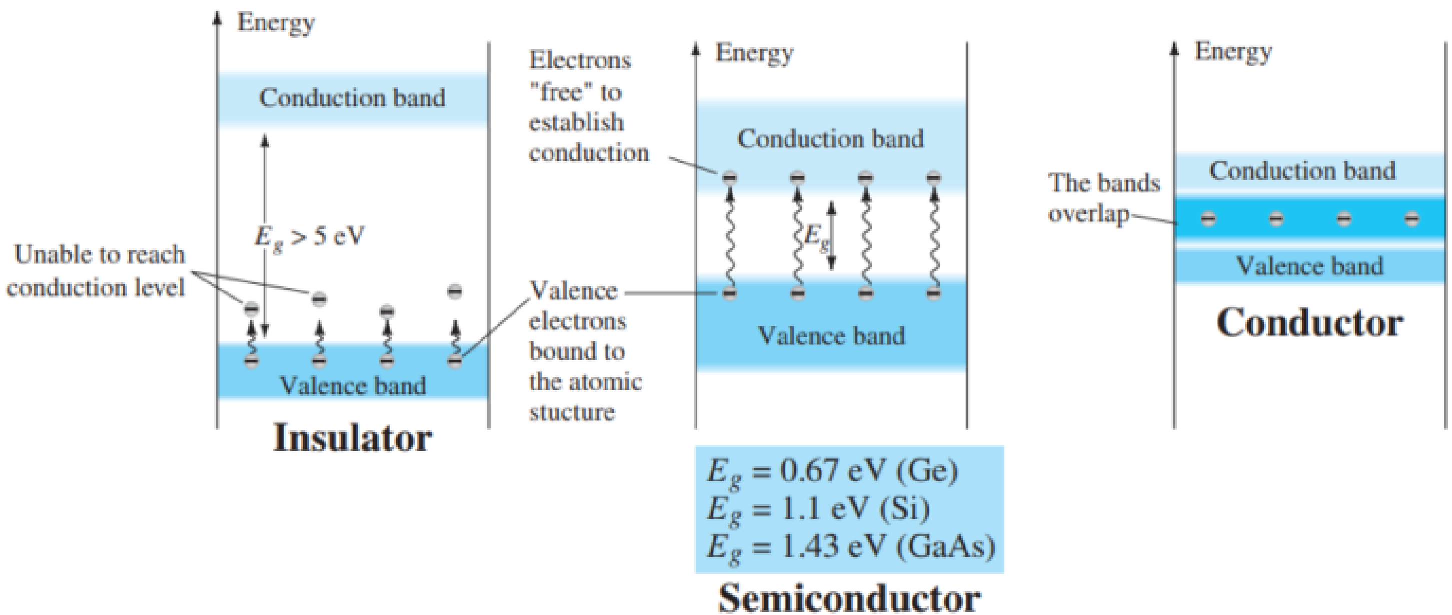
Energy Levels



Conductors, Insulators and Semiconductors



(a)



(b)

Intrinsic Semiconductors

The term intrinsic is applied to any semiconductor material that has been carefully refined to reduce the number of impurities to a very low level—essentially as pure as can be made available through modern technology.

- For germanium and silicon there are four electrons in the outermost shell, which are referred to as valence electrons.
- Gallium has three valence electrons and arsenic has five valence electrons.
- Atoms that have four valence electrons are called tetravalent, those with three are called trivalent, and those with five are called pentavalent.
- The term valence is used to indicate that the potential (ionization potential) required to remove any one of these electrons from the atomic structure is significantly lower than that required for any other electron in the structure.

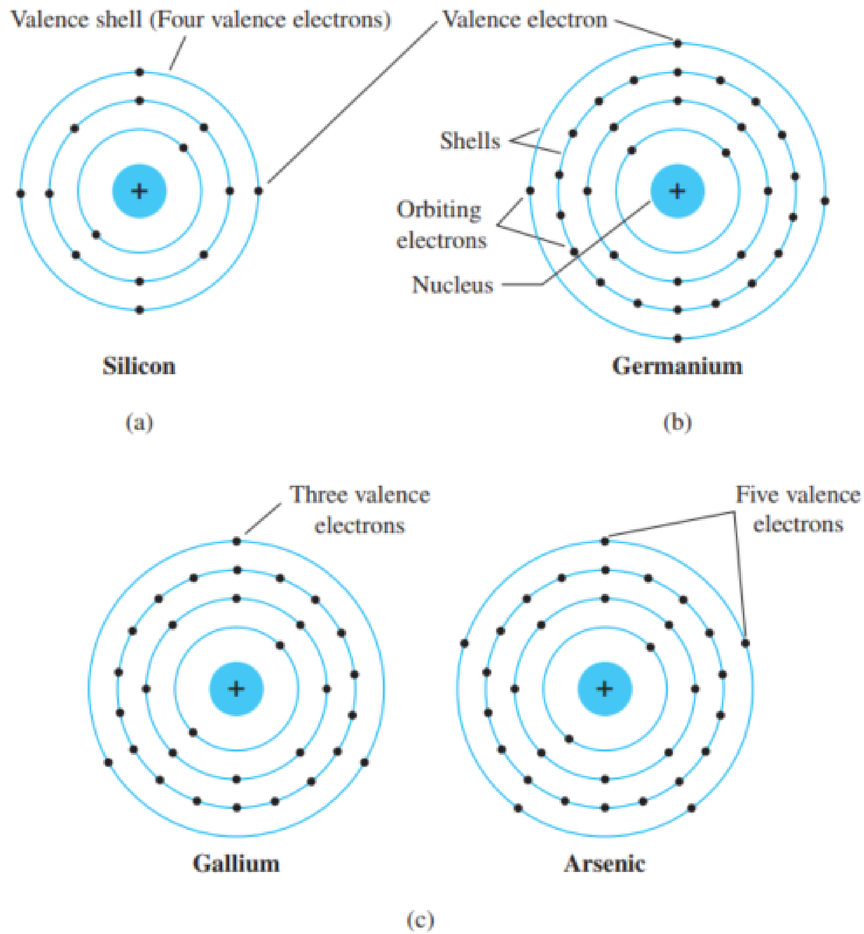


FIG. 1.3
Atomic structure of (a) silicon; (b) germanium; and (c) gallium and arsenic.

Intrinsic Semiconductors

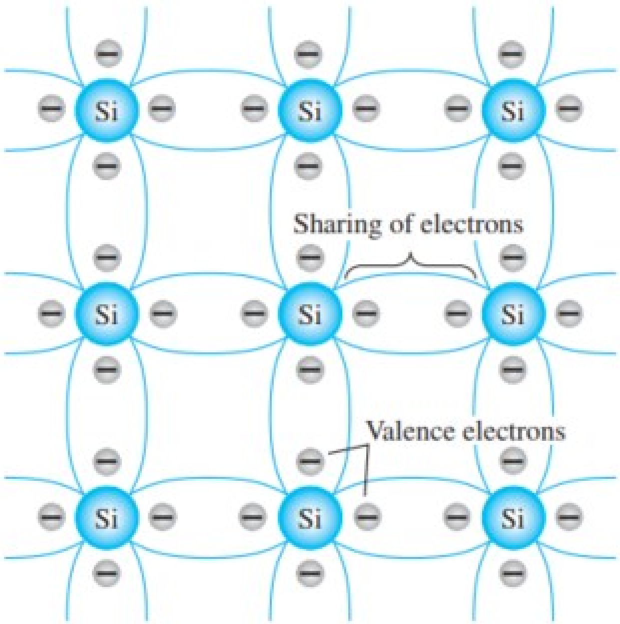
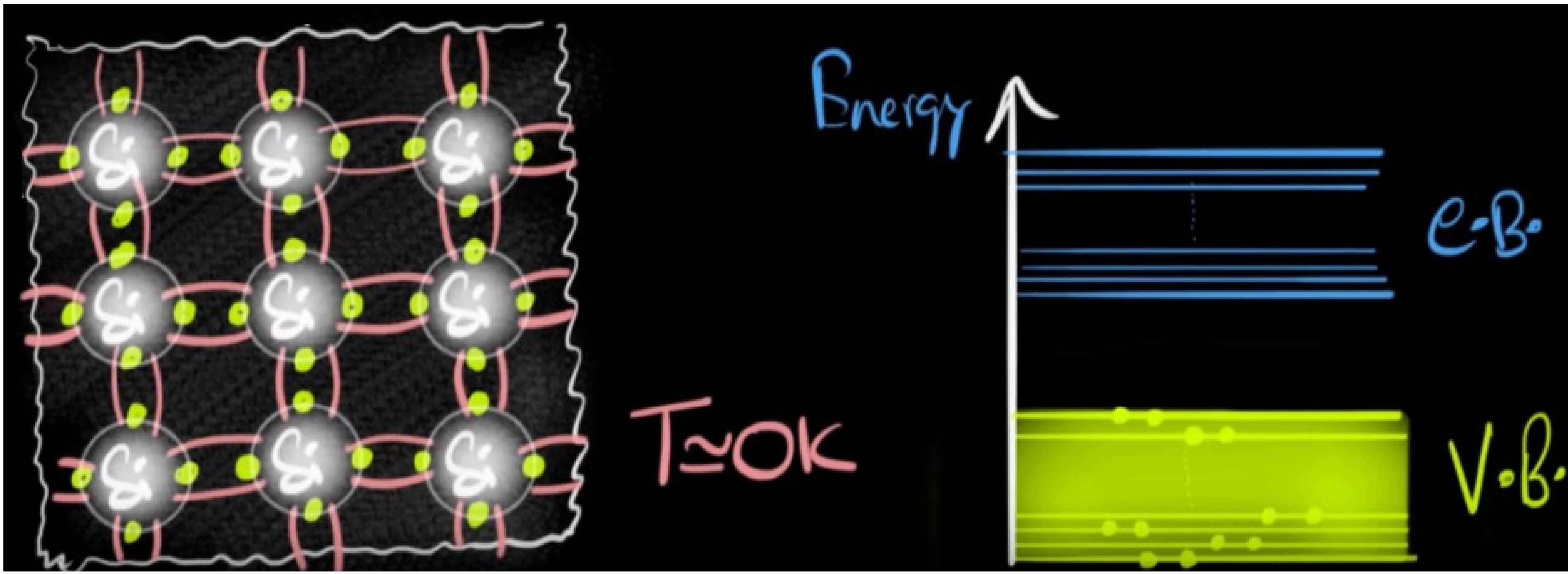


FIG. 1.4
Covalent bonding of the silicon atom.

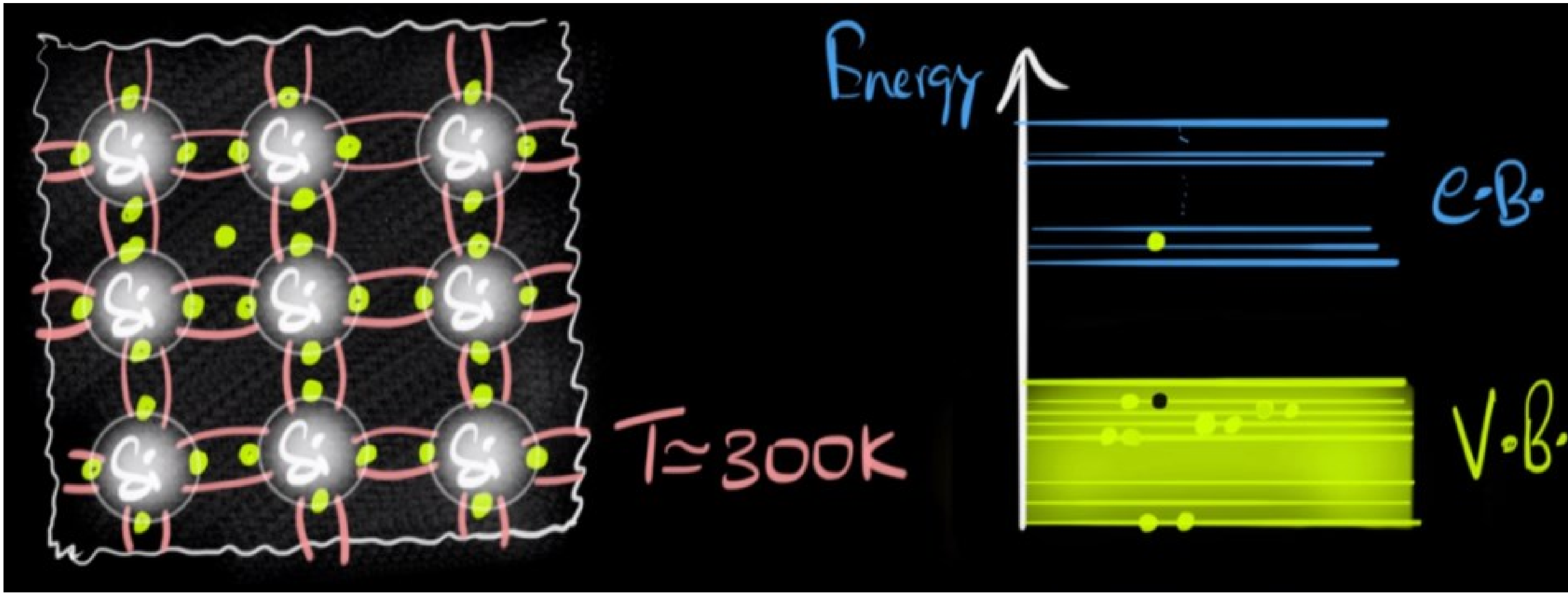
- In a pure silicon crystal the four valence electrons of one atom form a bonding arrangement with four adjoining atoms.
- This bonding of atoms, strengthened by the sharing of electrons, is called covalent bonding.

