MPHYCC-12 ELECTRONICS II

Unit 3: Semiconductor Devices

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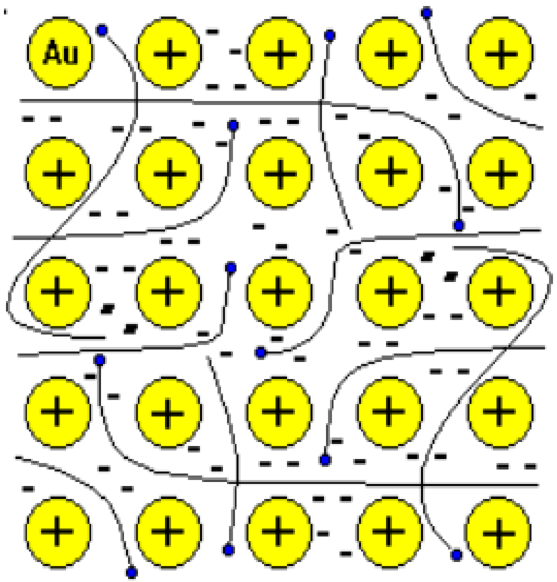
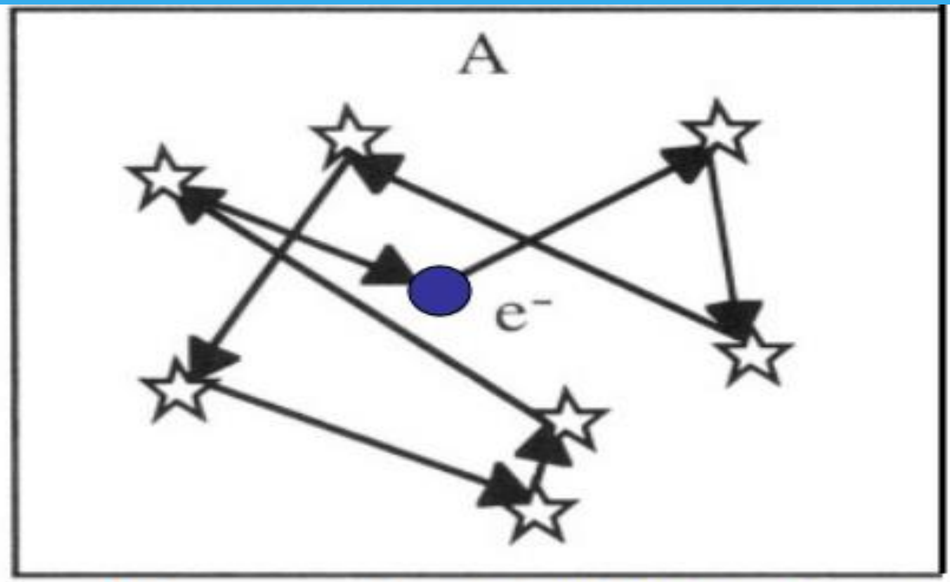
The Origin of Electric Conductance



- Free electrons can freely move along the crystal (colliding with the atoms)
- Their kinetic energy comes from the lattice vibrations
- In equilibrium, free electrons move **randomly** inside the crystal.

Electron mobility in crystals



<u>Equilibrium condition, no electric field (voltage) applied</u>

Free electron experiences very frequent collisions with atoms in the metal.

