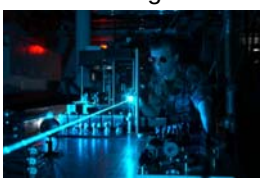
9.1 Applications of Quantum Mechanics

- Lasers
- Semiconductors
- Semiconductor devices

Lasers

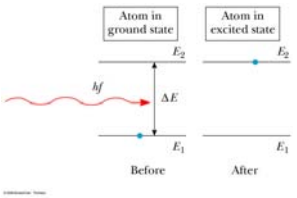
A laser is a light source that produces a focused, collimated, monochromatic beam of light.

The laser operates using the principle of stimulated emission of light.



Stimulated Absorption of light

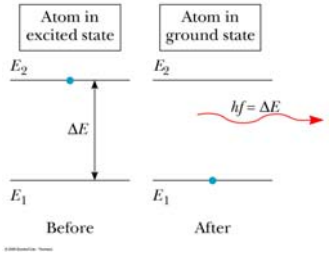
$\Delta E = hf$



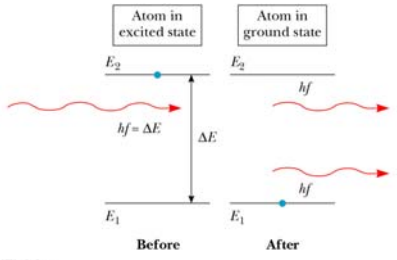
Oscillating electric field at the resonant frequency excited an electron.

Spontaneous Emission of light

This is the normal process of emission e.g. in an atomic arc lamp.



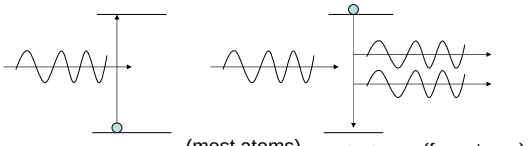
Stimulated Emission of light



Similar to stimulated absorption except from the excited state.

The excess energy is emitted as a photon that is in phase with the incident photon.

Probabilities of simulated absorption and emission



absorption (most atoms) emission (few atoms)

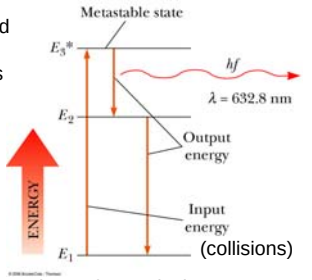
The probabilities for absorption and emission are the same.

Normally absorption dominates emission because most atoms are in the ground state.

Laser

In order to have stimulated emission dominate –
Need to have more atoms in the excited state than in the ground state i.e.

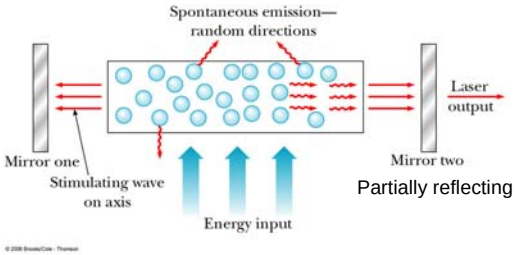
Population Inversion



(collisions)

a scheme for producing a population inversion in He Ne laser

Laser cavity



Stimulated Emission is enhanced along the direction of the reflected light giving a collimated light beam.

Lasers

ruby laser (1960)

Laser diode

Used in cd players etc.

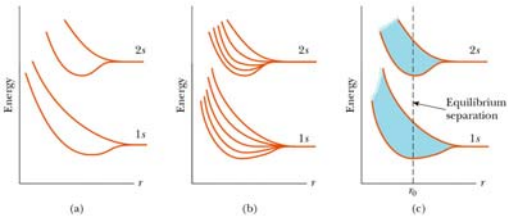
Semiconductors

Semiconductors are materials such as silicon that in the crystalline state can be used to fabricate components such as diodes and transistors used in electronics devices such computers, cell phones, music players etc.