Intrinsic Semiconductor, Behaviour at 0 Kelvin



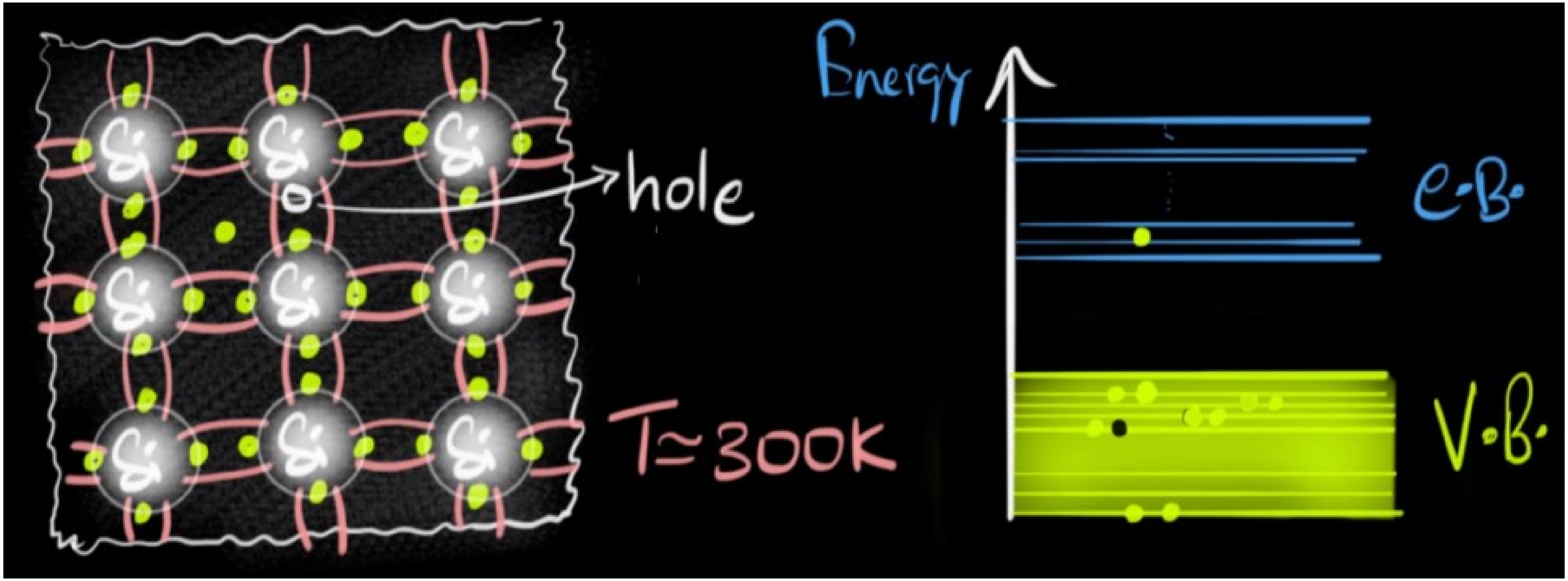
Acts like an insulator, no free electrons

Intrinsic Semiconductor, Behaviour at 300 Kelvin



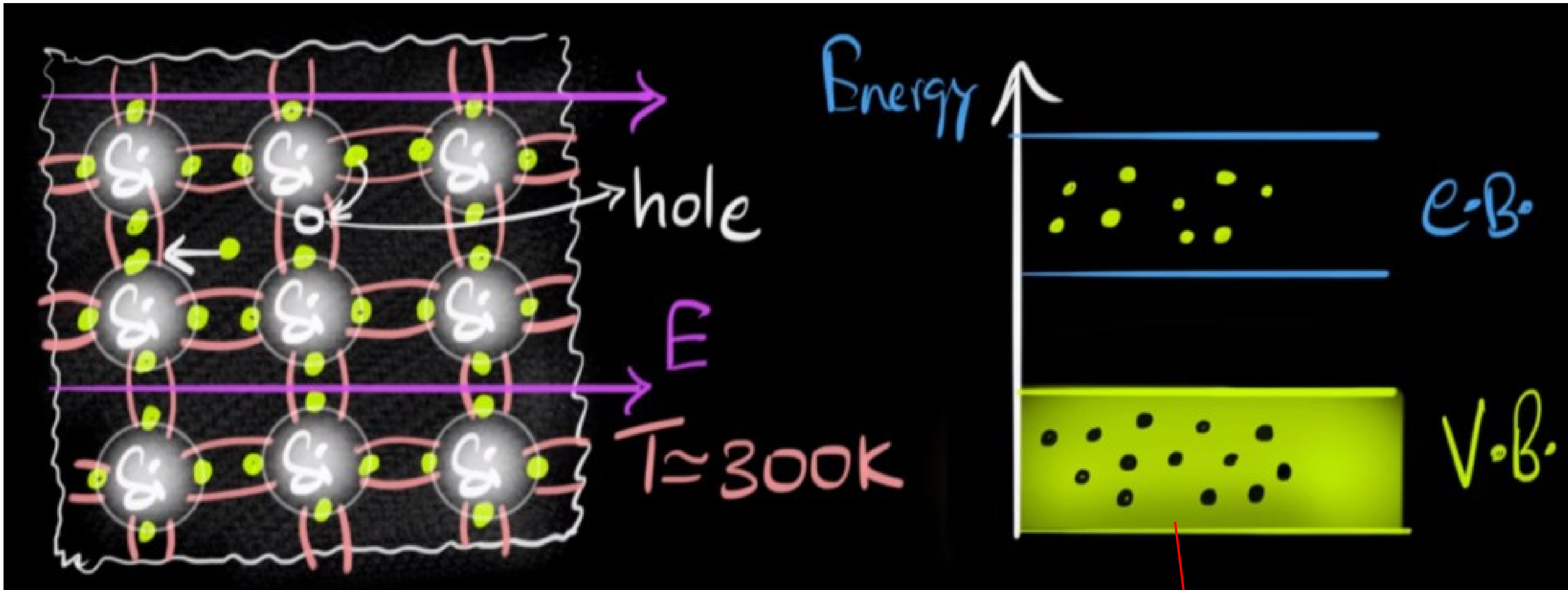
Electrons can jump to conduction band as a result of heat.
A single electron example is given above.

Intrinsic Semiconductor, Behaviour at 300 Kelvin



- Then we will have freely movable holes which are the second charge carrier.
- Both electrons and holes are responsible from the current. (Holes are independently moving, not attracting electrons)

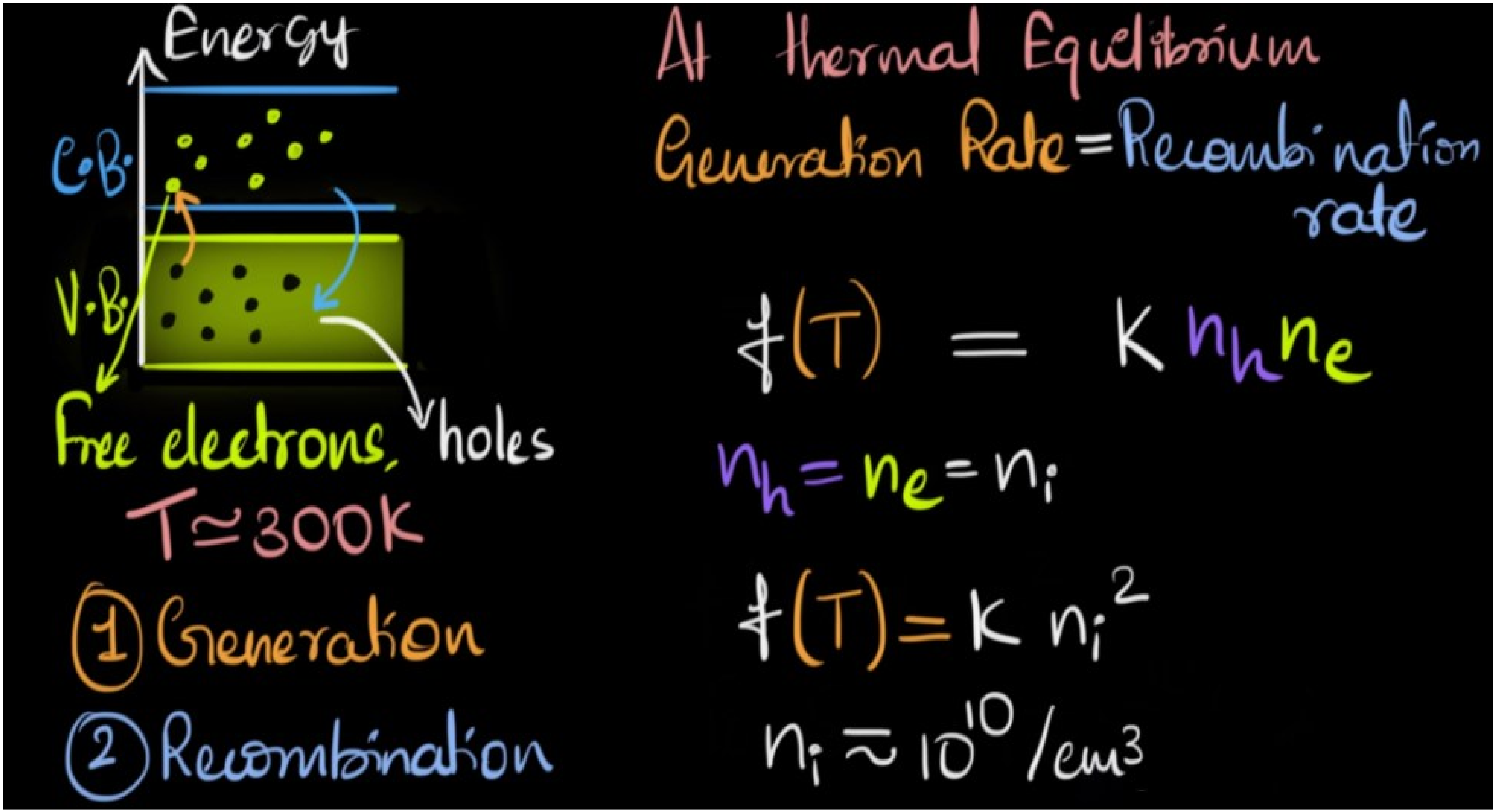
Intrinsic Semiconductor, Behaviour at 300 Kelvin



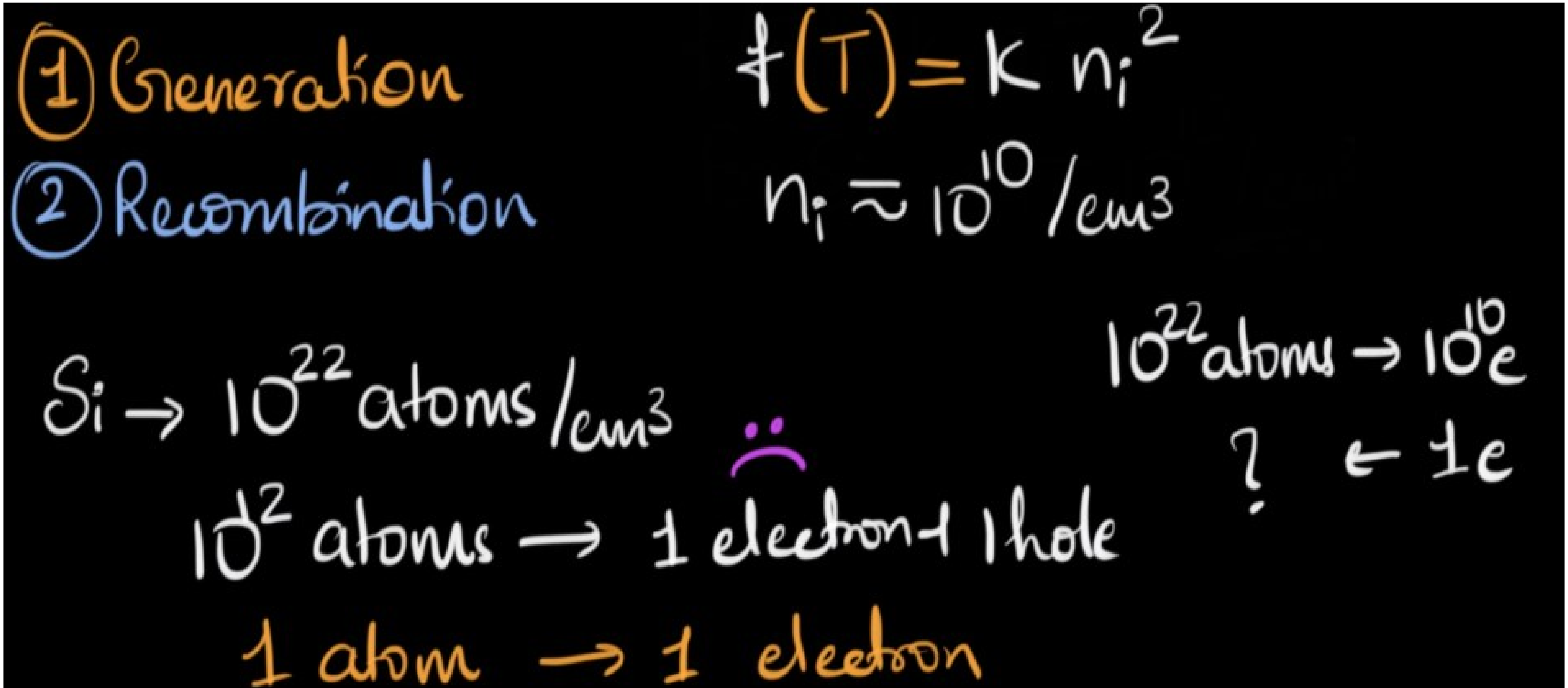
We can think that band region is continuous

Under the electric field (E), Electrons (negative carriers) and holes (positive carriers) will move to opposite directions.

Generation and Recombination In Semiconductors



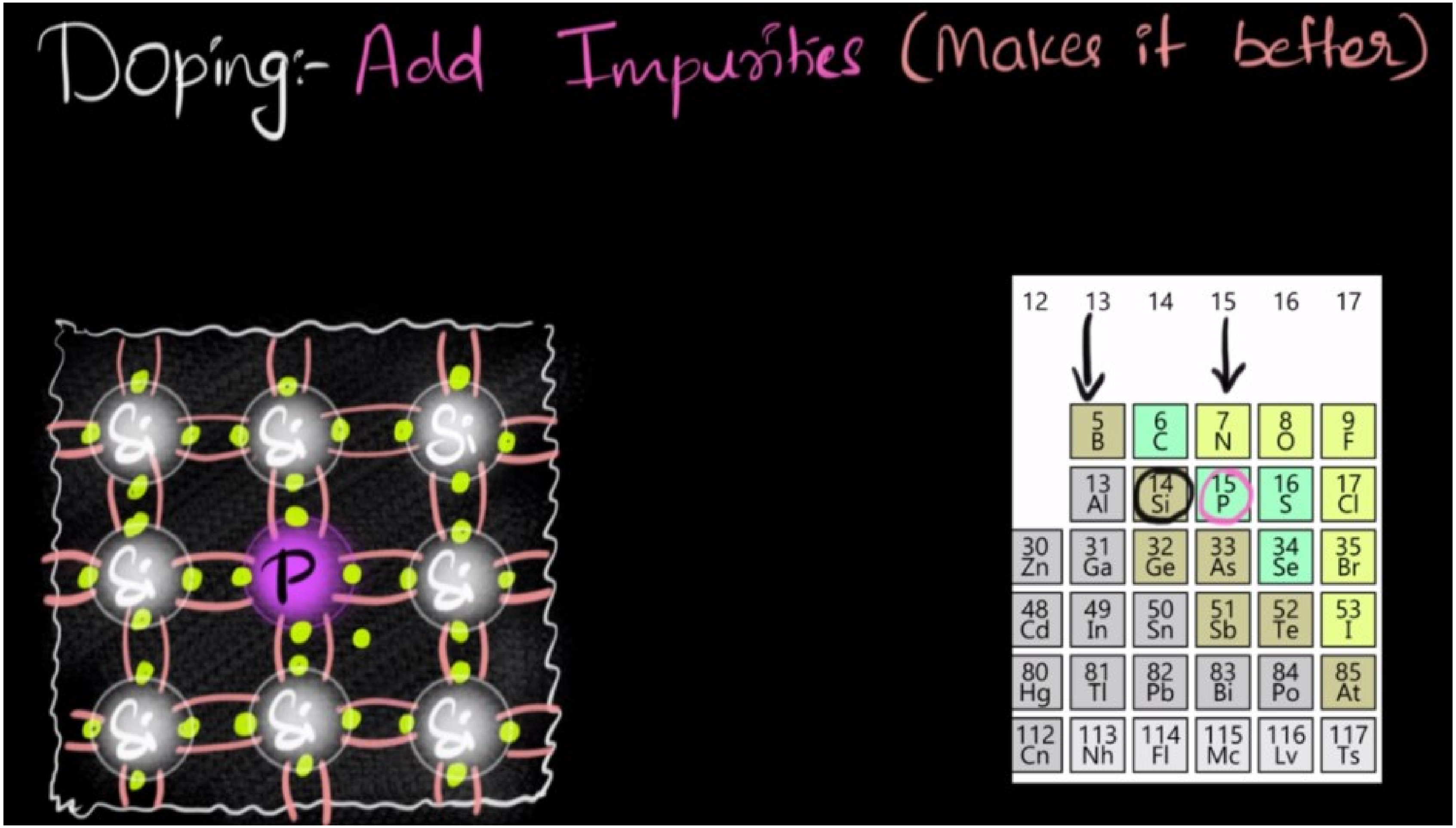
Generation and Recombination In Semiconductors