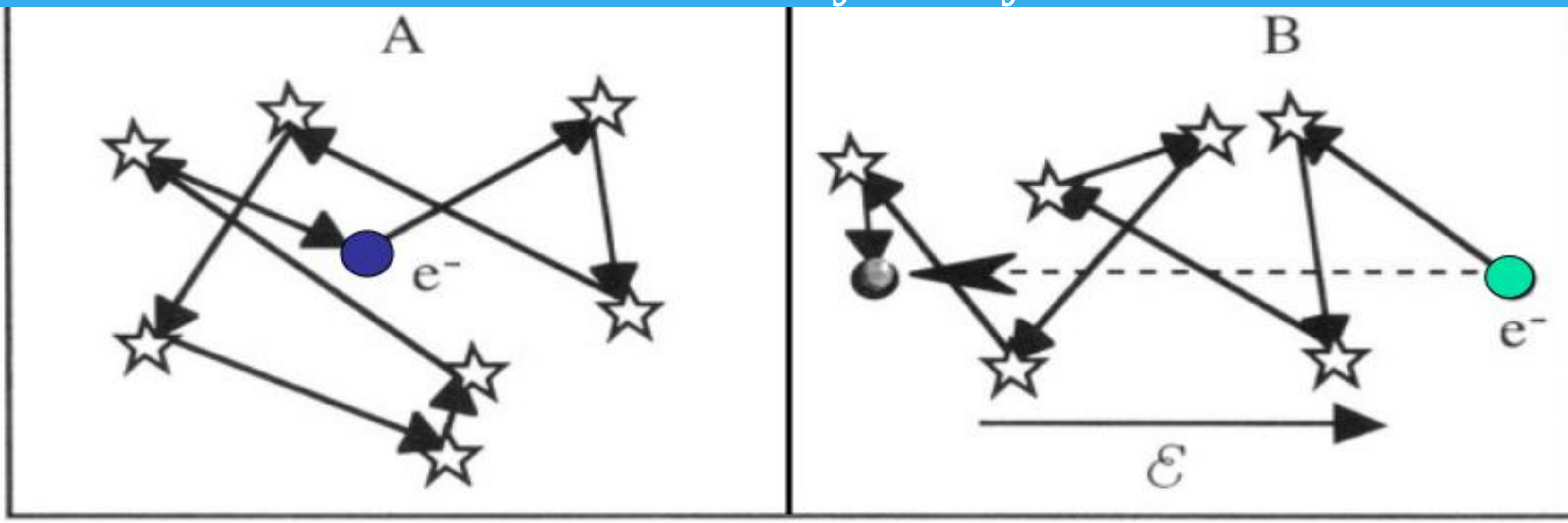
As a result it moves randomly *(with the velocity of around 10^5 m/s)*.

On average, the electron does not go anywhere!

Average electric current is equal to zero

(There is a flicker charge transfer, or the NOISE current though)

Electron mobility in crystals



<u>Electric field applied</u>:

There is an electric force, ***F* = *e E*** exerting on any free electron.

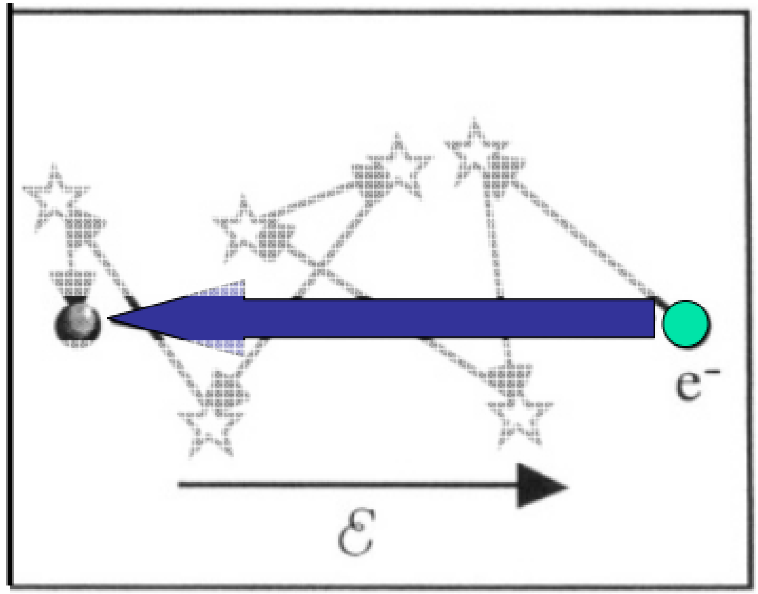
Electron still experiences very frequent random collisions.

