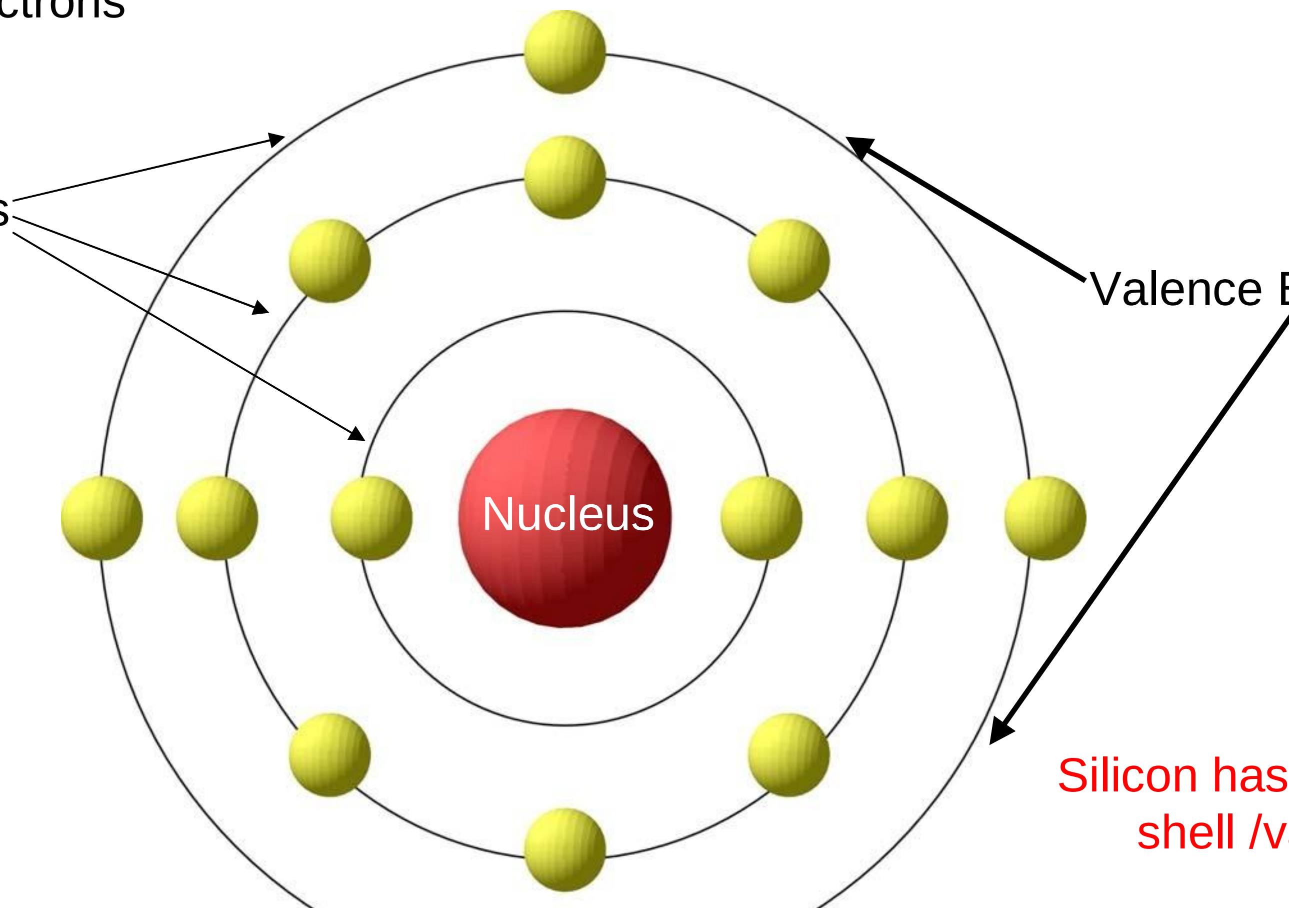
Silicon

Silicon is the primary semiconductor used in VLSI systems

Si has 14 Electrons

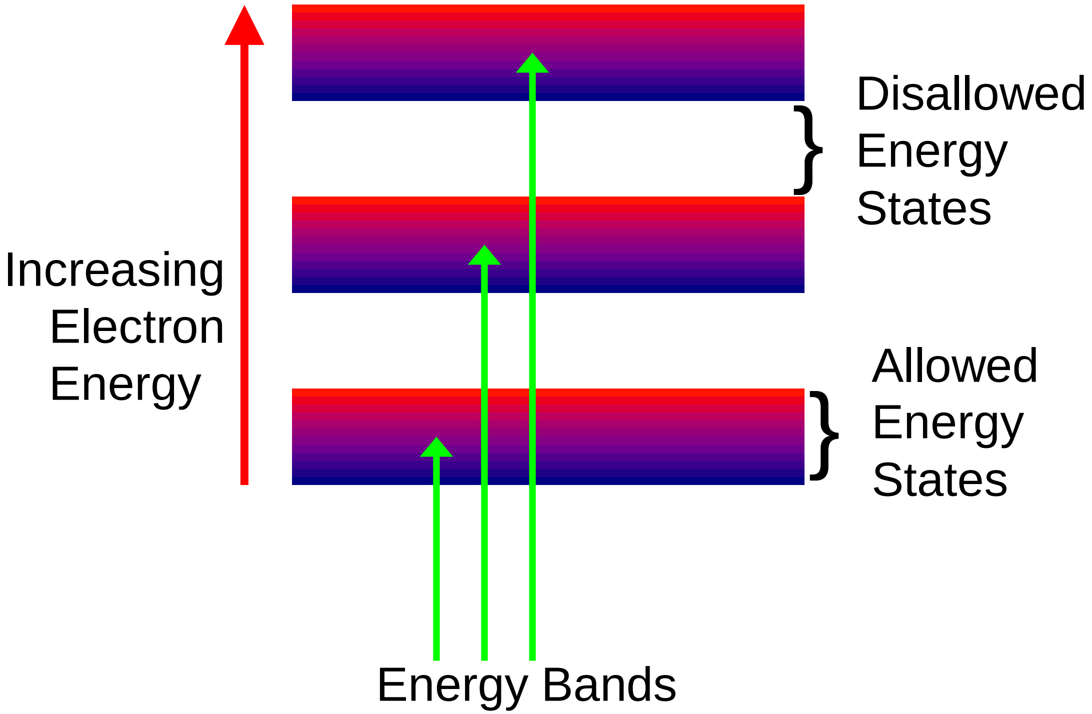