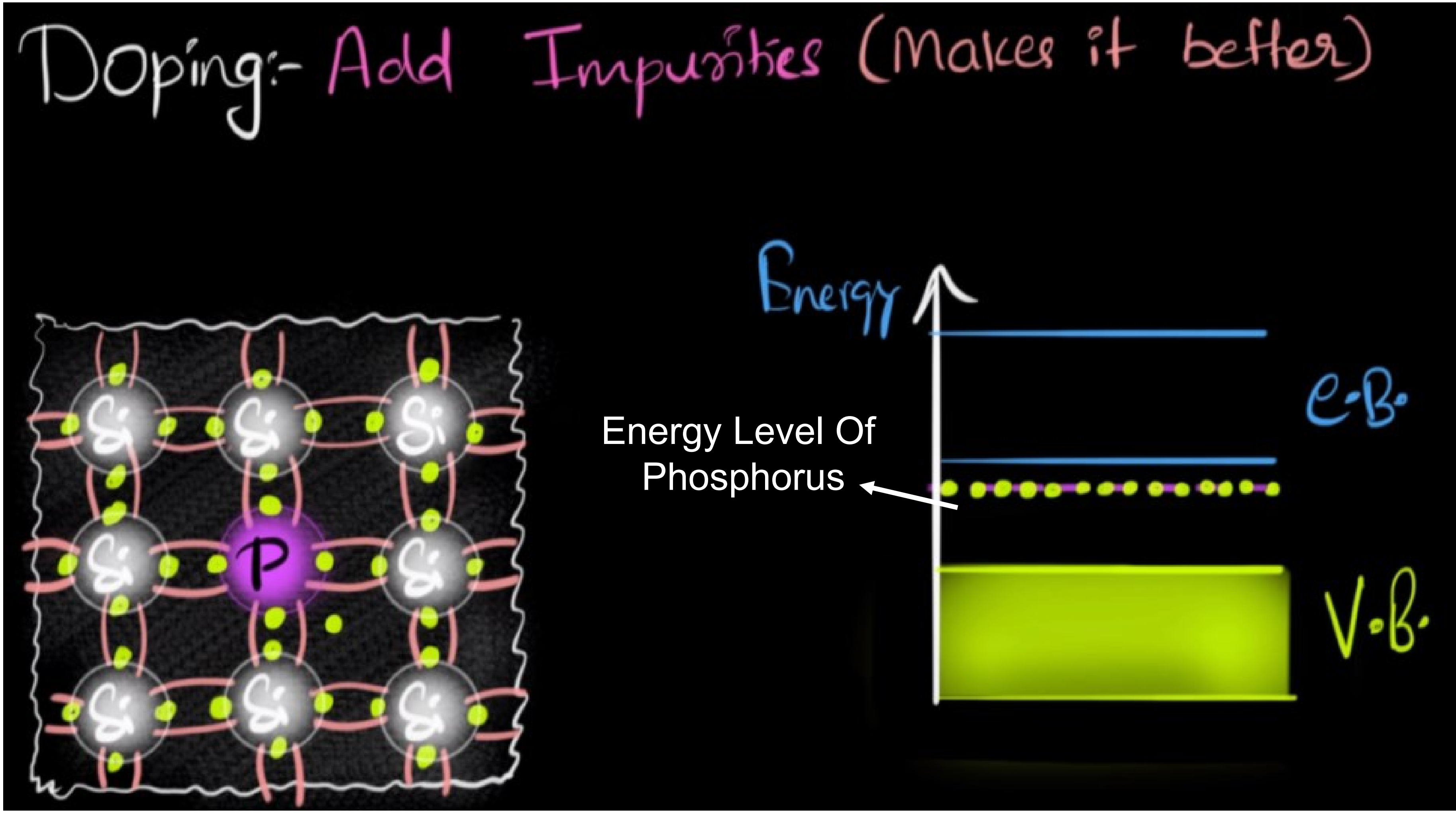
In Copper

We need doping elements

Extrinsic semiconductors N-type

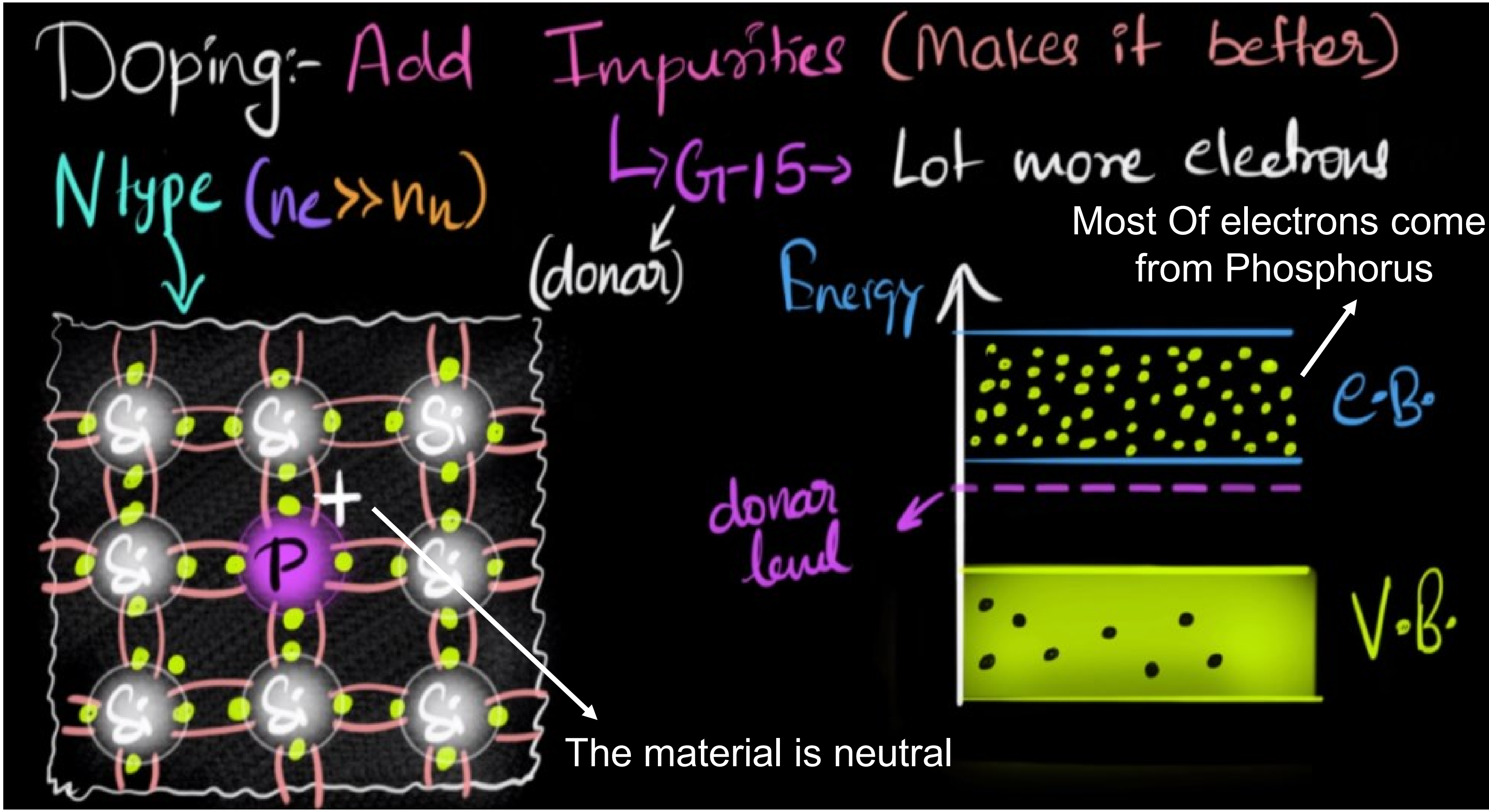


Extrinsic semiconductors N-type



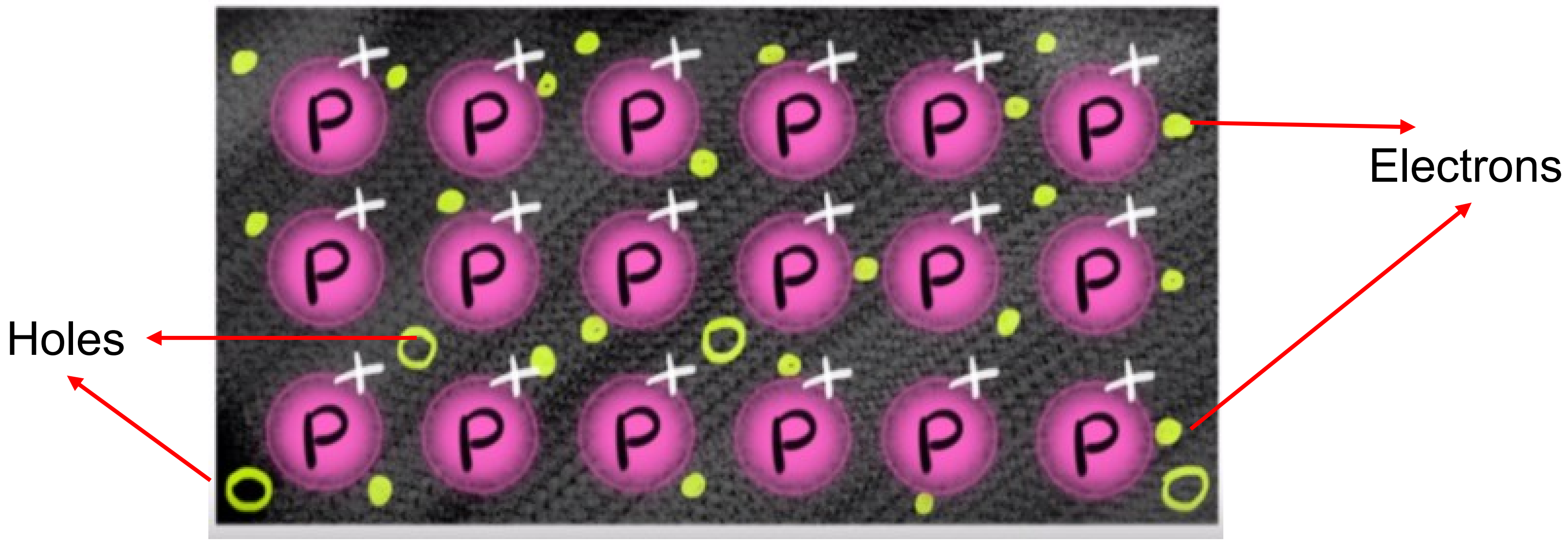
At 0 Kelvin.

Extrinsic semiconductors N-type



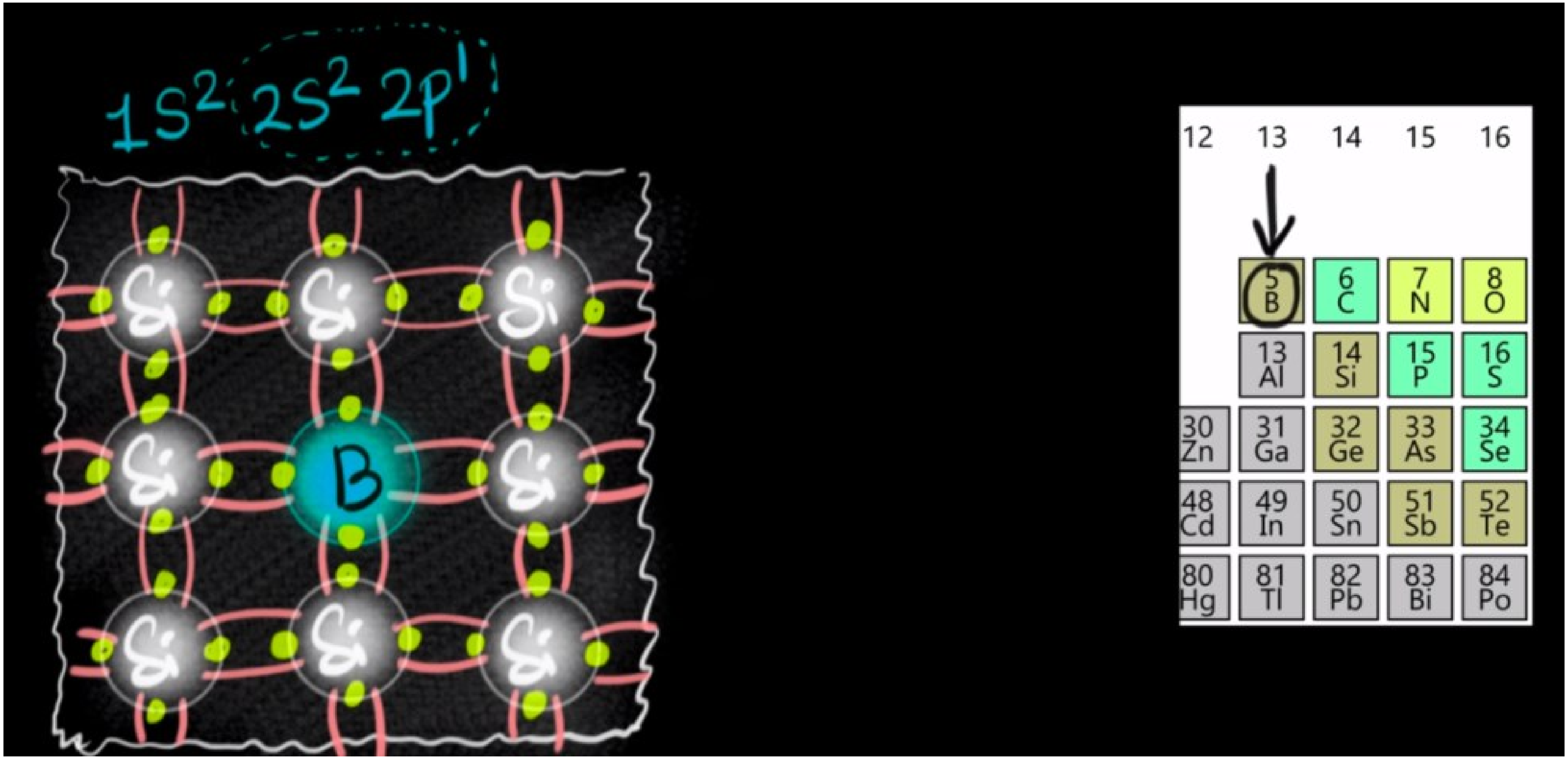
Room Temperature.

