Semiconductor Basics

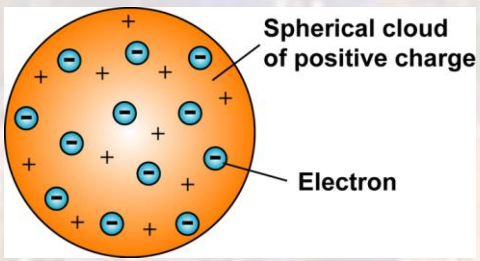
Last updated 12/27/24

These concepts have been **greatly** simplified

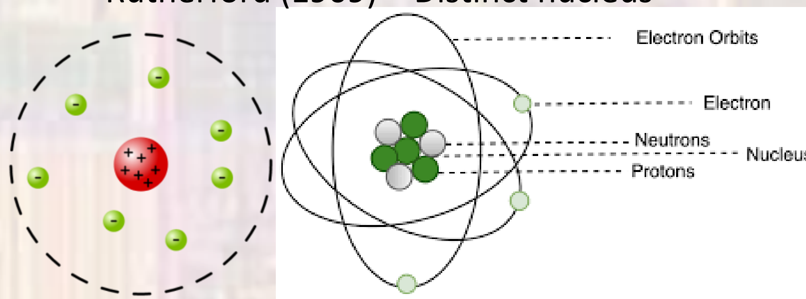
The Atom

- Our understanding of atomic structure has changed over time

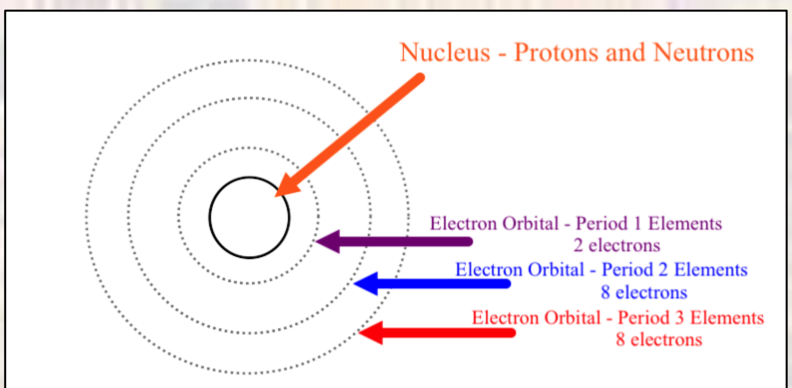
Thomson (1897) – Plum Pudding



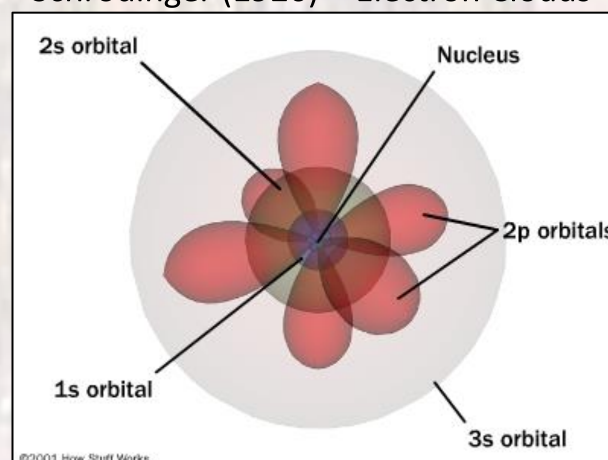
Rutherford (1909) – Distinct nucleus



Bohr (1913) – Electron Orbitals

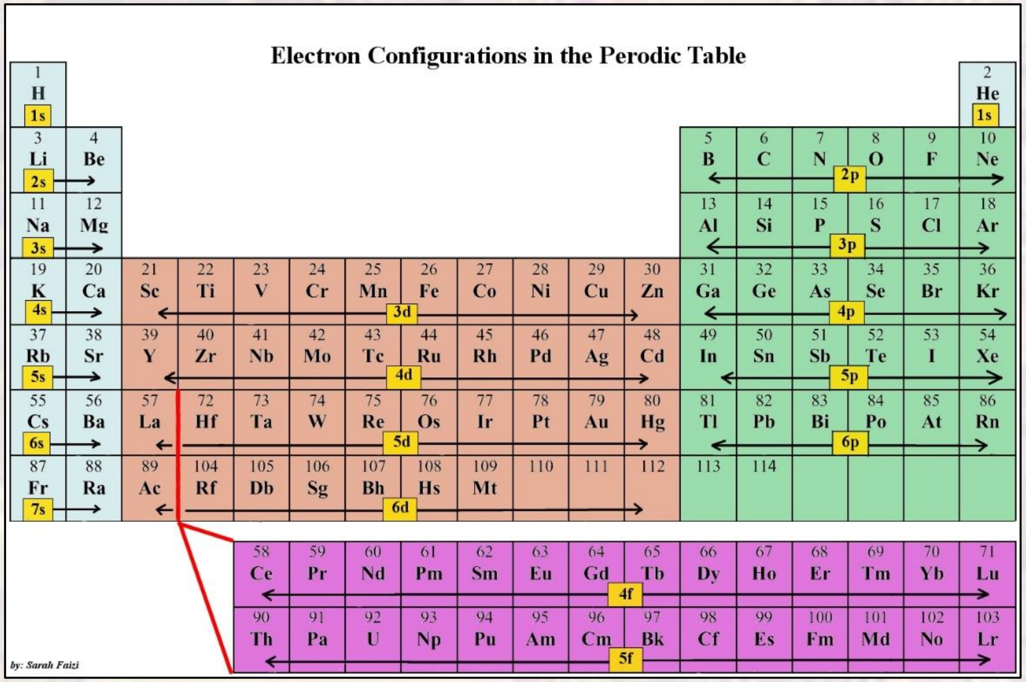


Schrödinger (1926) – Electron Clouds



The Atom

- Electron configurations



1s - 2 orbitals
2s – 2 orbitals
2p – 6 orbitals
3s – 2 orbitals
3p – 6 orbitals

Most stable when all orbitals are filled
- inert gasses

Discrete electron orbitals <-> Discrete energy levels to free/capture electrons