Silicon has 4 outer shell /valence

electrons

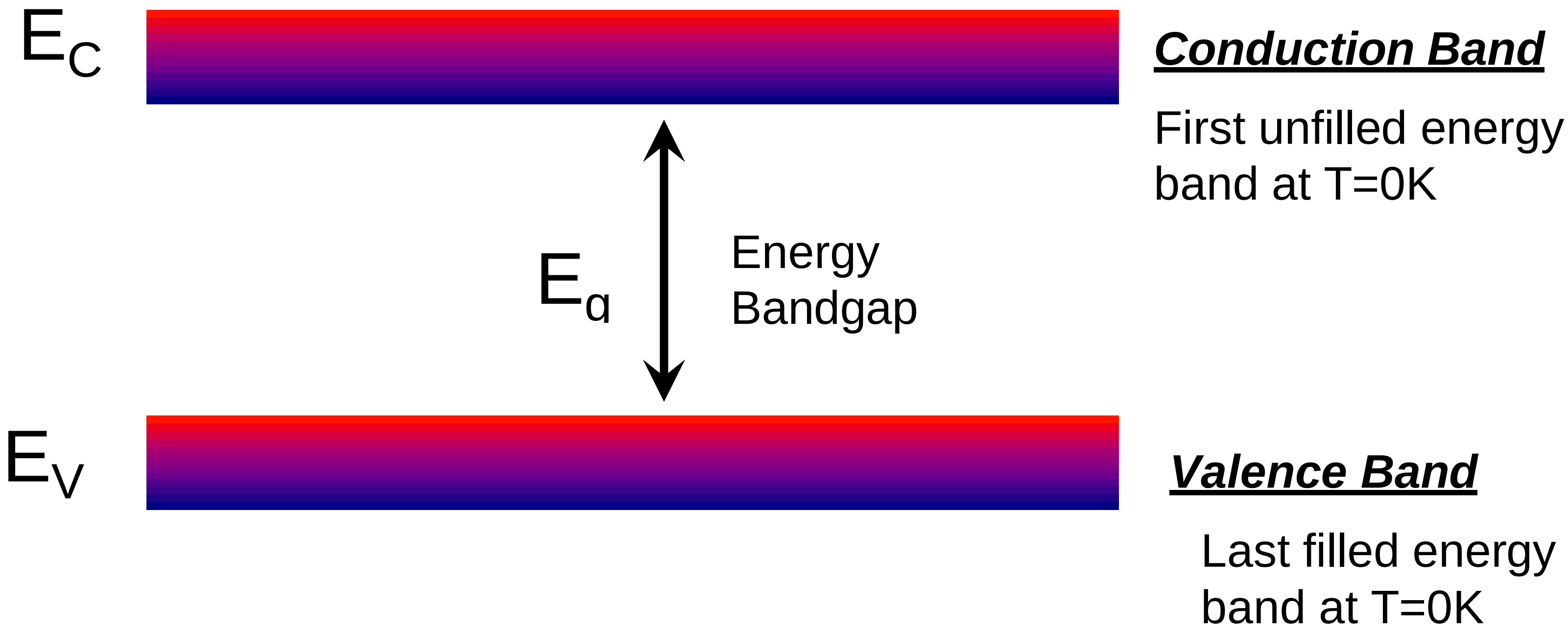
At T=0K, the highest energy band occupied by an electron is called the valence band.