However, after each collision the electron's velocity has a component toward the positive electrode (against the field direction)

On average, the electron drifts from negative electrode toward positive.

There is a current flowing through the metal.

Electron mobility in crystals



Let us ignore the random collisions and only monitor the drift in the electric field

Ignoring the collisions, which are completely random, we can say that

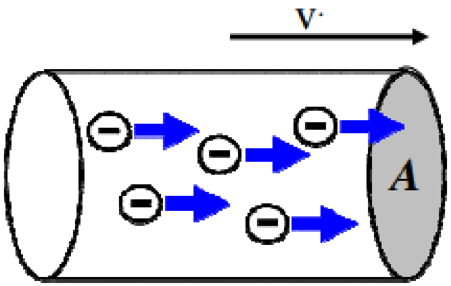
average electron velocity (drift velocity) is proportional to the electric field applied:

$$v \sim E$$

$$v = \mu E$$

μ is called the **electron mobility:** $\mu = v/E$ [(m/s)/(V/m) = $m^2/(V \cdot s)$]

Electric current and conductivity



A = wire cross-section area

The electric current is: $I = q\,n\,v\,A$

Electron velocity, $\boldsymbol{v} = \mu\,\mathbf{E}$, where the electric field **E = V/L** (V is the voltage)

the velocity becomes $\boldsymbol{v} = \mu\,V/L$

the current becomes $I = qn\mu\,A\,V/L$

$$\sigma = q \times n \times \mu$$ is the conductivity of the material

$$I = \sigma \frac{A}{L} \times V$$

Conductivity and Resistance

$$I = \sigma \frac{A}{L} \times V$$

$$\sigma = q \times n \times \mu$$ is the conductivity of the material

I-V relationship can be rewritten as $$V = \frac{1}{\sigma}\frac{L}{A} \times I$$

Compare this to the Ohm's law: $$V = R \times I$$

$$R = \frac{1}{\sigma}\frac{L}{A};$$

Resistance, conductivity, resistivity

$$R = \frac{1}{\sigma}\frac{L}{A}$$

The resistance of the sample with conductivity σ, the length L and the cross section area A.

$$\sigma = q \times n \times \mu$$

The conductivity σ [(Ohm ×m)$^{-1}$] is proportional to the free electron concentration in the sample n and the electron mobility μ.

n [m^{-3}] is the free electron concentration

(the number of electrons per unit volume)

μ [m^2/(V×s)] is the electron mobility
defined as the drift velocity - electric field ratio:
$\boldsymbol{\mu = v / E}$, or $\boldsymbol{v = \mu E}$

$$\rho = \frac{1}{\sigma}$$

The resistivity ρ [(Ohm ×m)]; using ρ,

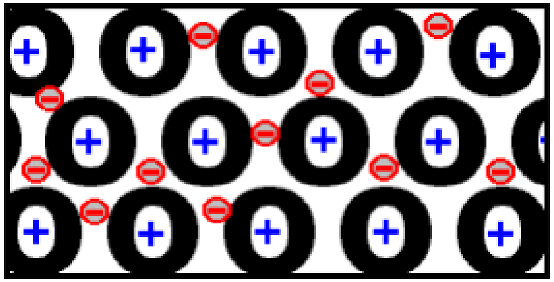
$$R = \rho\frac{L}{A}$$

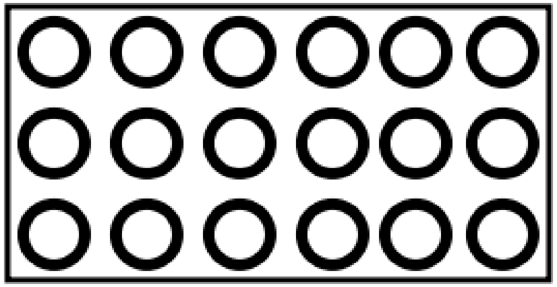
Conductors, Insulators and Semiconductors

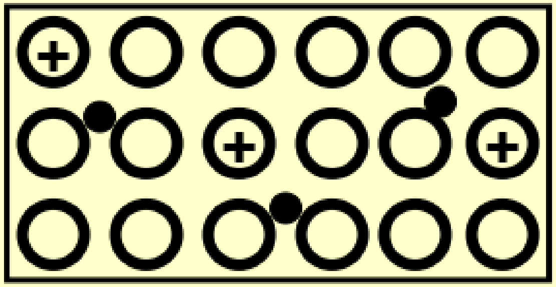
$$\sigma = q n \mu$$

The mobility in different materials differs around **1000** times.