Extrinsic semiconductors N-type

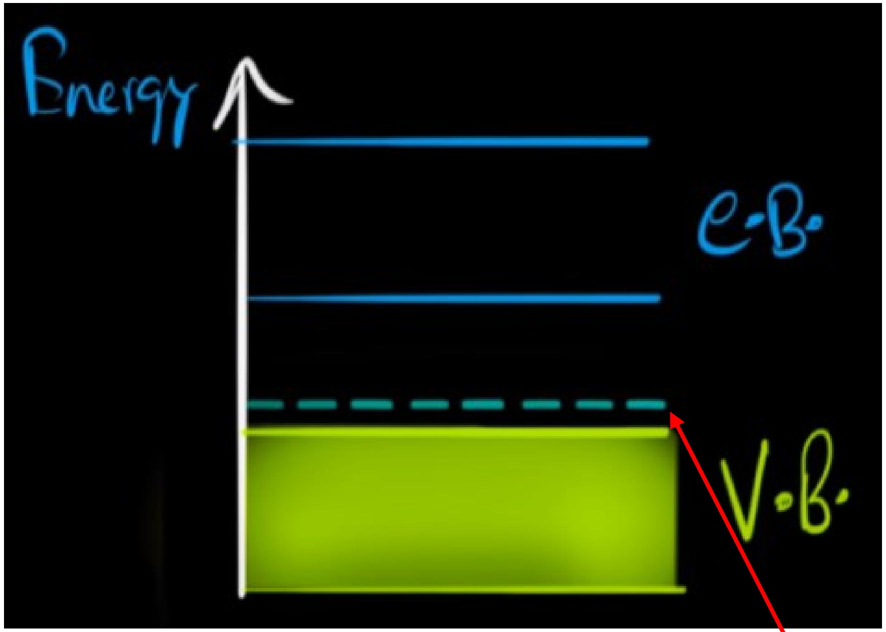


Still two way conductor
Majority carriers – electrons
Minority carriers - holes

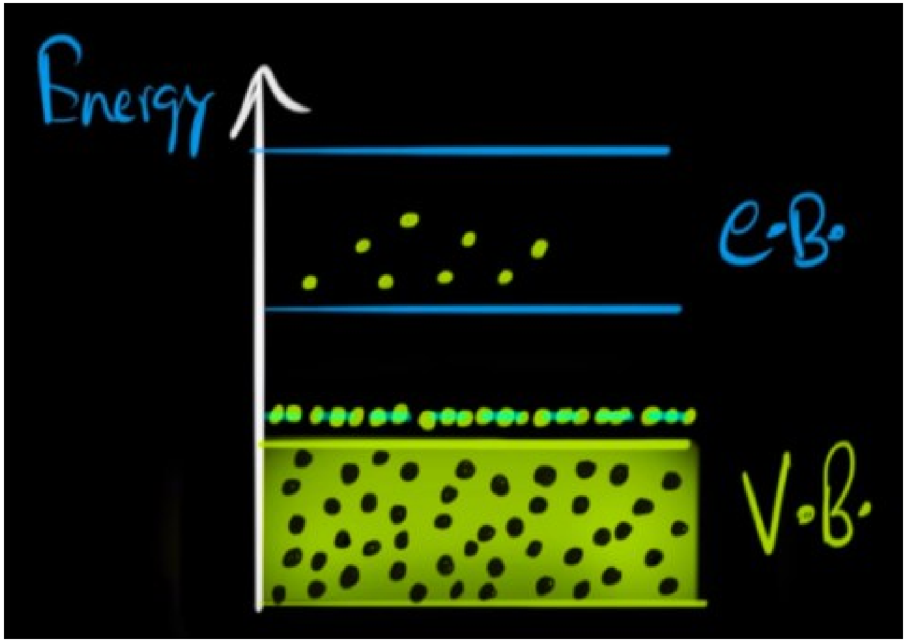
Extrinsic semiconductors P-type



Extrinsic semiconductors P-type



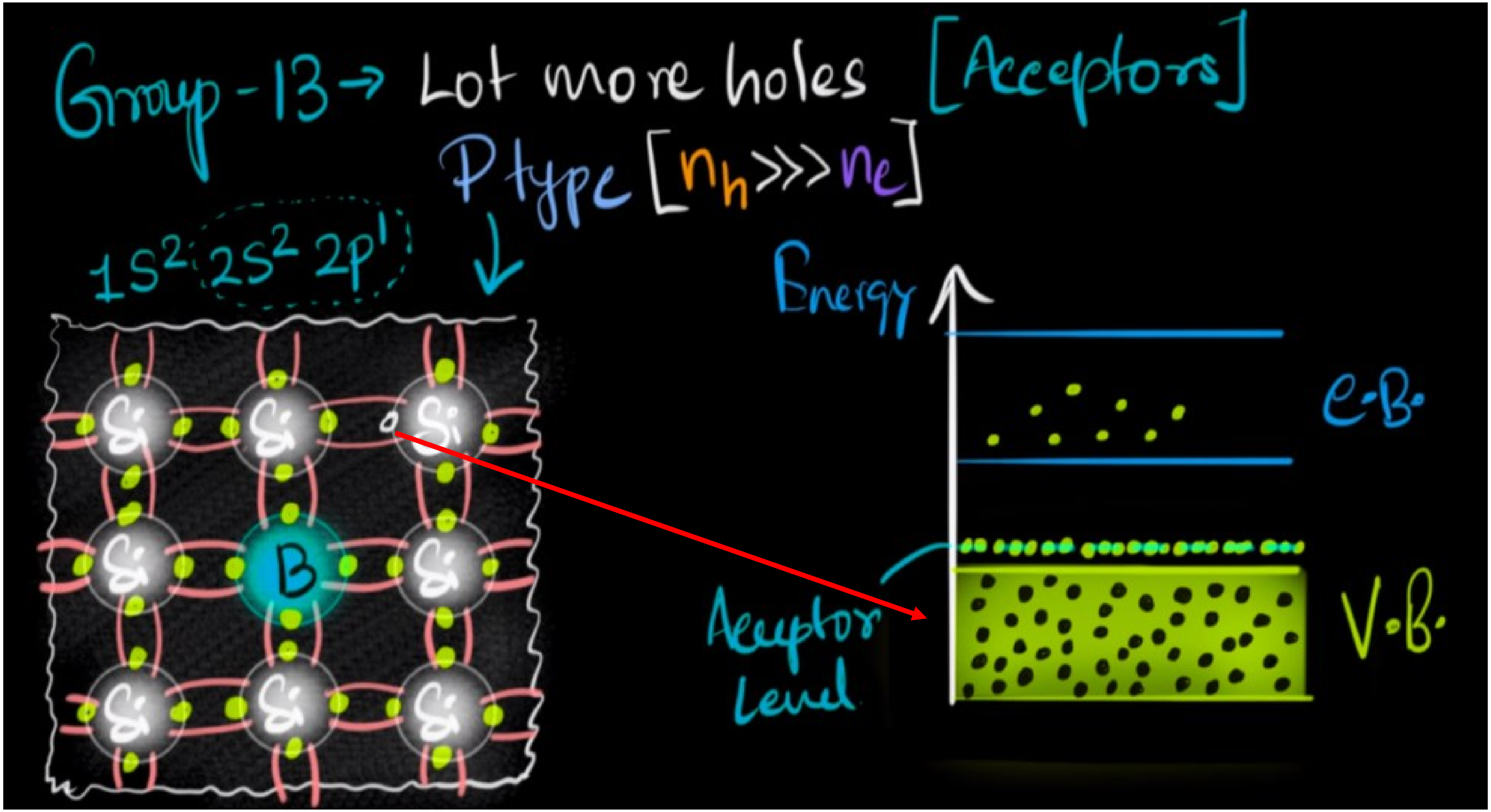
At 0 Kelvin.



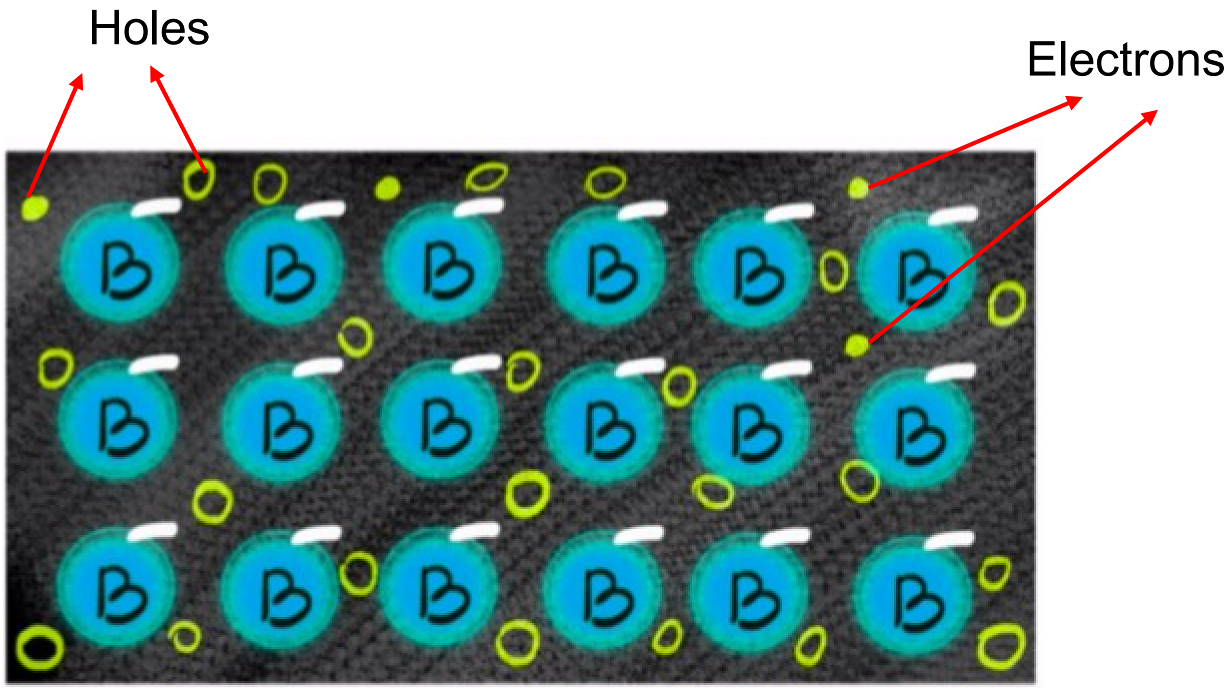
At 300 Kelvin.

For electrons, it is easier to
jump to this energy level of boron

Extrinsic semiconductors P-type

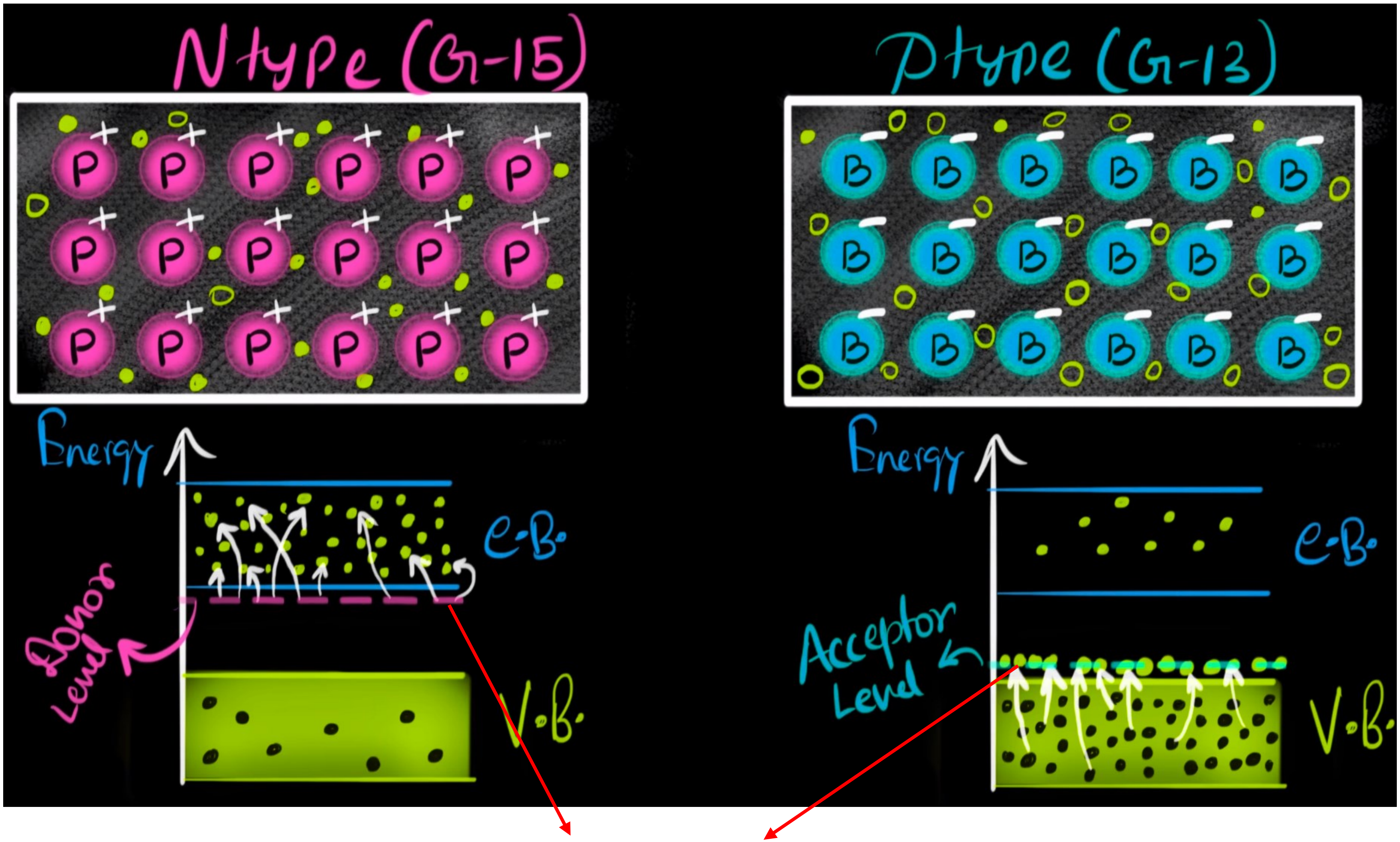


Extrinsic semiconductors P-type



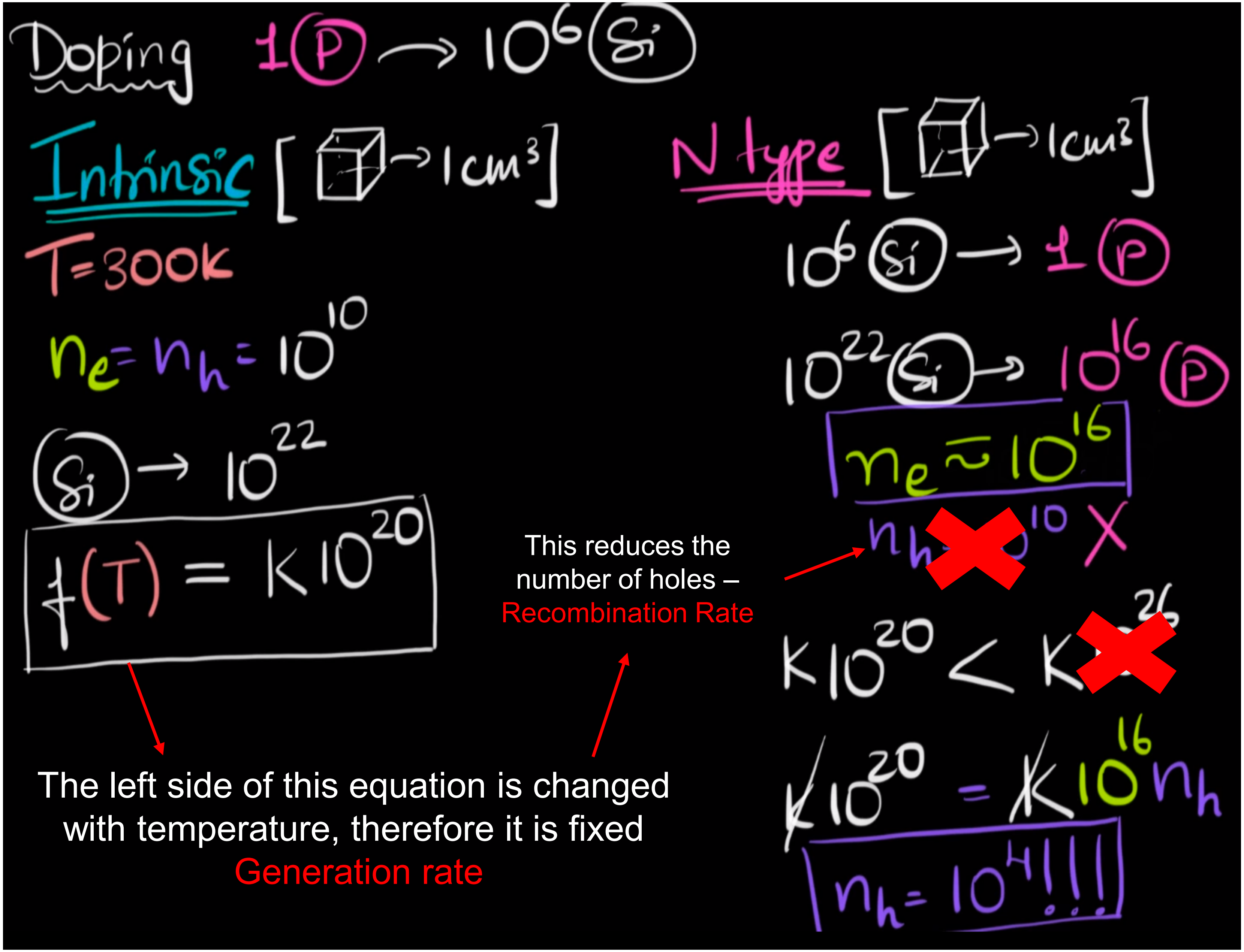
Still two way conductor
Majority carriers – holes
Minority carriers - electrons