Energy Bands

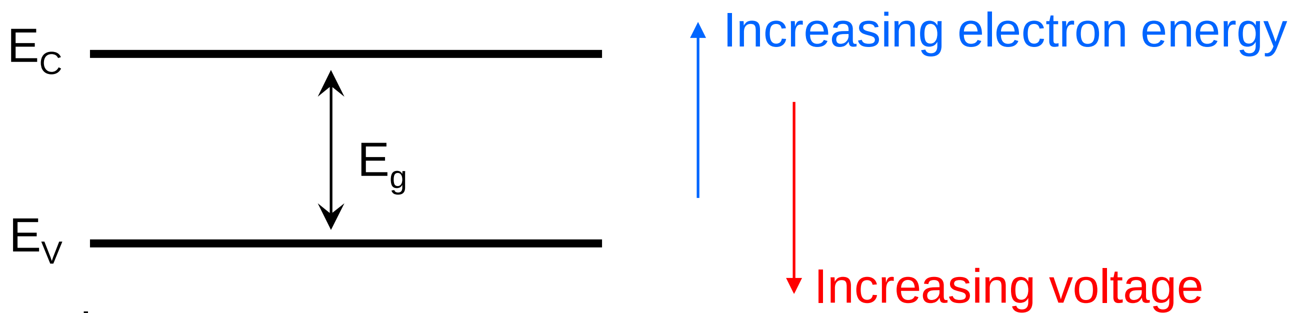


- Electrons try to occupy the lowest energy band possible
- Not every energy level is a legal state for an electron to occupy
- These legal states tend to arrange themselves in bands

Energy Bands



Band Diagrams



<u>Band Diagram Representation</u>

Energy plotted as a function of position

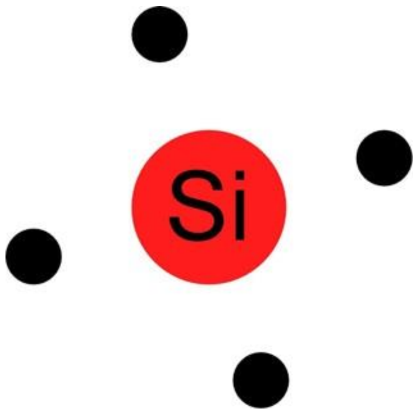
E_C → Conduction band
→ Lowest energy state for a free electron