The concentration of free electrons *n* in different materials differs around 10^{23} times!







Metal:
~ 10^{23} atoms per 1 cm^3

Every atom donates 1 free electron:
n ~ 10^{23} cm^{-3}

Insulator:
~ 10^{23} atoms per 1 cm^3;

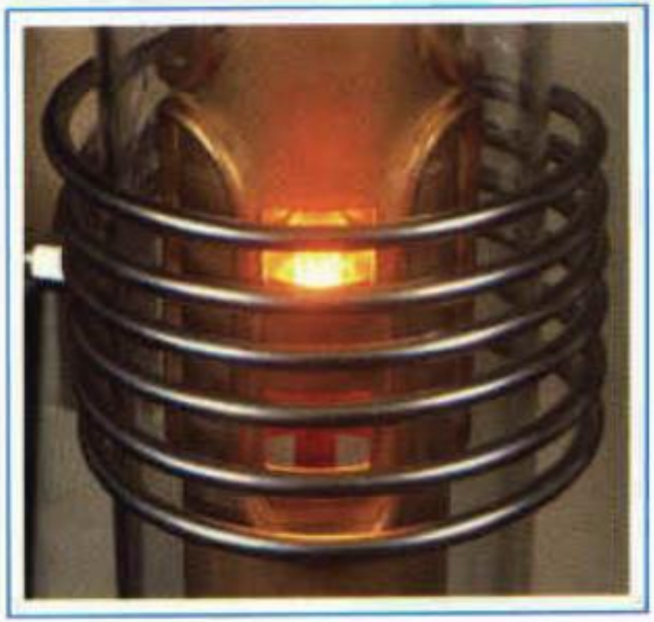
No free electrons:

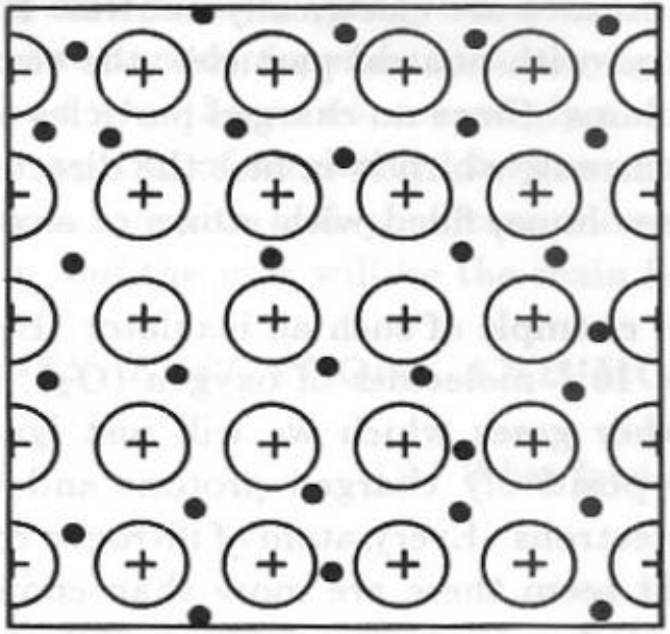
n ~ 0

Semiconductor:
~ 10^{23} atoms per 1 cm^3;

Some atoms donate free electrons
n ~ 10^{10} - 10^{19} cm^{-3}

Metals





In metals, the atom-to-atom interactions free up one electron from each atom.