Higher electron configuration orbitals <-> Less energy to free the electron

Full electron configuration orbitals <-> More energy to free an electron

The Atom

- A few atoms of interest

Silicon

Symbol:	Si	
Atomic number:	14	
Atomic mass:	28.0855 au	
Electron Config:	$1s^2 2s^2 2p^6 3s^2 3p^2$	[Ne] $3s^2 3p^2$
Valance Electrons:	4, (4 empty spots)	

8 possible states / atom

Boron

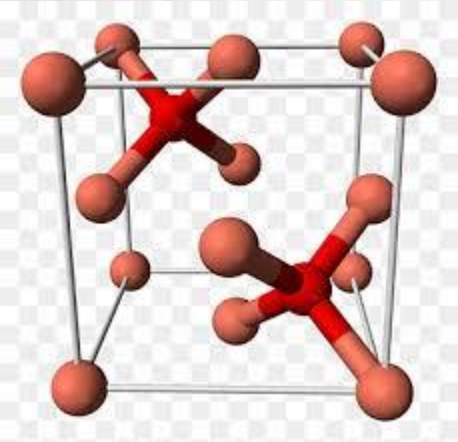
Symbol:	B	
Atomic number:	5	
Atomic mass:	10.811 au	
Electron Config:	$1s^2 2s^2 2p^1$	[He] $2s^2 2p^1$
Valance Electrons:	3, (1 empty spot)	

Phosphorus

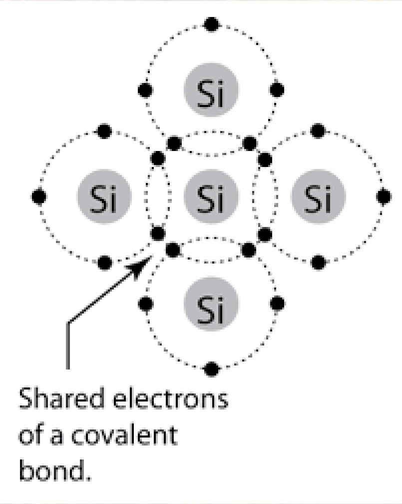
Symbol:	P	
Atomic number:	15	
Atomic mass:	30.974 au	
Electron Config:	$1s^2 2s^2 2p^6 3s^2 3p^3$	[Ne] $3s^2 3p^3$
Valance Electrons:	5, (3 empty spots)	