Minority charge carriers in extrinsic semiconductors

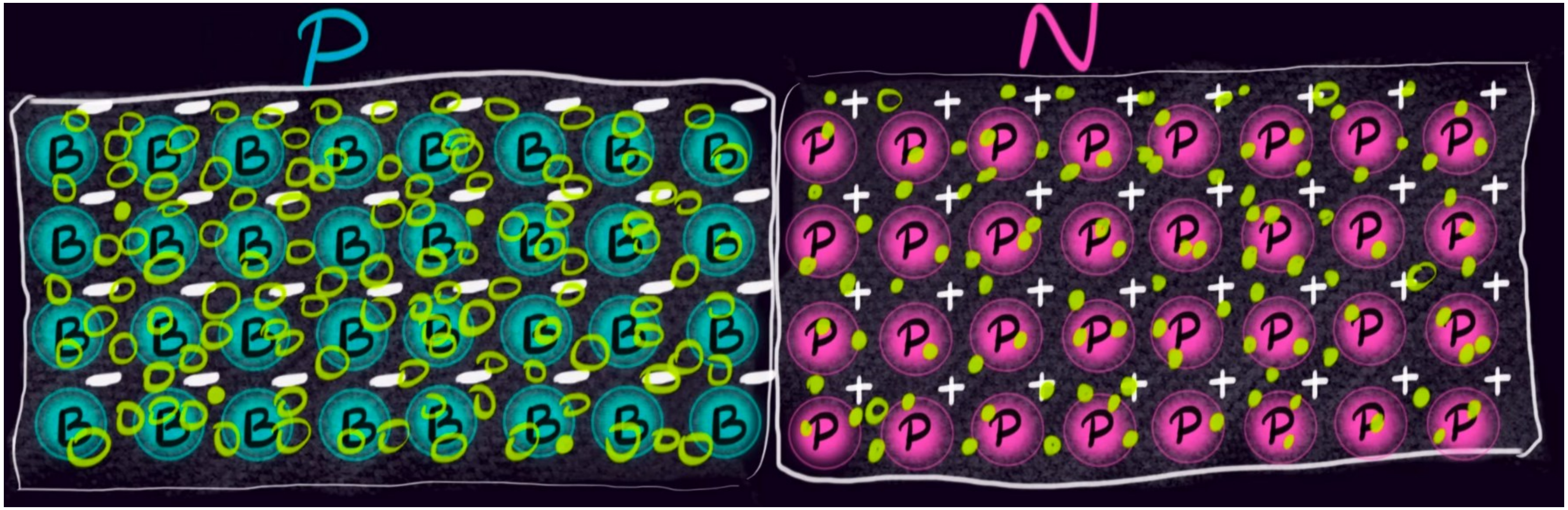


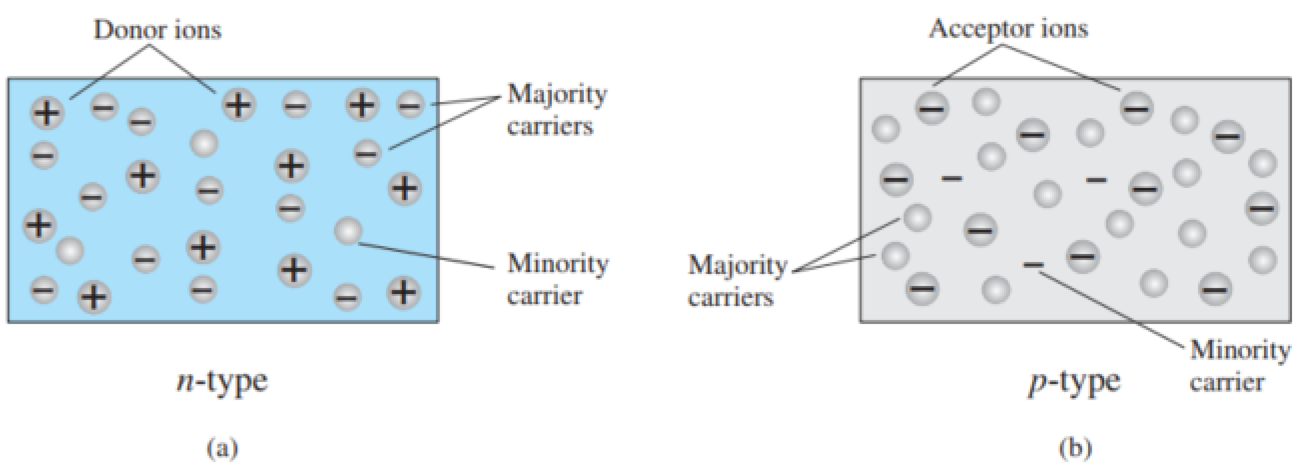
Doping Concentration is very low, therefore we use energy levels instead of bands for donors and acceptors.

Minority charge carriers in extrinsic semiconductors



PN Junction





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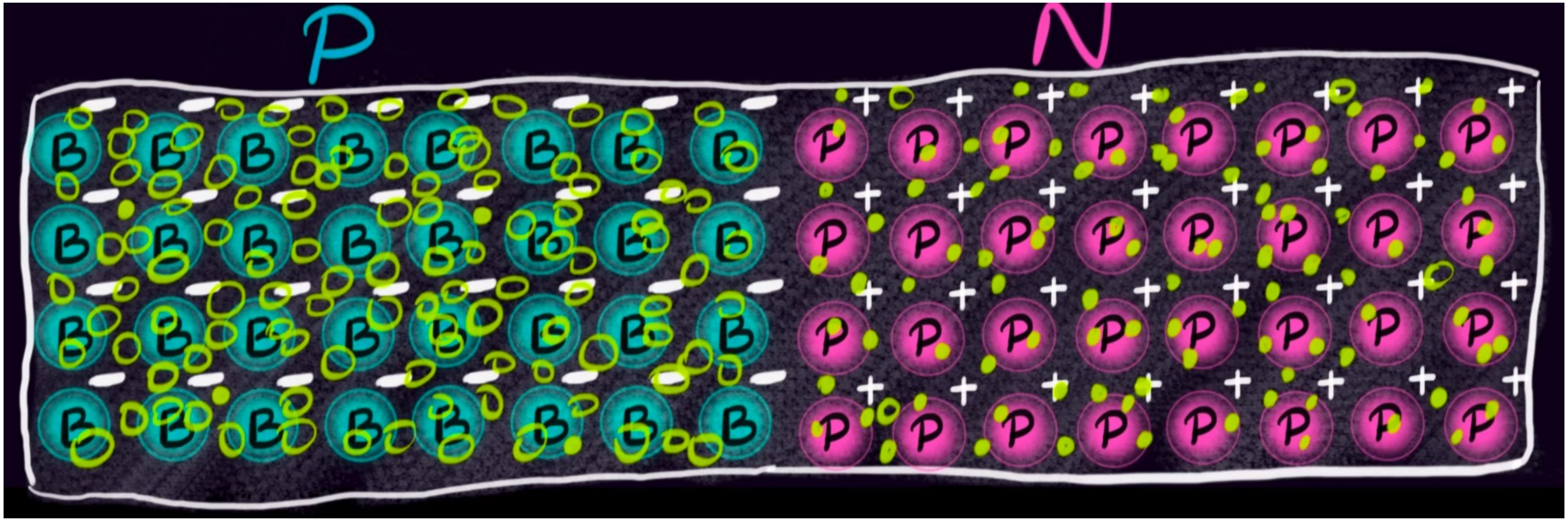
PN Junction

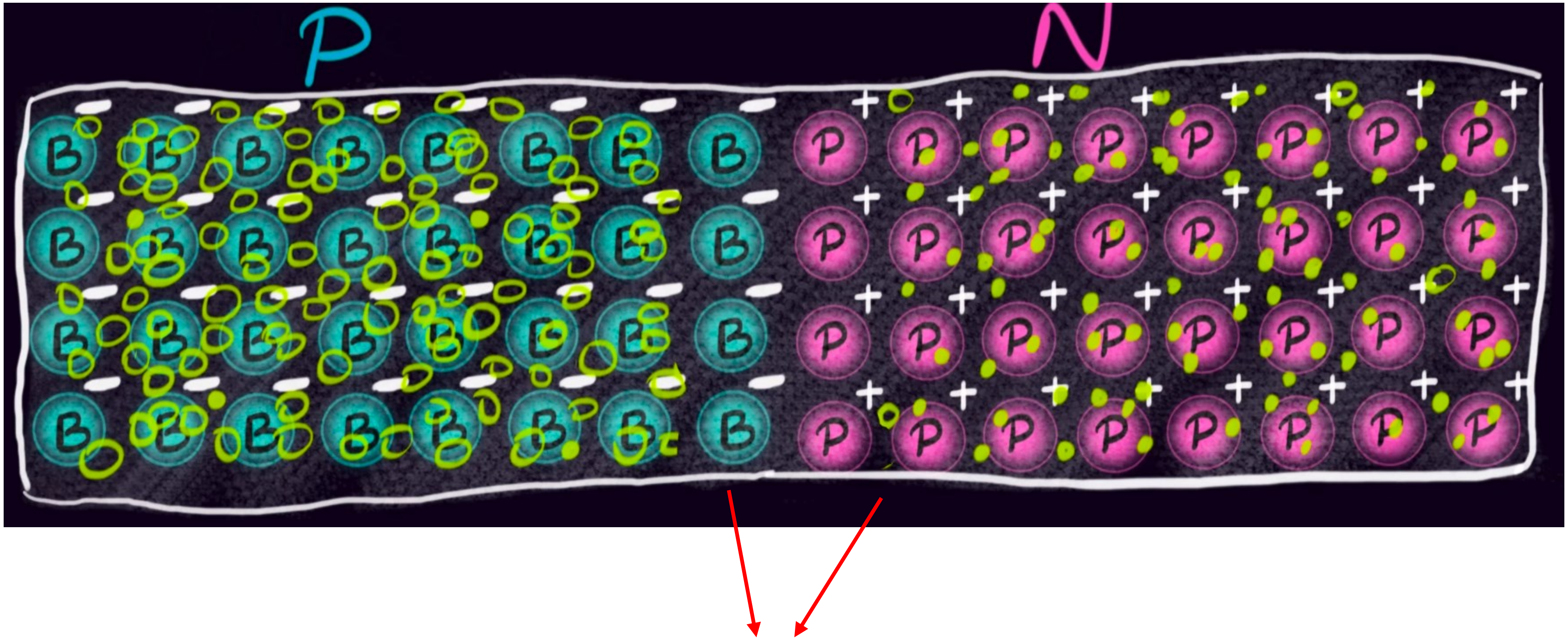


Combine the P and N type material in a single crystal

- In the centre (at junction) of crystal, holes and electrons will diffuse randomly

- the electrons and the holes in the region of the junction will combine, resulting in a lack of free carriers in the region near the junction
- the only particles displayed in this region are the positive and the negative ions remaining once the free carriers have been absorbed

PN Junction

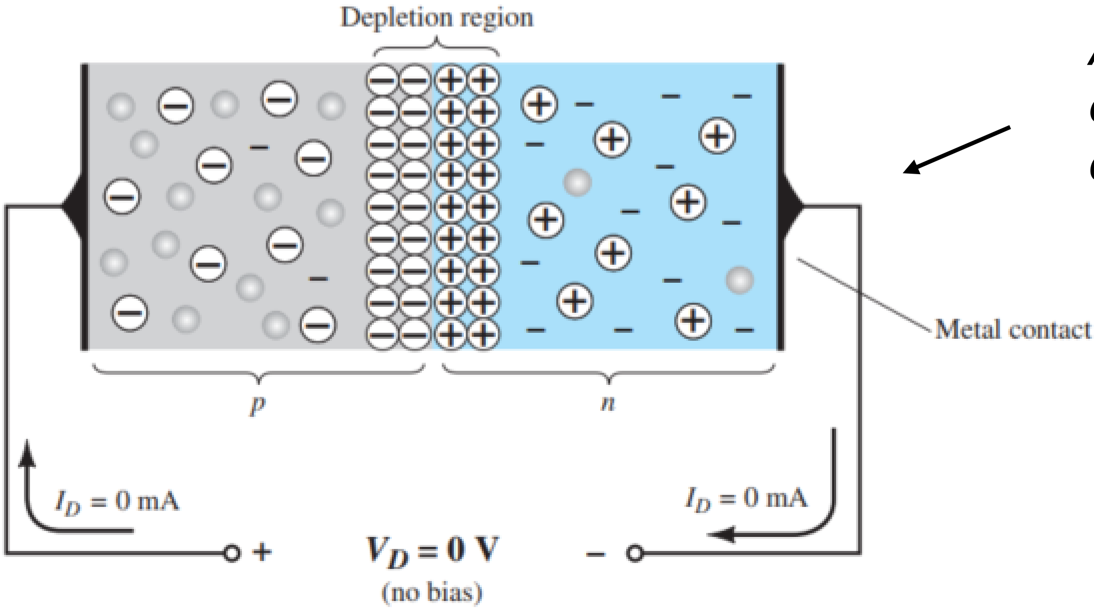


Depletion Region = region of uncovered positive and negative ions

- If leads are connected to the ends of each material, a *two-terminal device* results.
- Three options then become available: *no bias*, *forward bias*, and *reverse bias*.
- The term *bias* refers to the application of an external voltage across the two terminals of the device to extract a response.
- In the no-bias situation there is no external voltage applied.