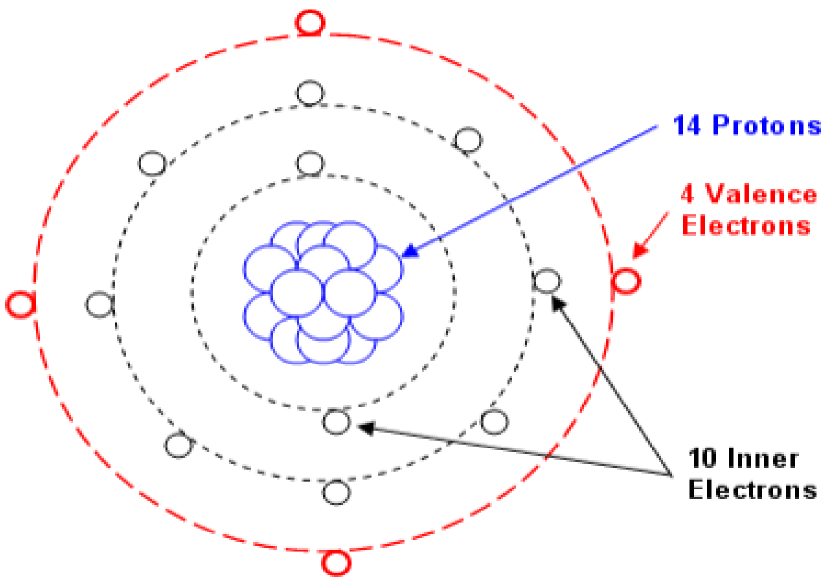
The metal crystals have as many free electrons as they do atoms.

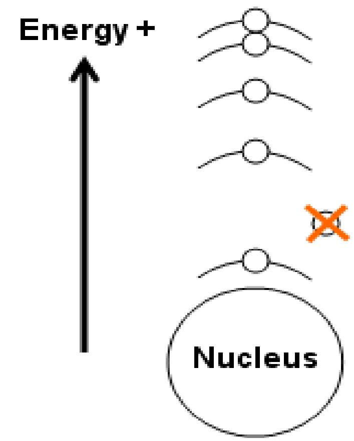
Atom concentration N ~ 10^{23} atoms per 1 cm^3. Free electron concentration, **n ~ 10^{23} cm^{-3}**

The metal conductivity is very high.

Free Electrons in Semiconductors

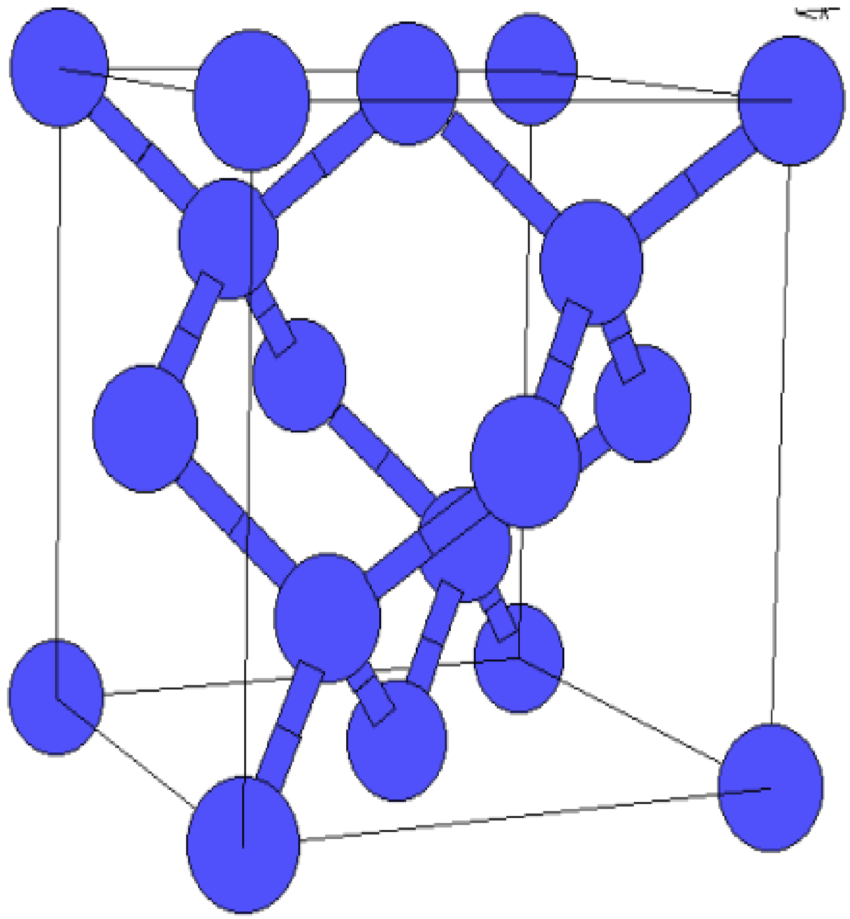
Silicon (Si) is the most important semiconductor material