The key feature of semiconductors is the energy gap (Band Gap) between filled and vacant energy levels

Energy levels

Band Structure



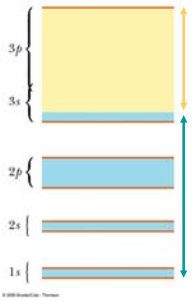
Two atoms

Five atoms

many atoms (Crystal)

Energy levels in a crystal of a conductor (Na)

Conductor
no energy gap between filled and empty levels.
Free movement of electrons



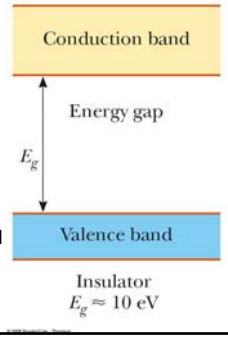
Empty levels

Filled levels

Energy levels in crystals of an Insulator

Insulator
Large energy gap.

Large energy cost for electron to jump to conduction band



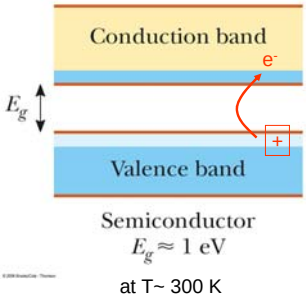
Energy levels in crystal of a semiconductor

Semiconductor
Moderate energy gap

Negative electrons can jump to the conduction band

Leaving positive vacancies (holes) in the valence band

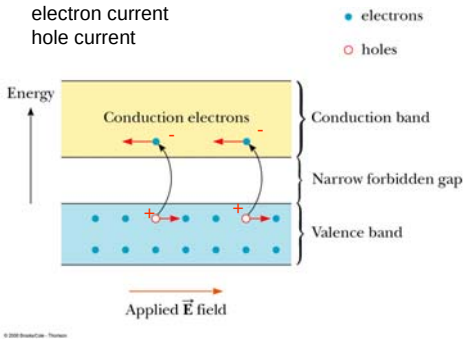
Both electron and hole are mobile



at T~ 300 K

Current flow in semiconductors

electron current
hole current



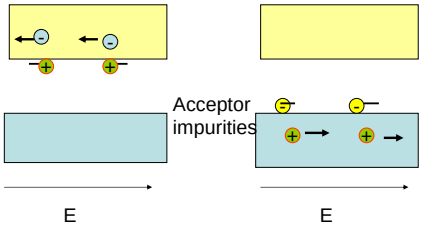
Doped semiconductors

n-type semiconductor
negative charge carriers
fixed positive charge

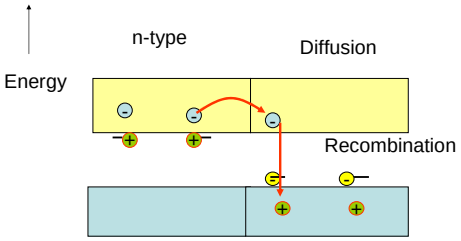
p-type semiconductor
positive charge carriers
fixed negative charge

Donor impurities

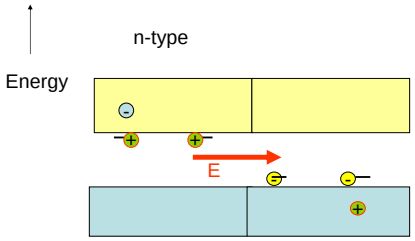
Acceptor impurities



p-n Junction



p-n Junction



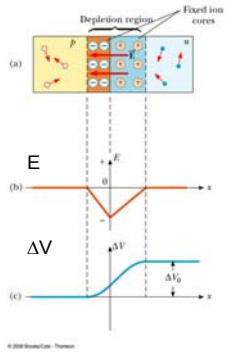
Depletion region (no mobile carriers)

Fixed charges give Electric Field

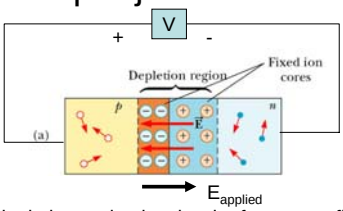
p-n Junction

Mobile charge carriers diffuse across the junction and create a depletion region of fixed charges.