E_V → Valence band
→ Highest energy state for filled outer shells

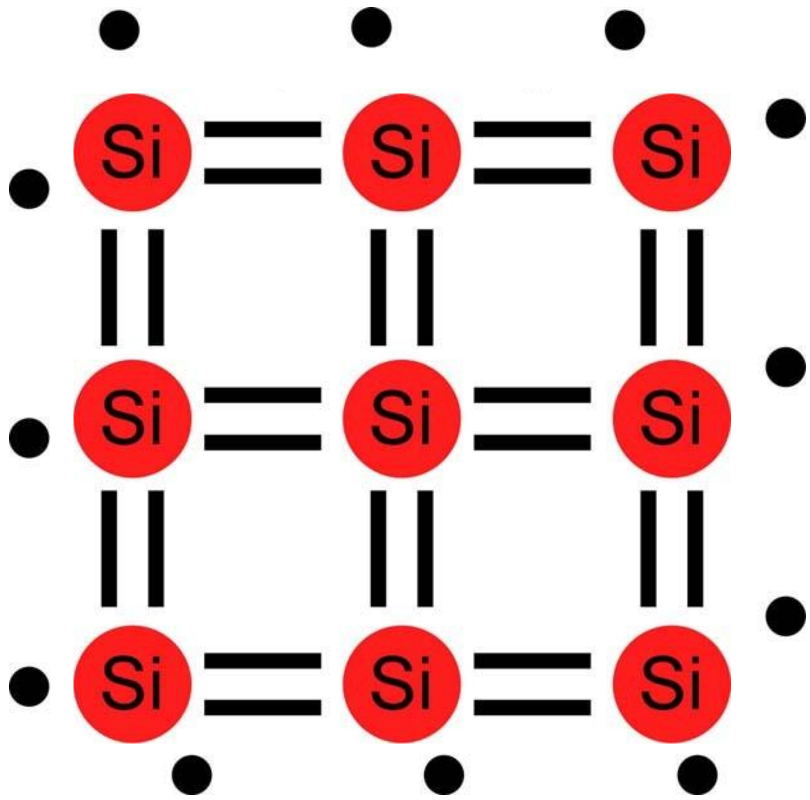
E_G → Band gap
→ Difference in energy levels between E_C and E_V
→ No electrons (e^-) in the bandgap (only above E_C or below E_V)
→ E_G = 1.12eV in Silicon

Intrinsic Semiconductor

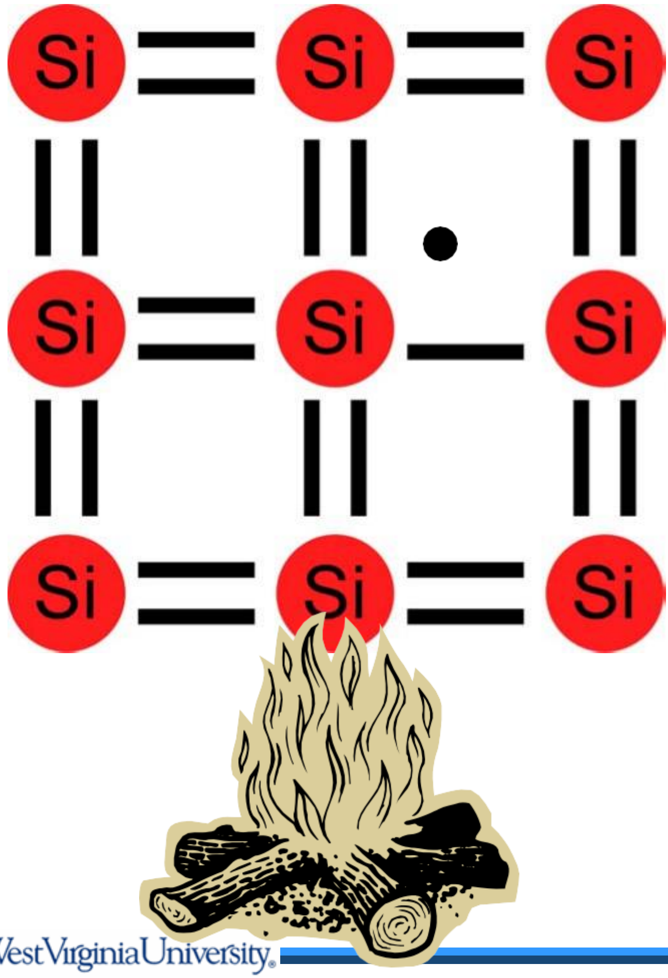
Silicon has 4 outer shell / valence electrons



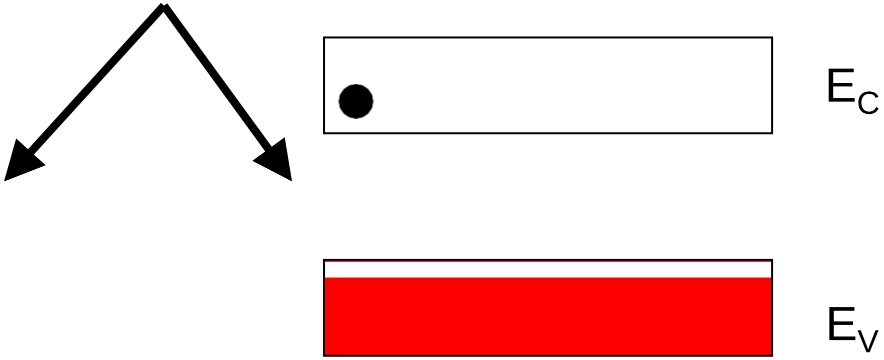
Forms into a lattice structure to share electrons