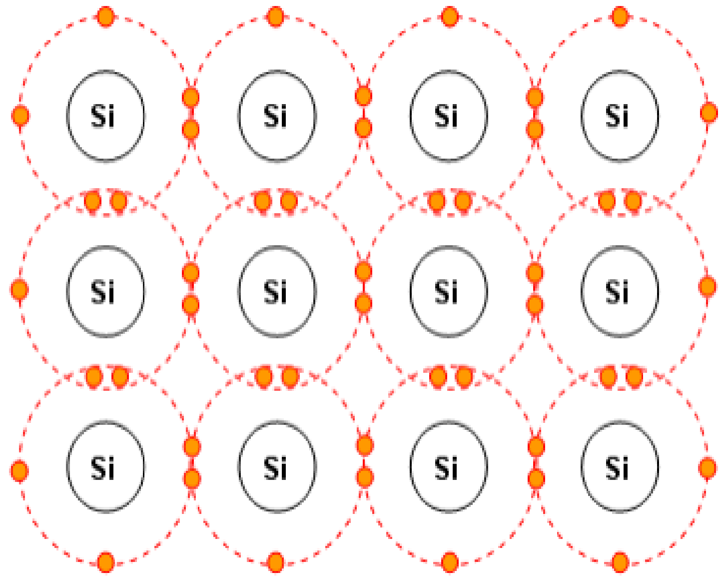
- ***Silicon atom.*** *There are 14 Protons in the nucleus, and 14 electrons orbiting. An electron can exist in any of these orbits, but not outside their confines.*
- *The farthest 4 are known as Valence electrons.*
- *No free electrons: the electrons in the isolated Si atom cannot leave the atom*

Si crystal structure



In Si crystal, each atom is connected to the four neighboring atoms by covalent bonds.