At the interface a dipole is formed (+ - charges separate) creating an electric field and a potential difference.



p-n junction



The depletion region is a barrier for current flow

An applied voltage that opposes the internal electric field reduces the size of the depletion region and current flows Forward bias

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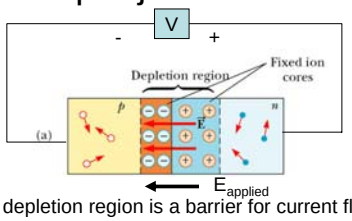
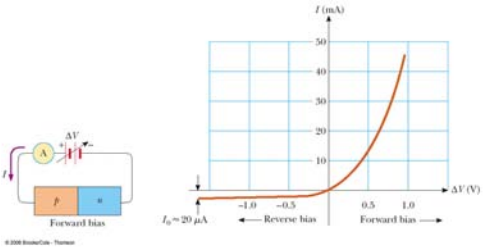
p-n junction



The depletion region is a barrier for current flow

An applied voltage that increases the internal electric field increases the size of the depletion region and no current flows. Reverse bias

p-n Junction diode

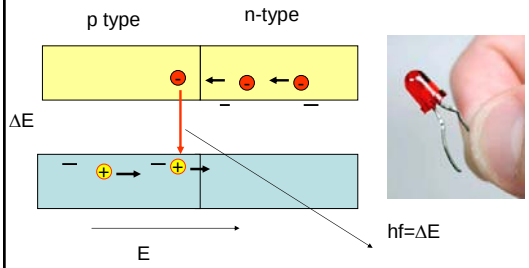


Current only flows in one direction.

p-n junctions

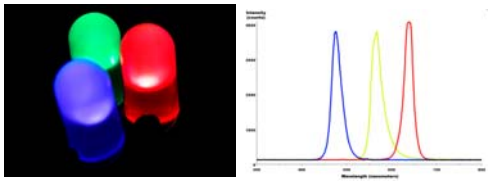
Diodes
Light emitting diodes
Solar Cells
Transistors

Light emitting diode LED



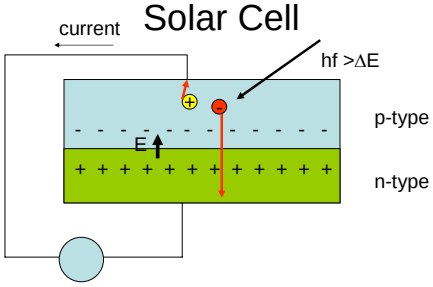
When charge carriers recombine light is emitted. The wavelength of the light is determined by the Energy Gap

Light emitting diode LED



Different colors are produced by different energy gaps.

Solar Cell



Light creates electron-hole pairs that diffuse across the p-n junction and are separated by the electric field causing current to flow through the circuit.

Solar cells

Solar cells convert sunlight into electrical energy

Sunlight is free but the cost of solar cells is high

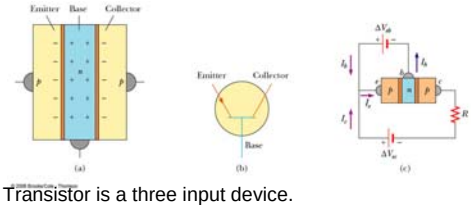
Currently

- Single crystal silicon.
- Polycrystalline silicon

New Advances

- New semiconductor materials (CdTl, $CuInSe_2$)
- Thin films materials.

Transistors

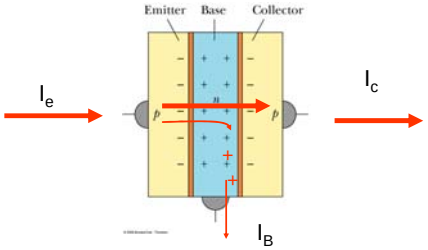


Transistor is a three input device.

A small current in one input (base) I_B changes the current flowing between the other two (emitter-collector) I_C giving rise to a Current Gain β ~100

$$I_c = \beta I_B$$

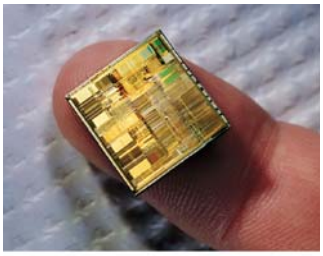
Current flow in a transistor



The base current I_B changes the charge in the base and electric field across the EB junction.

A small change in I_B produces a large change in I_c

Integrated circuits



Many (10^7 -10^9) of small components are fabricated onto semiconductor chips.