Intrinsic Silicon



The valence band is full, and no electrons are free to move about

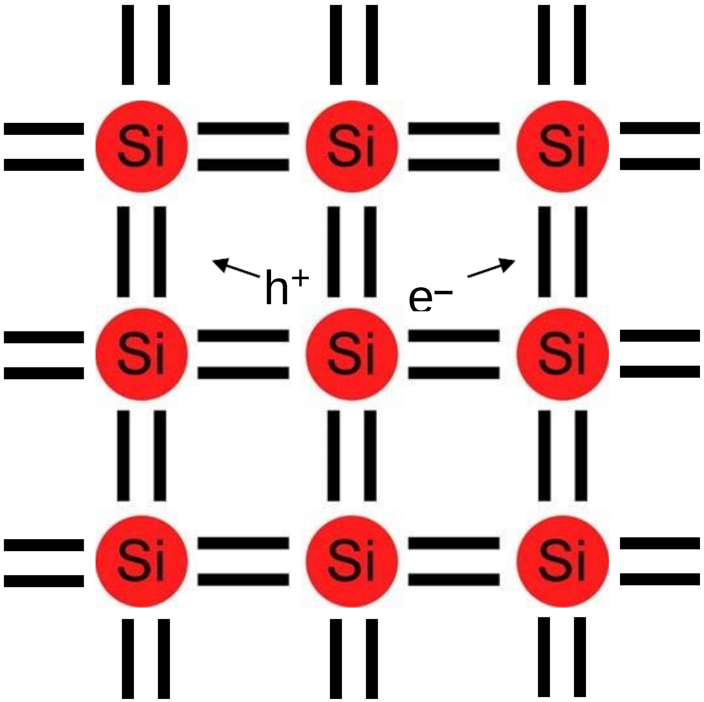


However, at temperatures above T=0K, thermal energy shakes an electron free

Semiconductor Properties

For T > 0K

Electron shaken free and can cause current to flow



- Generation – Creation of an electron (e^-) and hole (h^+) pair
- h^+ is simply a missing electron, which leaves an excess positive charge (due to an extra proton)
- Recombination – if an e^- and an h^+ come in contact, they annihilate each other
- Electrons and holes are called "carriers" because they are charged particles – when they move, they carry current
- Therefore, semiconductors can conduct electricity for T > 0K … but not much current (at room temperature (300K), pure silicon has only 1 free electron per 3 trillion atoms)