PN Junction

Boylestad, 11 th edition



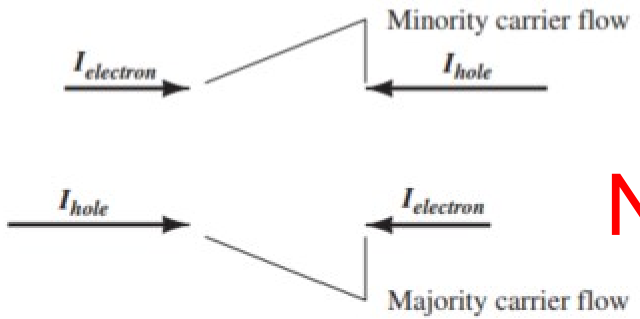
A p–n junction with no external bias, an internal distribution of charge

- Under no-bias conditions, the negative and positive ions located in the depletion region will stop the transfer of majority carriers, but not all of them.
- Any minority carriers of the *n*-type material that find themselves in the depletion region will pass directly into the *p*-type material.

PN Junction

- The majority carriers (electrons) of the *n*-type material must overcome the attractive forces of the layer of positive ions in the *n*-type material and the shield of negative ions in the *p*-type material to migrate into the area beyond the depletion region of the *p*-type material.
- However, the number of majority carriers is so large in the *n*-type material that there will invariably be a small number of majority carriers with sufficient kinetic energy to pass through the depletion region into the *p*-type material.
- Again, the same type of discussion can be applied to the majority carriers (holes) of the *p*-type material.

Random movement, minority carriers are sucked into regions

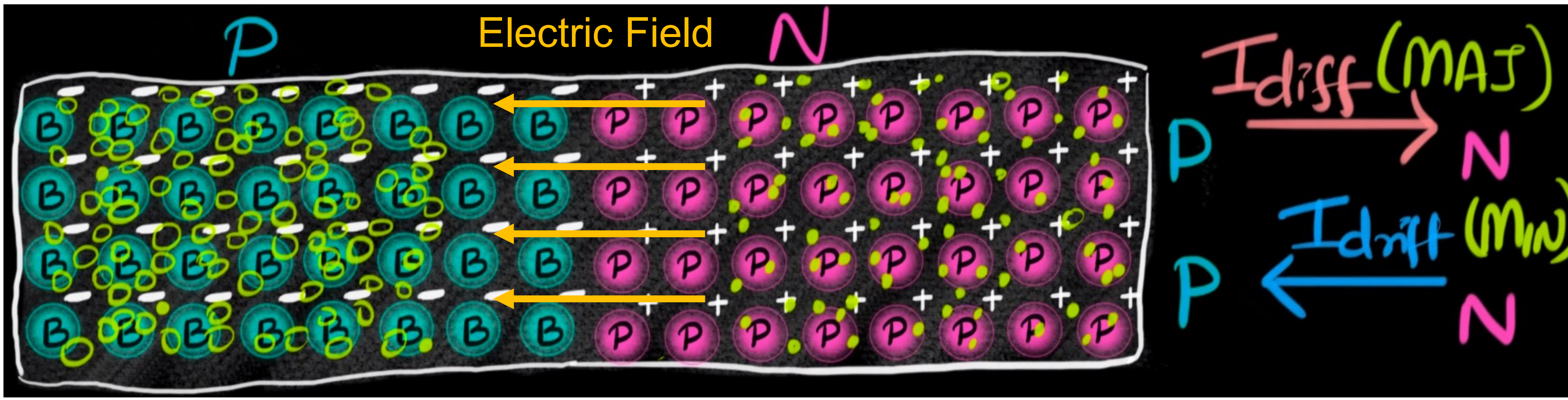


Net Current is Zero

Very few of majority carriers are energetic enough to overcome the repulsion forces of ions