Silicon Crystal Structure

- Silicon unit cell – bonding model
  - Si has a half full outer electron shell (4 / 8)
  - Lowest energy state is the Diamond Lattice
    - 4 electrons are shared between 4 nearest neighbors



Atoms showing
4 nearest neighbor
structure

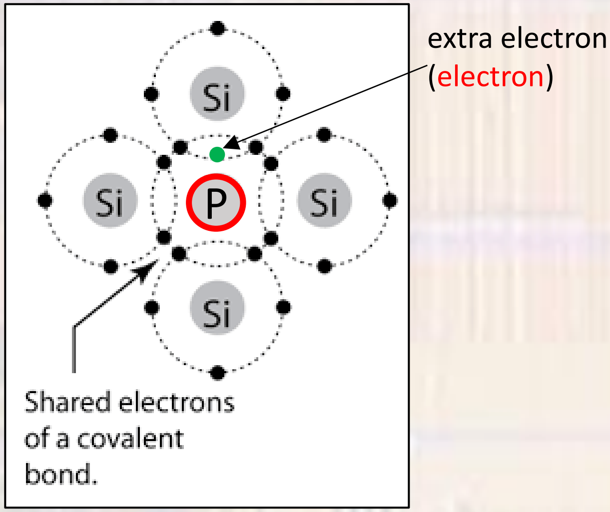


Each atom appears to have a full valence band → very stable

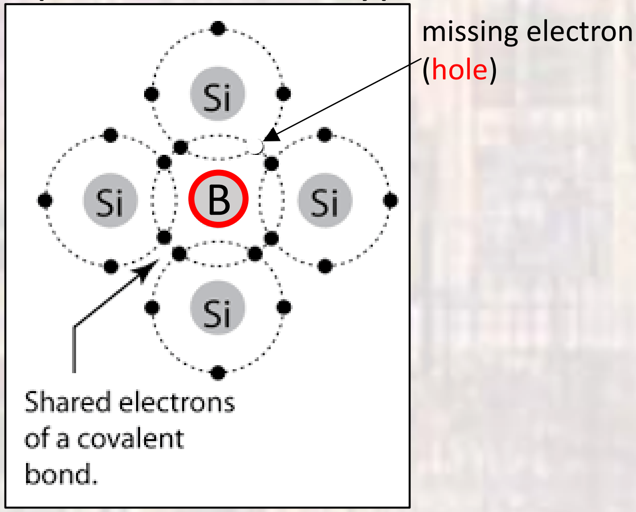
Silicon Doping

- Replace some of the Si atoms in the crystal with another atom

Phosphorus
5 e- in its outer shell
Donor atom → N-type Si



Boron
3 e- in its outer shell
Acceptor atom → P-type Si

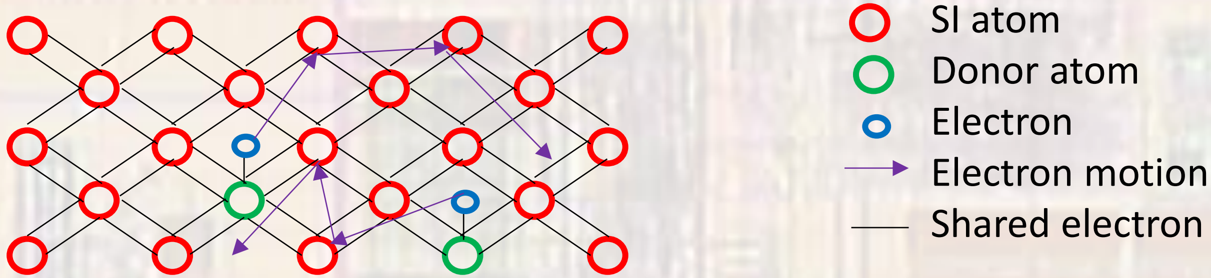


excess e- is easily freed
Acts like a conductor for Electrons
(negative charge carriers)

excess hole is easily freed
Acts like a conductor for Holes
(positive charge carriers)