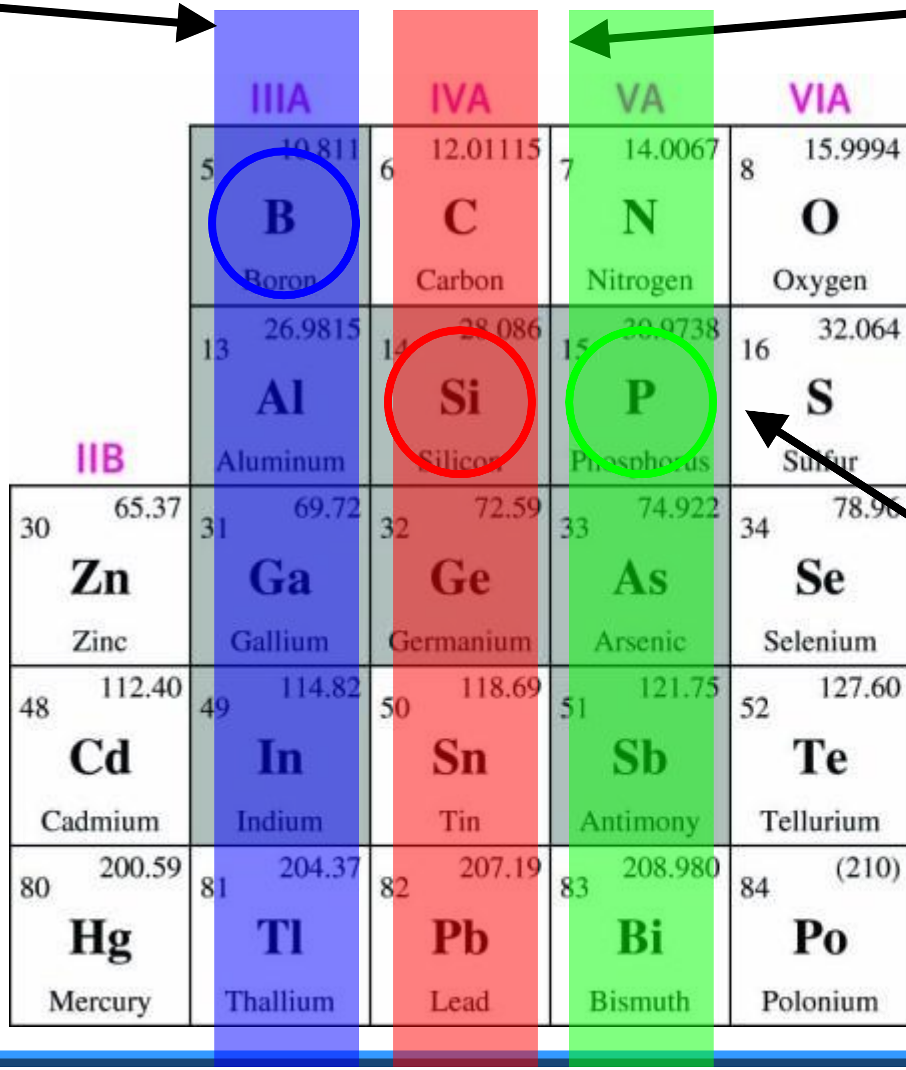
Doping

- Doping – Adding impurities to the silicon crystal lattice to increase the number of carriers
- Add a small number of atoms to increase either the number of electrons or holes