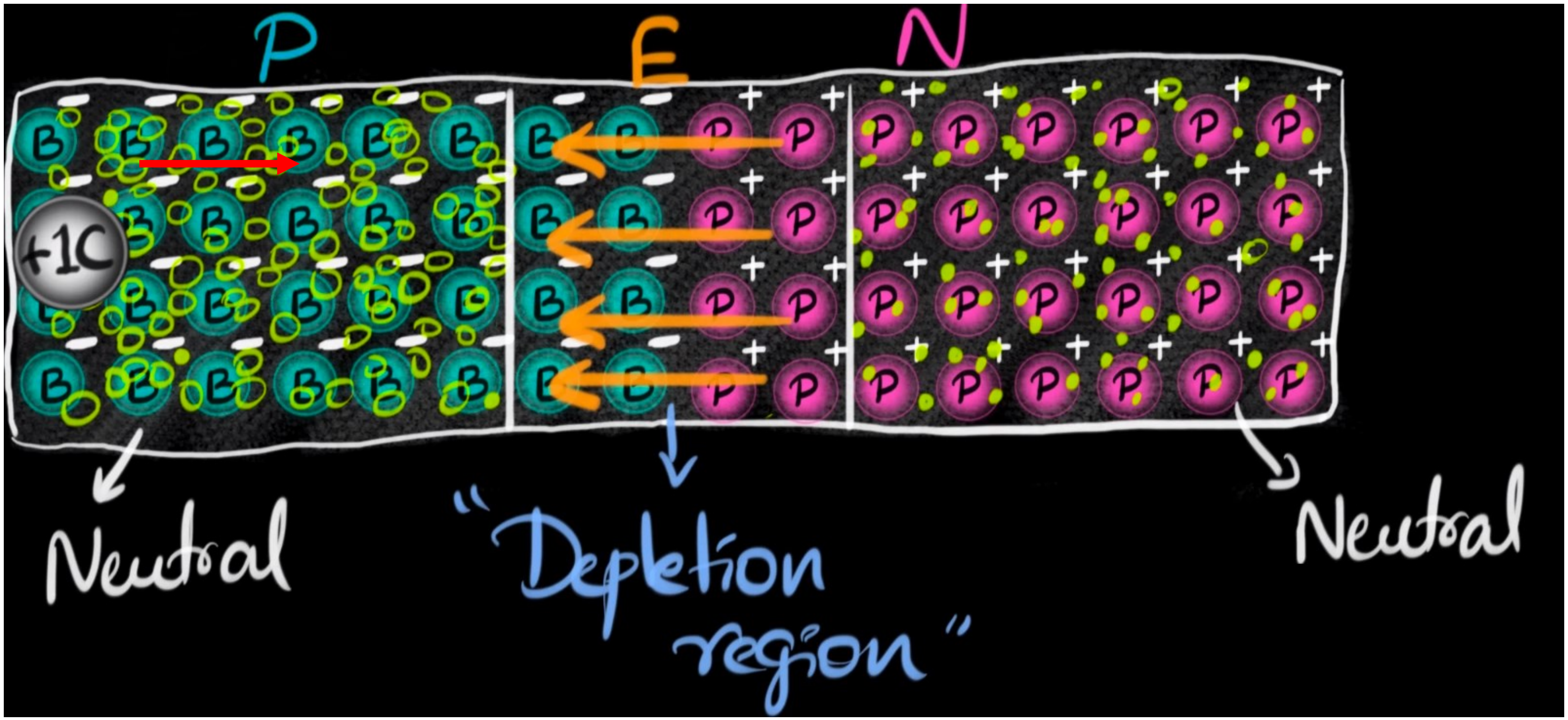
Diffusion and Drift Current

Electric Field causes the drift current

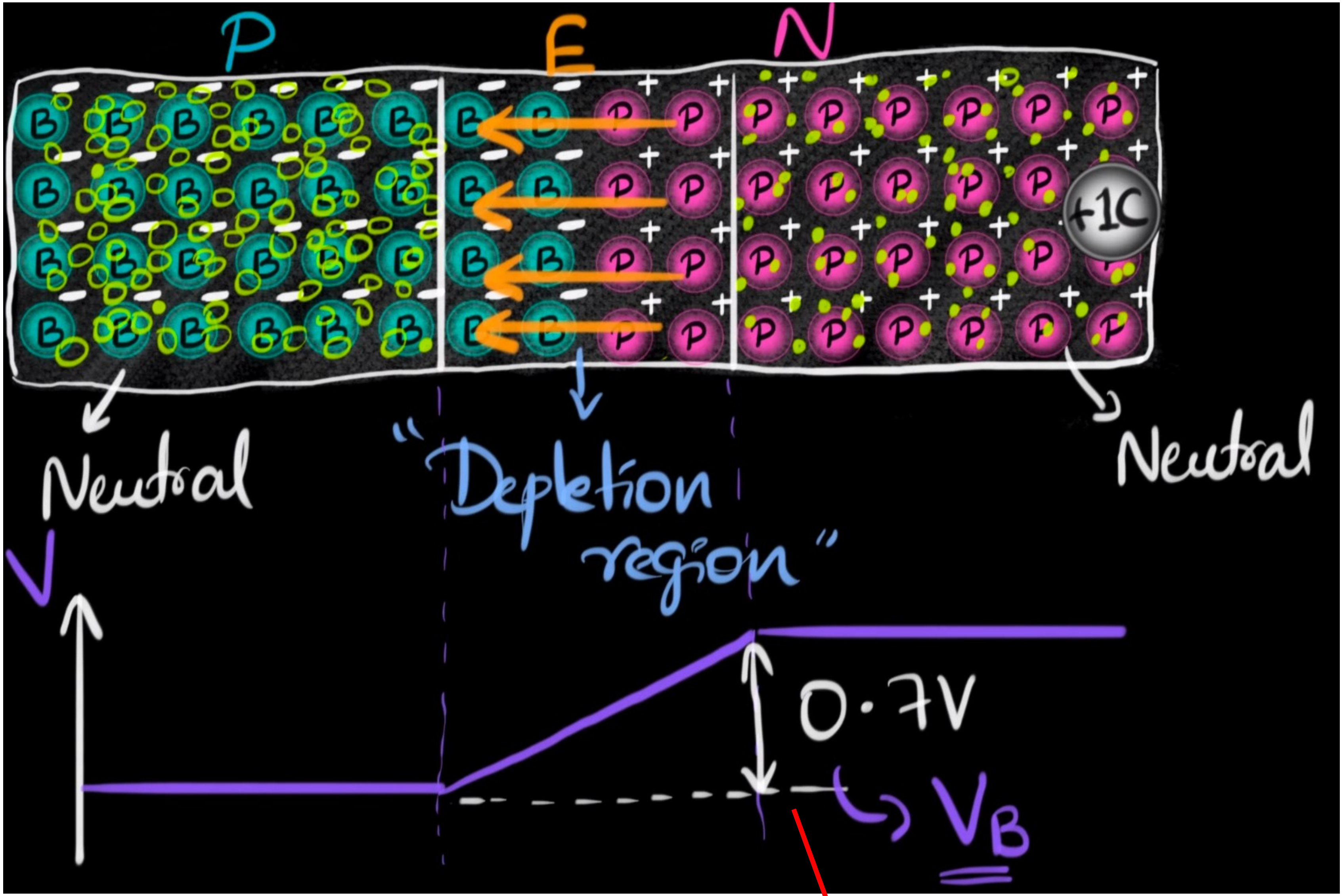


Barrier Voltage

Voltage is the potential energy change of 1C

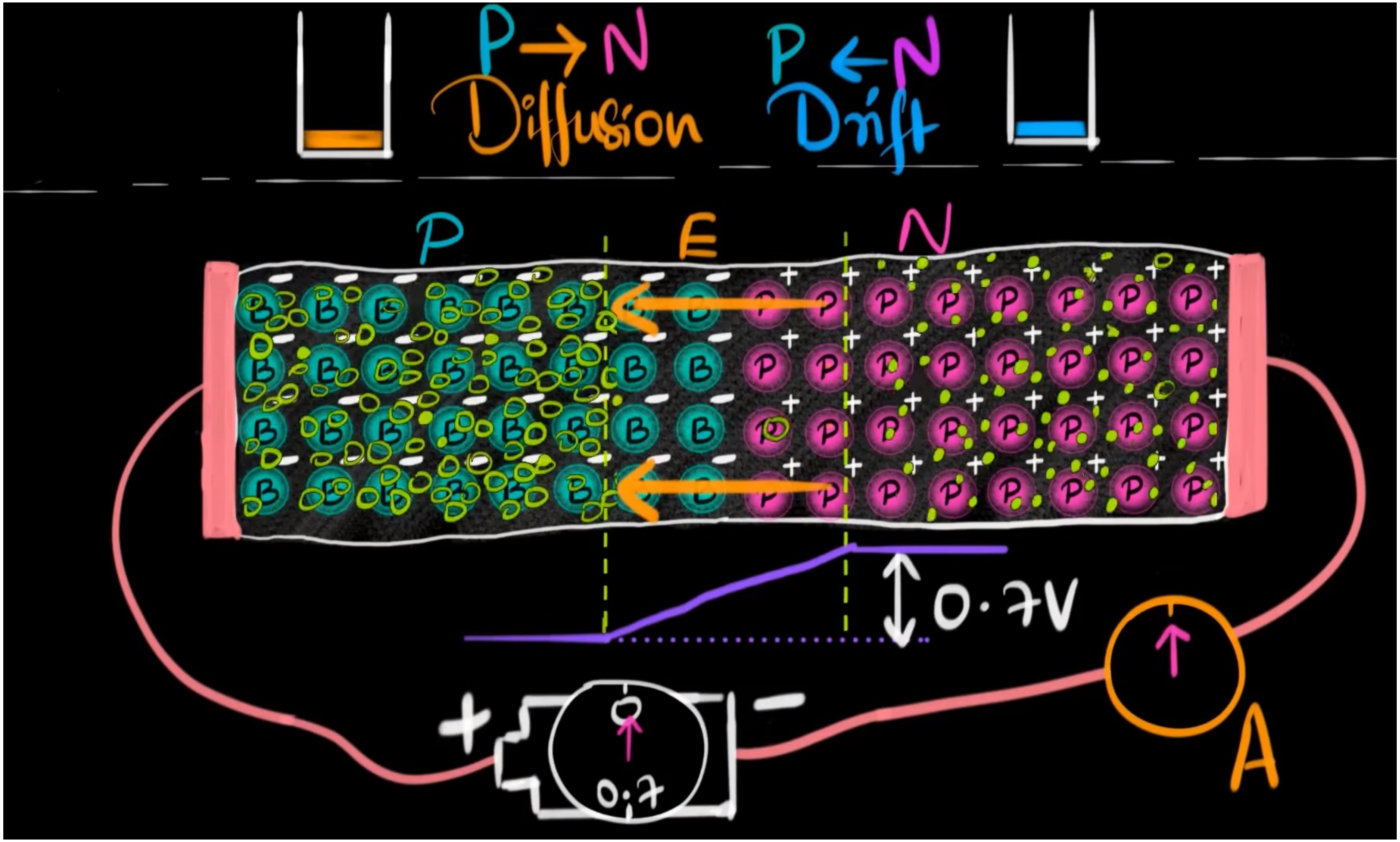


Barrier Voltage

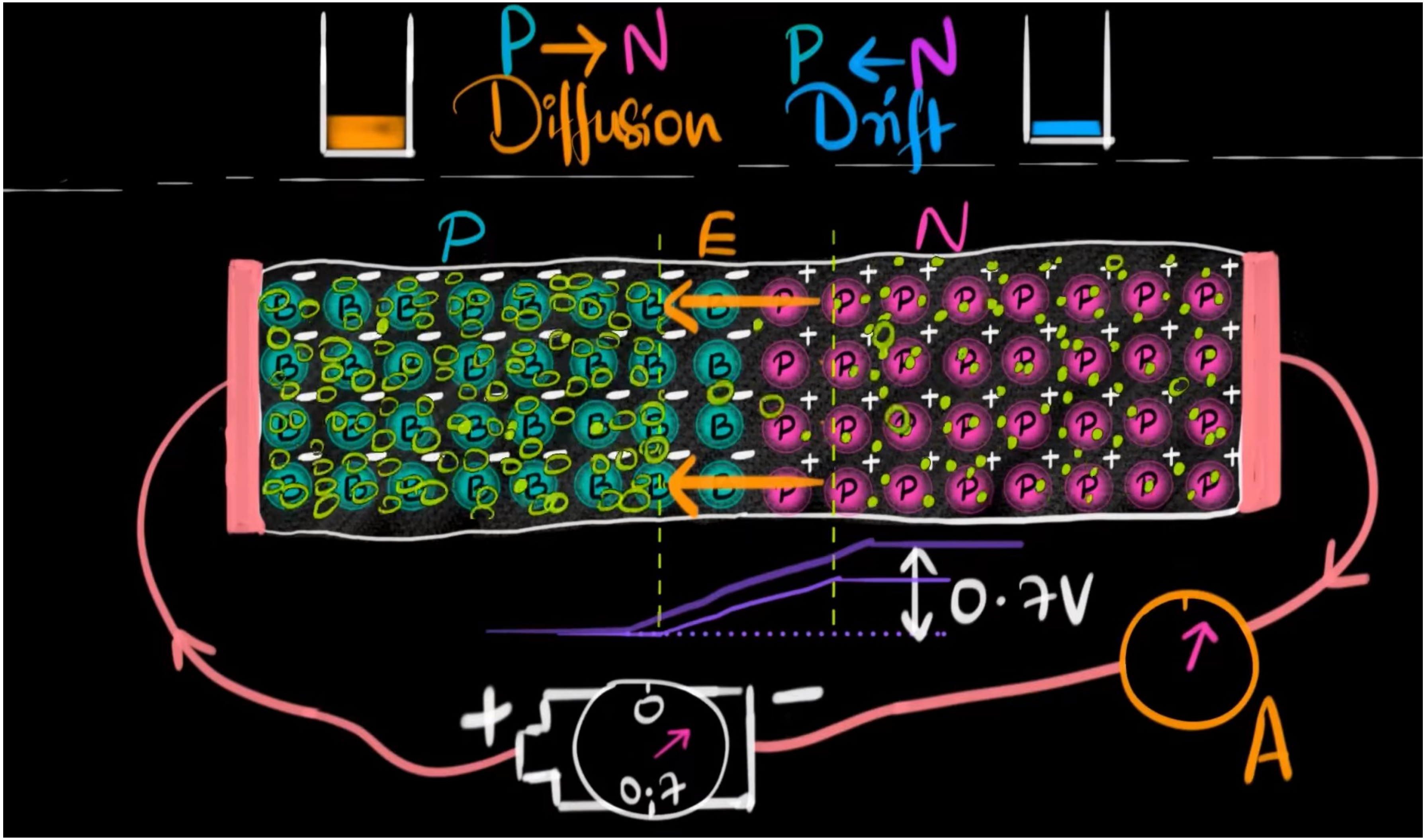


In Silicon

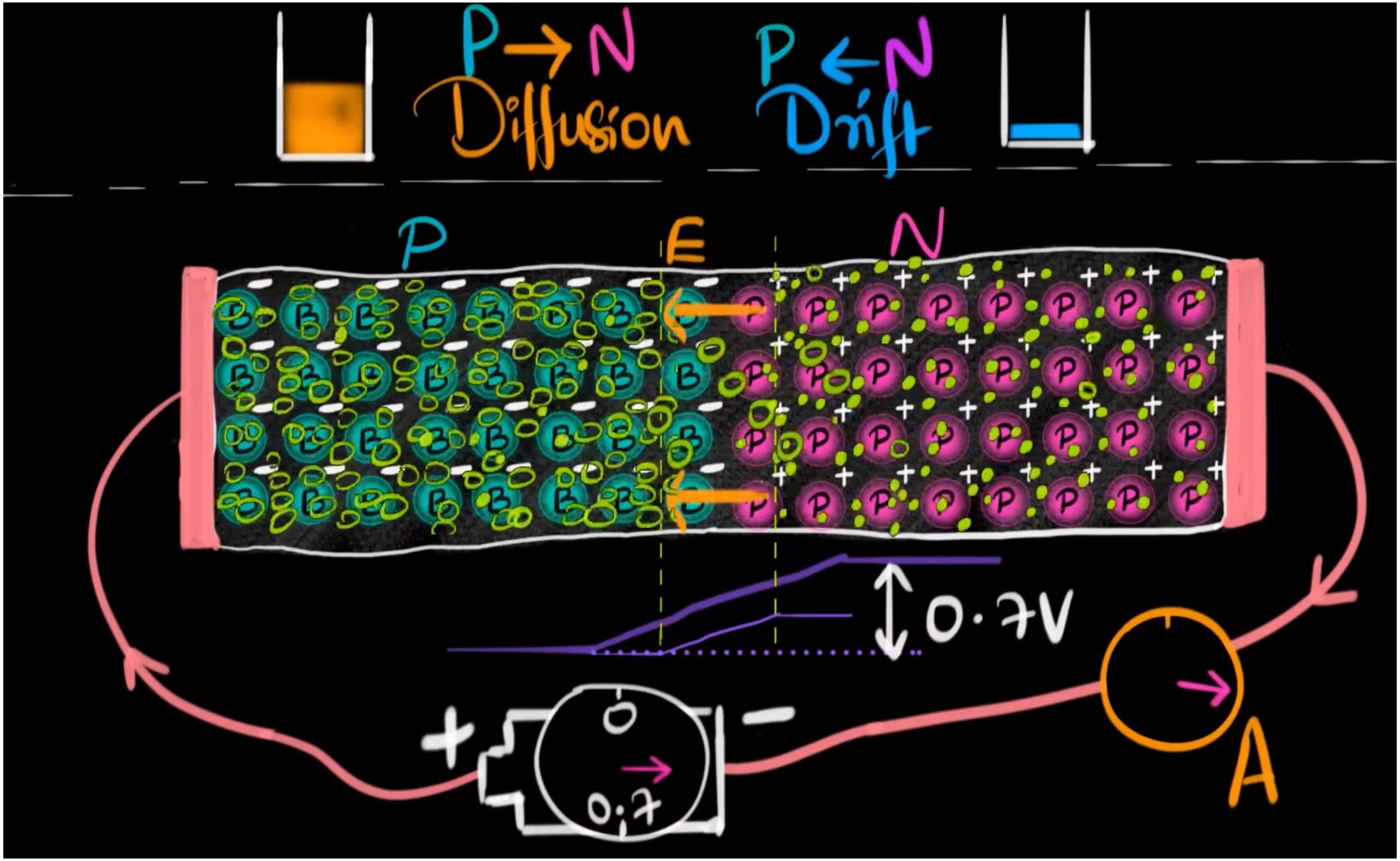
Forward biasing a PN junction



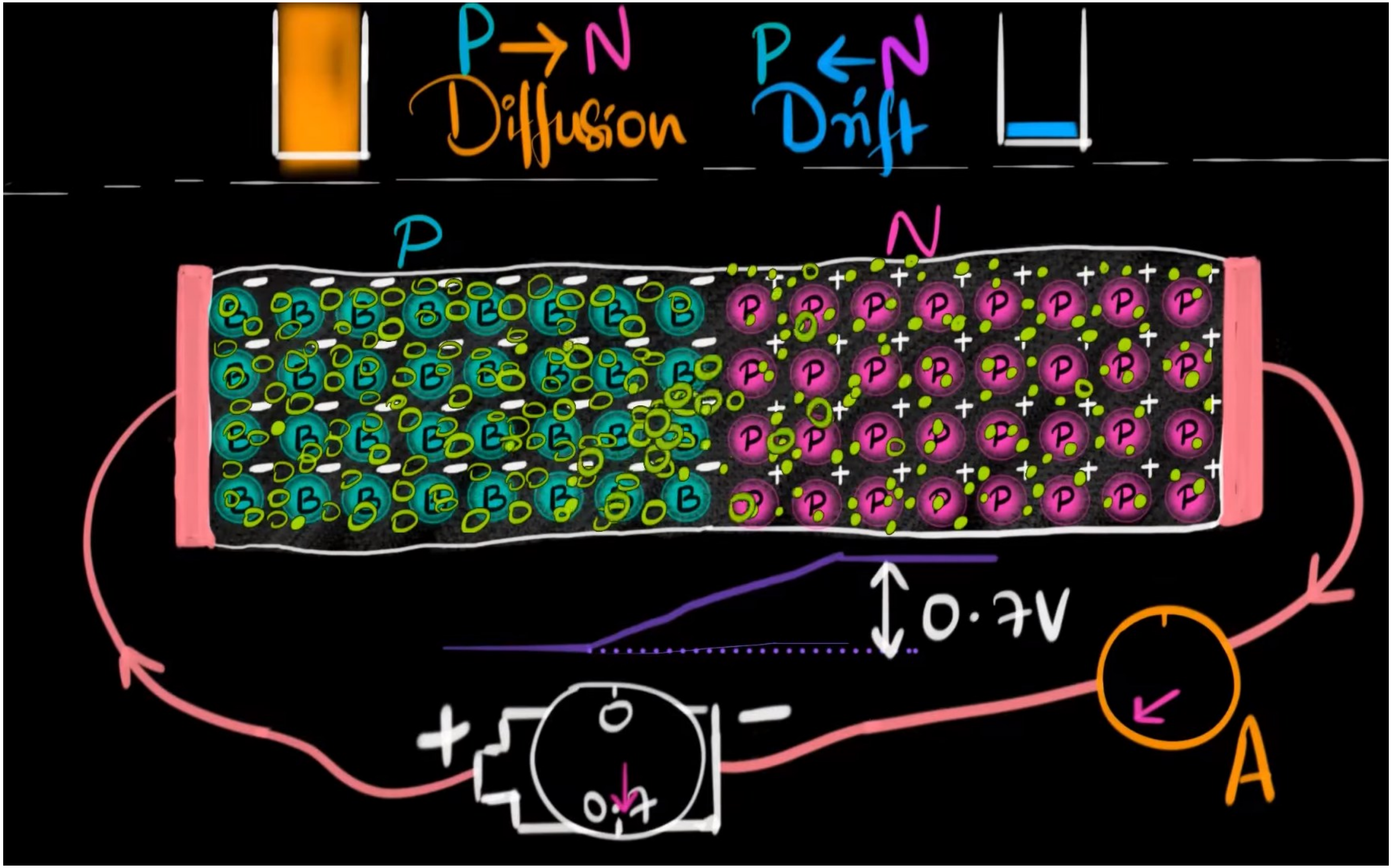
Forward biasing a PN junction



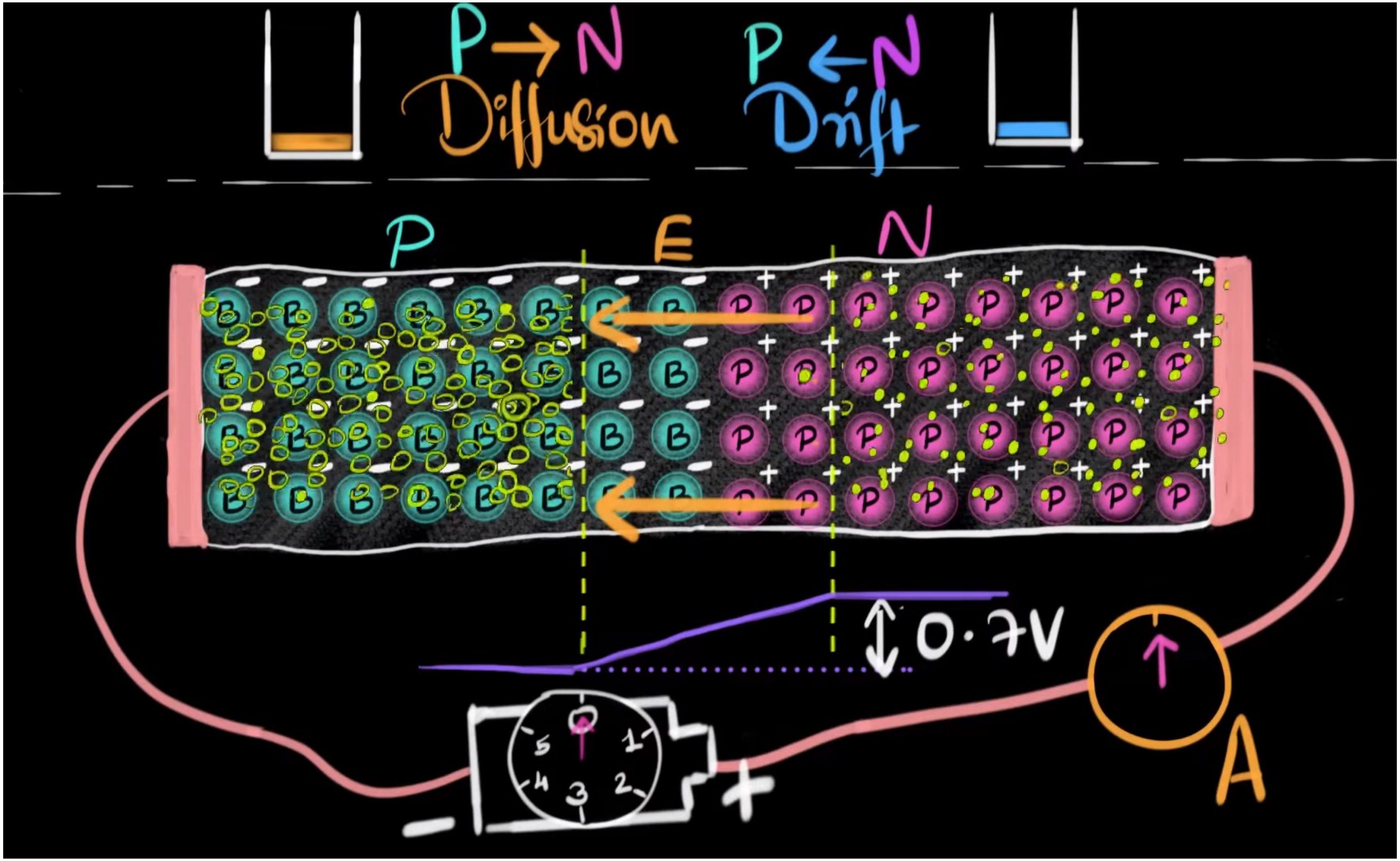
Forward biasing a PN junction



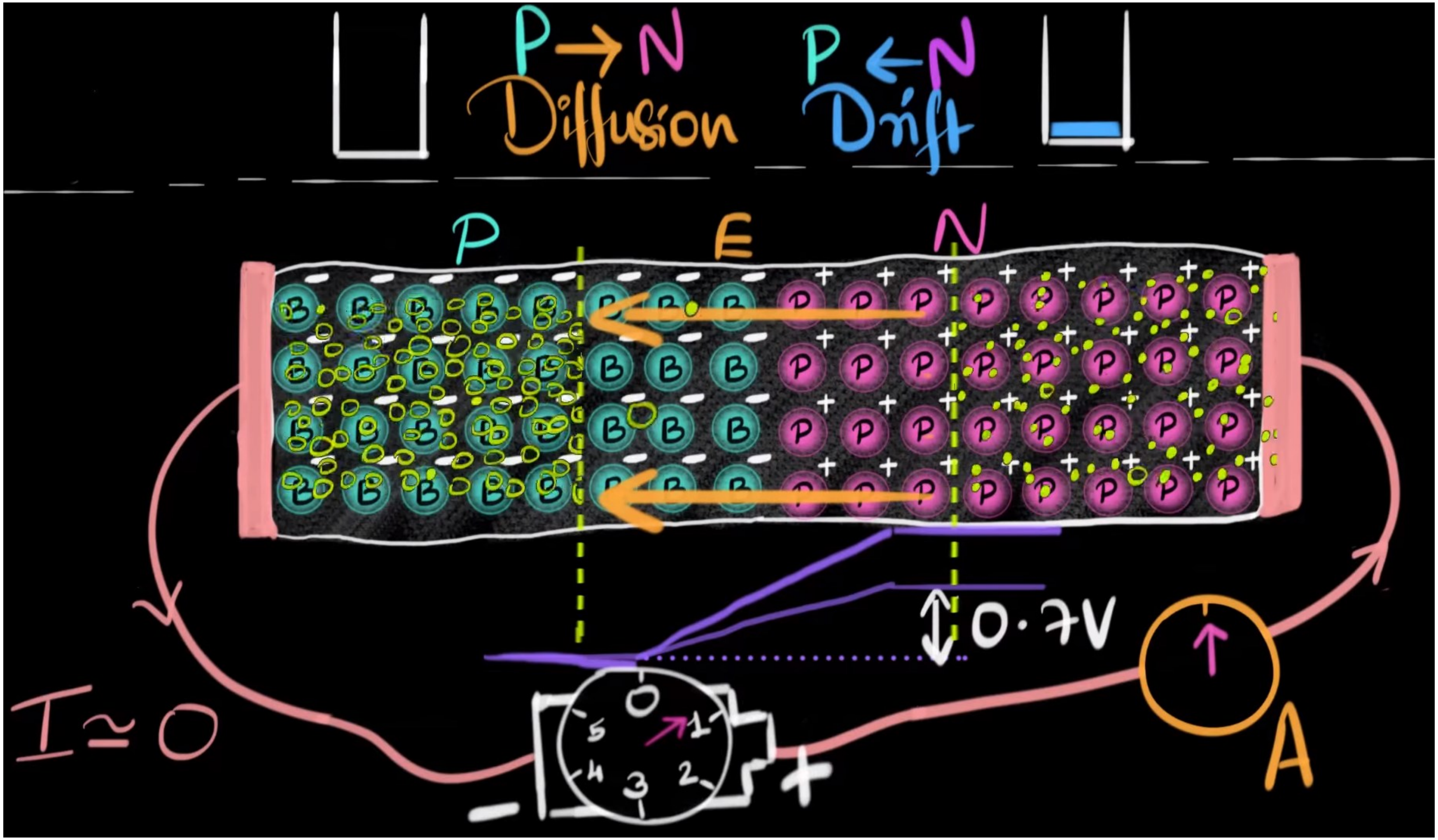