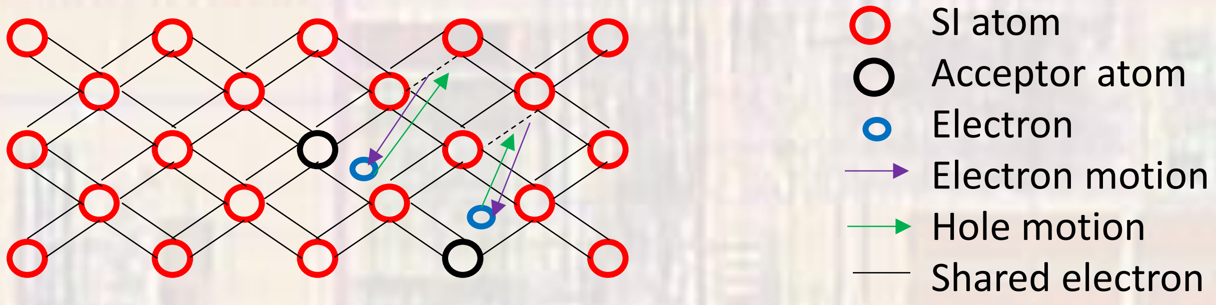
Carrier Action

- Mobility - Electrons
  - Measure of how easy(hard) it is to move a charged particle through a solid
  - Lots of physics here – but to simplify – for Si
    - Conduction electrons represent an excess electron in the shared 3sp band from donor atoms
      - Free electron generation requires breaking a relatively weak bond
      - Movement is limited by collisions



Carrier Action

- Mobility - Holes
  - Measure of how easy(hard) it is to move a charged particle through a solid
  - Lots of physics here – but to simplify – for Si
    - Valence holes represent a missing electron in the shared 3sp band from acceptor atoms
      - Hole generation requires breaking a relatively strong "normal" electron bond
      - Electrons must 'find' an open bond to move



Carrier Action

- Mobility
  - Measure of how easy(hard) it is to move a charged particle through a solid
  - Historical bulk Si:

    Electron mobility: $\mu_n \approx 1500 \frac{cm^2}{Vs}$

    Hole mobility: $\mu_p \approx 500 \frac{cm^2}{Vs}$

  - For modern FinFETs:

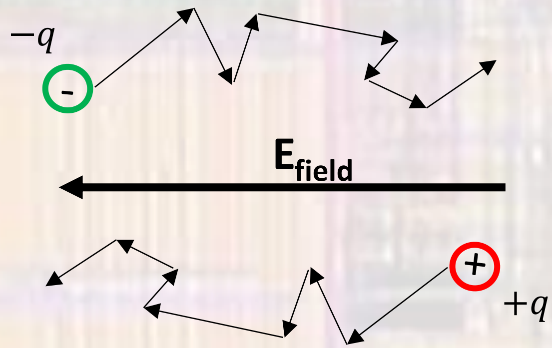
    Electron mobility: $\mu_n \approx 240 \frac{cm^2}{Vs}$

    Hole mobility: $\mu_p \approx 80 \frac{cm^2}{Vs}$

This 3:1 ratio is critical to understand for good electronic circuit design

Carrier Action

- Drift
  - Motion of a charged particle due to an electric field
  - Subject to collisions and random thermal motion



current density: *current per cross sectional area*

Hole current density: $J_{p-drift} = qp\mu_p$E   Electron current density: $J_{n-drift} = qn\mu_n$E

p − *hole density*
μ_p − *hole mobility*

n − *electron density*
μ_n − *electron mobility*

Carrier Action

- Drift Current
  - For equal cross-sectional areas (A) of silicon (one n, one p)
  - With the same doping density (n = p)
  - In the same Electric field (E)

$$I_p = qp\mu_p \text{EA} \qquad I_n = qn\mu_n \text{EA}$$

- But remember, μ_n ~ 3 x μ_p

Under equal circumstances:

N-type silicon conducts 3 times as much current as P-type silicon