Periodic Table

Column 3
Elements have 3 electrons in the Valence Shell

Column 4
Elements have 4 electrons in the Valence Shell

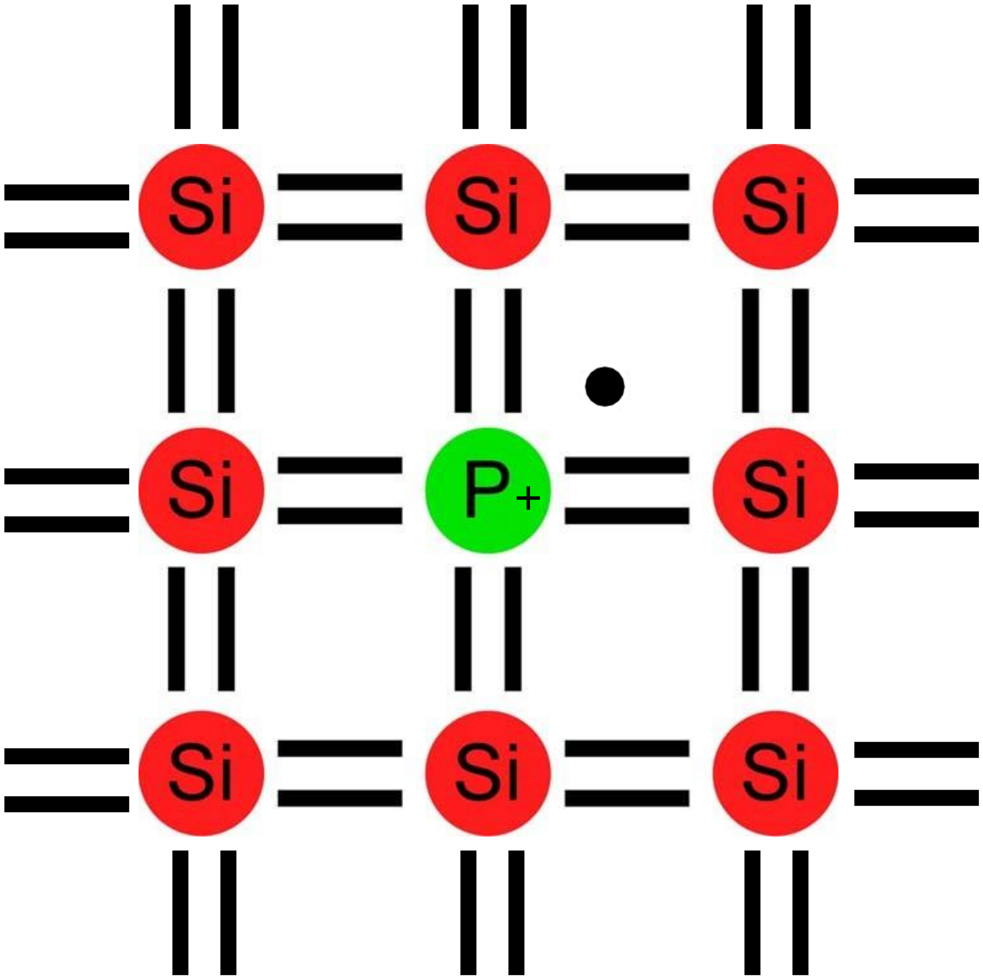


Column 5
Elements have 5 electrons in the Valence Shell

Donors n-Type Material

<u>Donors</u>

- Add atoms with 5 valence-band electrons
- ex. Phosphorous (P)
- "Donates" an extra e^- that can freely travel around
- Leaves behind a positively charged nucleus (cannot move)
- Overall, the crystal is still electrically neutral
- Called "n-type" material (added <u>n</u>egative carriers)
- N_D = the concentration of donor atoms [atoms/cm^3 or cm^{-3}] ~10^{15}-10^{20}cm^{-3}
- e^- is free to move about the crystal (Mobility μ_n ≈1350cm^2/V)



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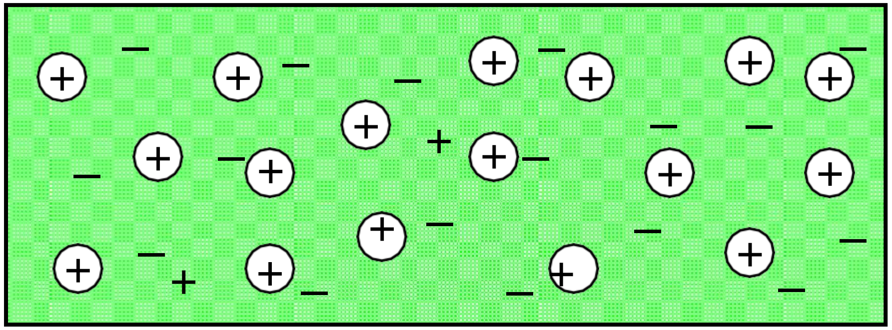
n-Type Material