Forward biasing a PN junction



Reverse biasing a PN junction



Reverse biasing a PN junction



Diode Symbol

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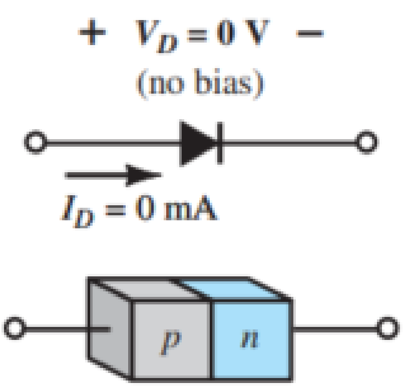
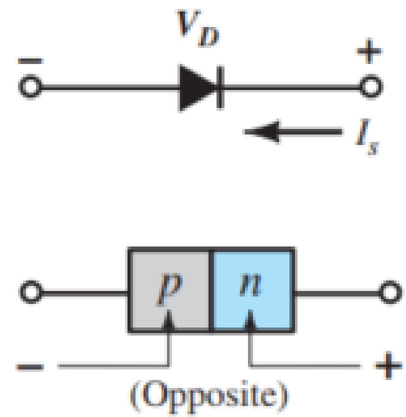
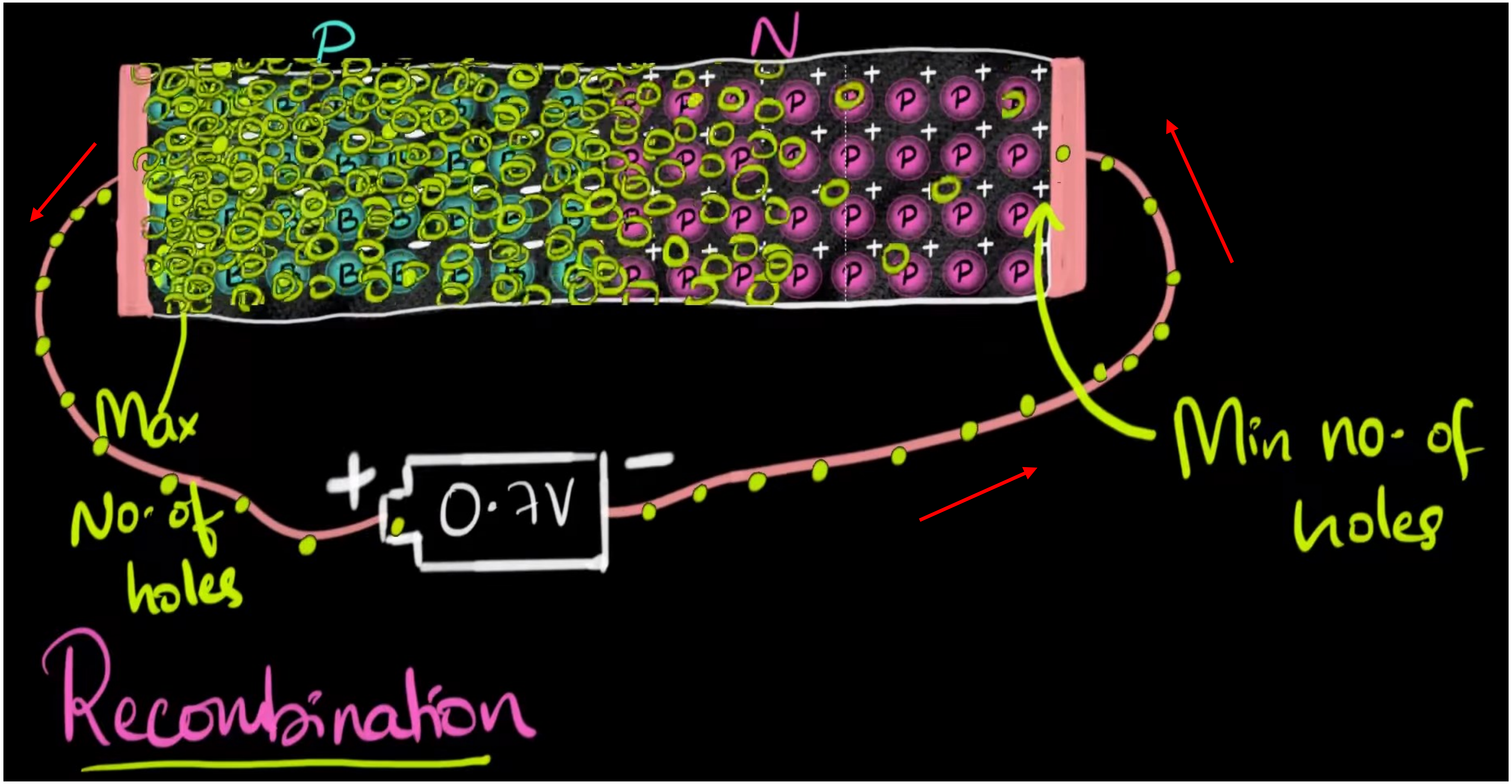


Forward bias



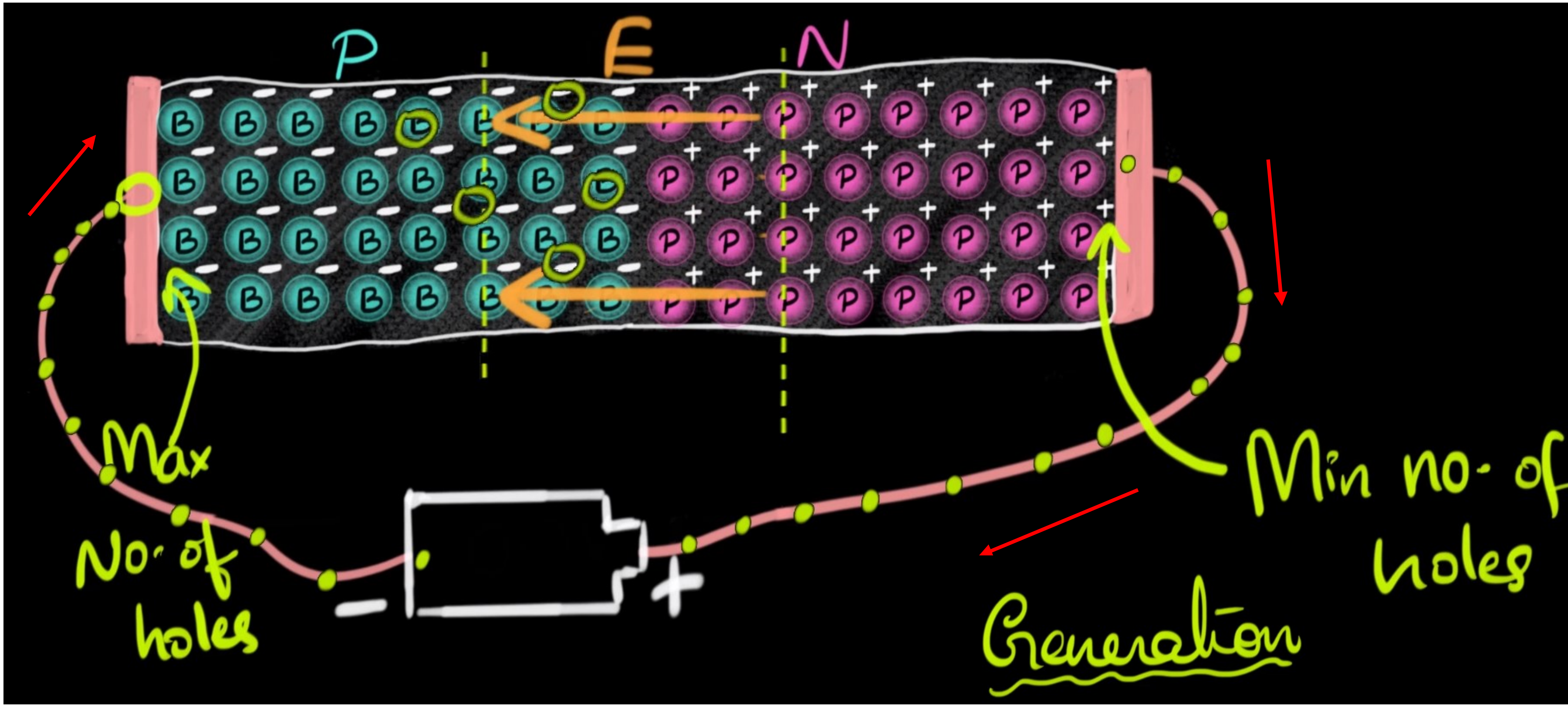
Reverse bias

Forward current mechanism



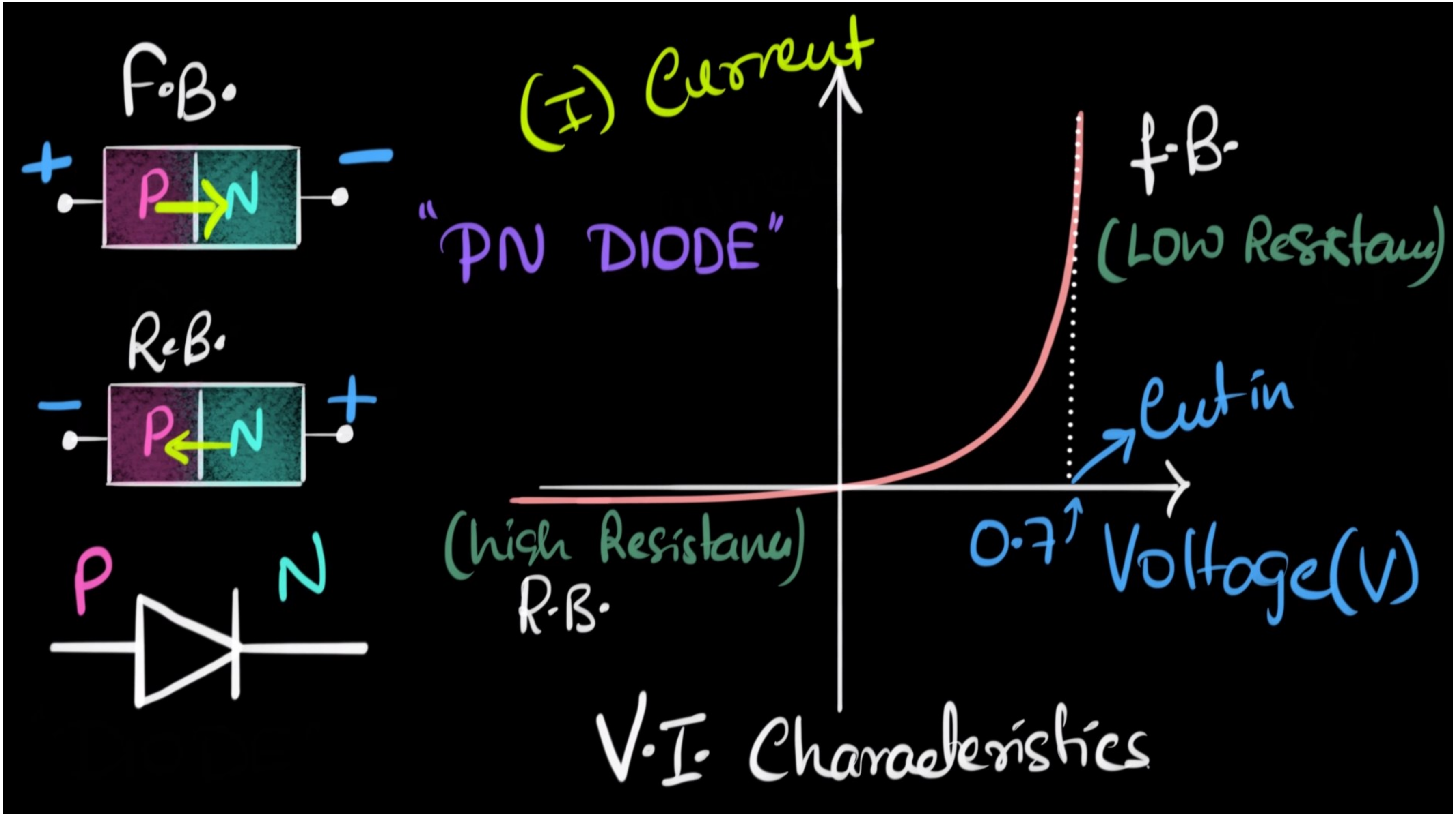
Recombination creates the forward current (diffusion)

Reverse current mechanism



Generation creates the reverse current

PN diode characteristics



PN breakdown and avalanche