Silicon crystal

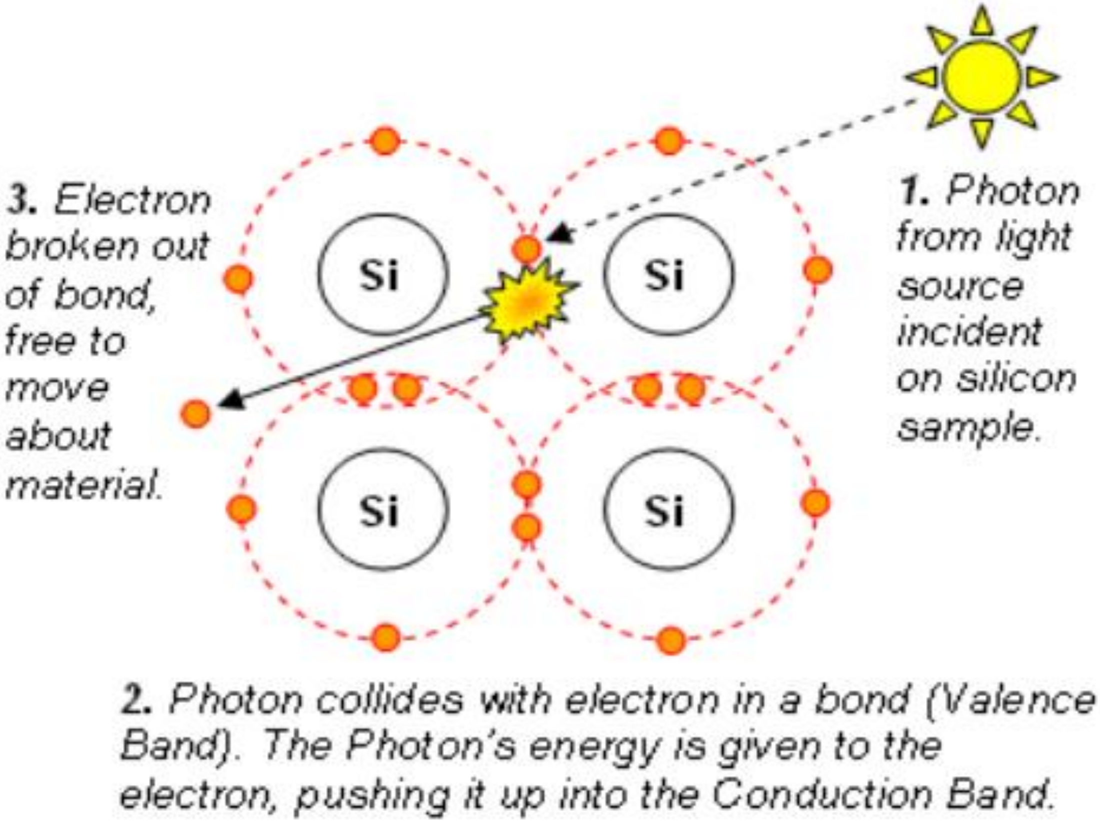


Si crystal lattice structure, showing the valence electrons associated with each bond.

Notice that each silicon atom now has **eight valence electrons**, but that **they are all shared**, two with each of its four neighbors.

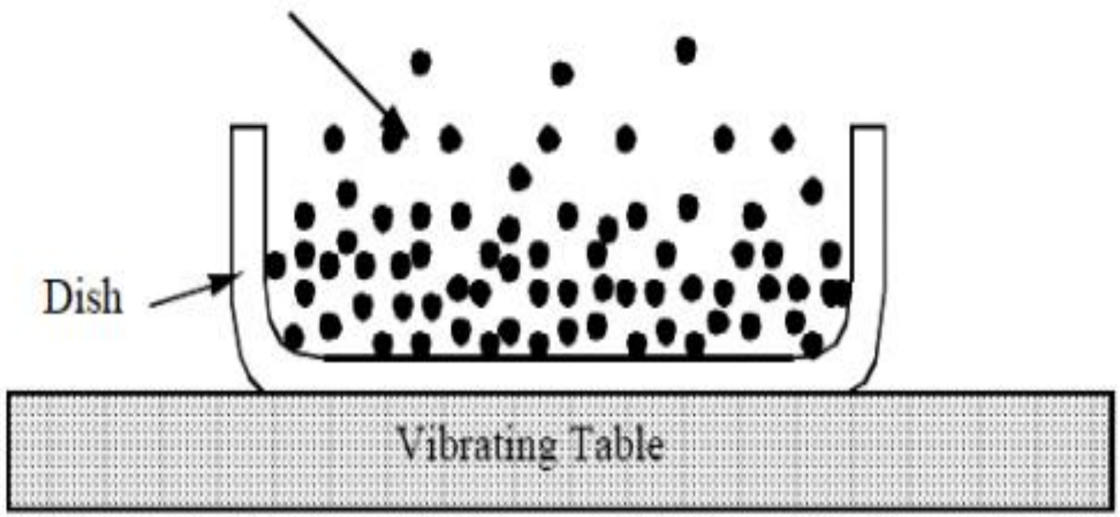
No free electrons!