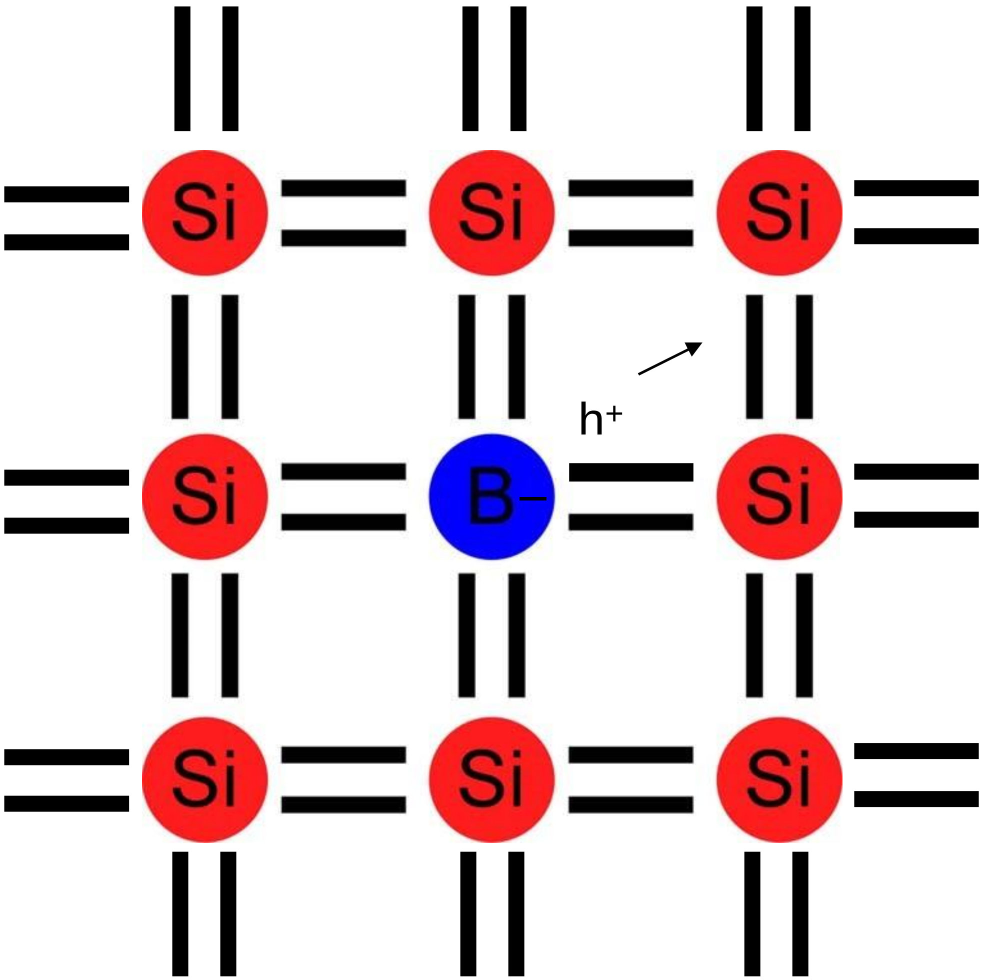
Shorthand Notation

⊕ Positively charged ion; immobile

– Negatively charged e-; mobile; Called "majority carrier"

\+ Positively charged h+; mobile; Called "minority carrier"

Acceptors Make p-Type Material

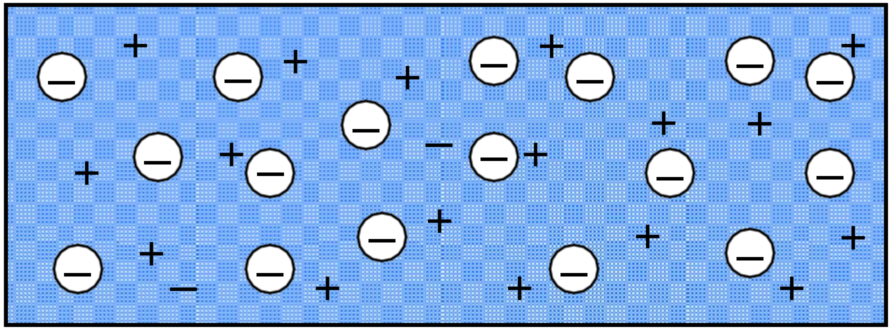


Acceptors

- Add atoms with only 3 valence-band electrons
- ex. Boron (B)
- "Accepts" e^- and provides extra h^+ to freely travel around
- Leaves behind a negatively charged nucleus (cannot move)
- Overall, the crystal is still electrically neutral
- Called "p-type" silicon (added positive carriers)
- N_A = the concentration of acceptor atoms [atoms/cm^3 or cm^{-3}]
- Movement of the hole requires breaking of a bond! (This is hard, so mobility is low, $\mu_p \approx 500 \text{cm}^2/\text{V}$)

Acceptors Make p-Type Material

p-Type Material



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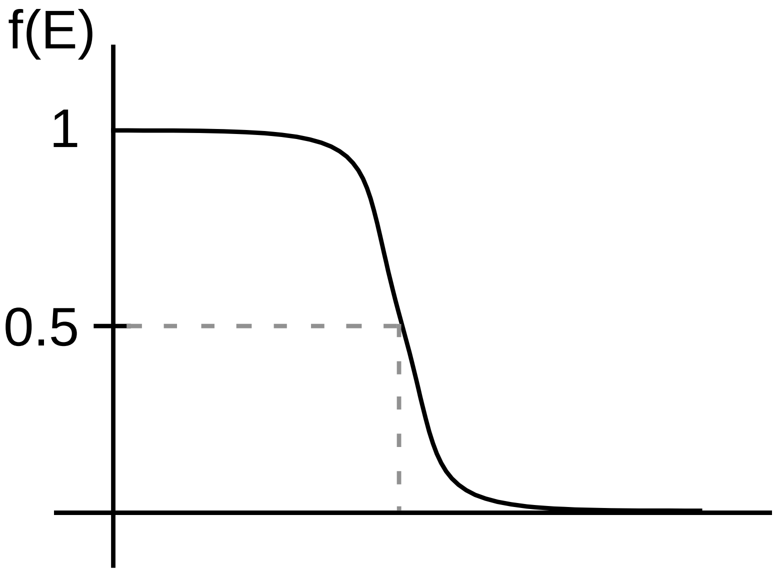
The Fermi Function

<u>The Fermi Function</u>

- Probability distribution function (PDF)
- The probability that an available state at an energy E will be occupied by an e^-

$$f(E) = \frac{1}{1 + e^{(E - E_f)/kT}}$$



The Fermi Function

E → Energy level of interestE_f → Fermi level

→ Halfway point

→ Where $f(E) = 0.5$

k → Boltzmann constant

$= 1.38\times10^{-23}$ J/K

$= 8.617\times10^{-5}$ eV/K

T → Absolute temperature (in Kelvins)