Silicon crystal under illumination



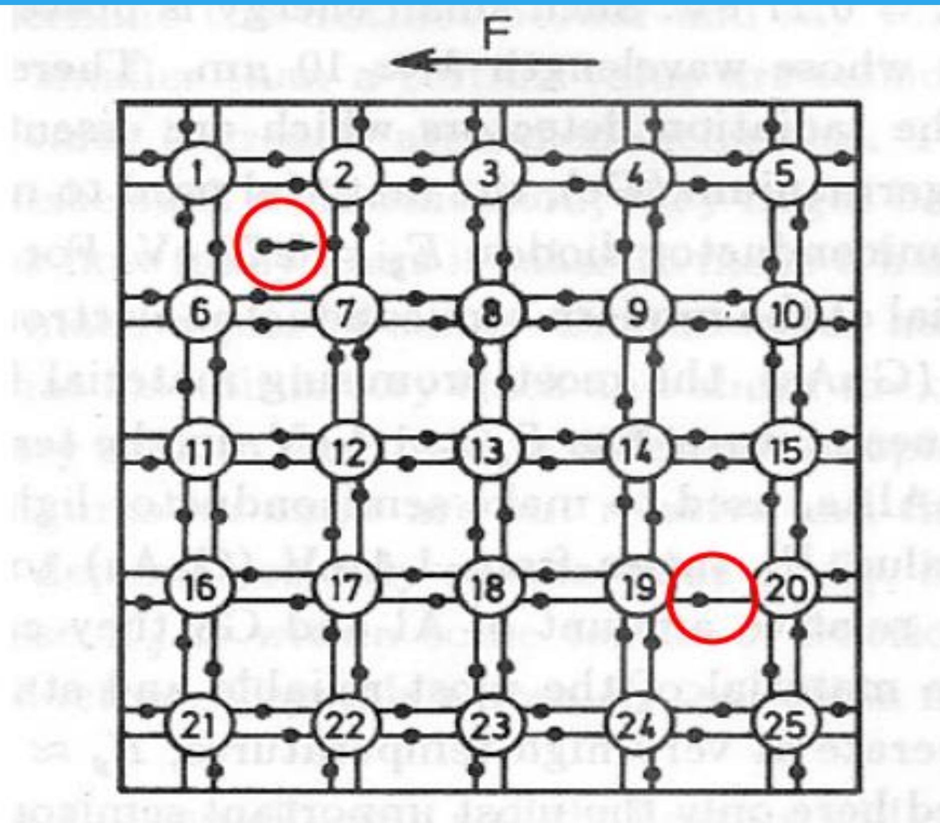
*The **photons** – elementary particles of light can break the bonds and create free electrons in the Si crystal*

Silicon crystal at elevated temperature



If the temperature is high enough the crystal lattice vibrates and delivers extra energy to electrons

Free electrons in semiconductors



The lattice vibrations supply extra energy to the electrons

Some of the electrons acquire high enough energy to become **free electrons.**

The term "free" means that the electrons can move around the crystal

Free electron concentration in semiconductors

The probability to acquire an energy high enough to break the atomic bonds is very low

This probability is a very strong function of the temperature
(at higher temperatures the lattice vibrations are stronger)

The energy required to produce a free electron in a crystal is called

the **bandgap energy, ΔE_G**

In the metals, the bandgap energy is equal to zero.

In dielectrics, the bandgap energy is much higher than in semiconductors.

$$n = N_0 \times e^{-\frac{\Delta E_G}{2kT}}$$

$k = 1.38 \times 10^{-23}$ J/K, is the Boltzmann constant,
T is the crystal temperature, in Kelvin (K)
$N_0 \approx 2\times10^{19}$ cm^{-3} for most semiconductor materials

Free electron concentration in semiconductors

$$n = N_0 \times e^{-\frac{\Delta E_G}{2kT}}$$

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k × T = 1.38 × 10^{-23} J/K × 300 K ≈

≈ 4 × 10^{-21} J (at room temperature, T ≈300 K)

In most semiconductors,

$E_G \approx (2\ldots10)\times 10^{-19}$ J

Note, $kT \ll E_G$

- ***Joule is too big unit to describe the electron energy***

STAY HOME STAY SAFE

THANKS…………..