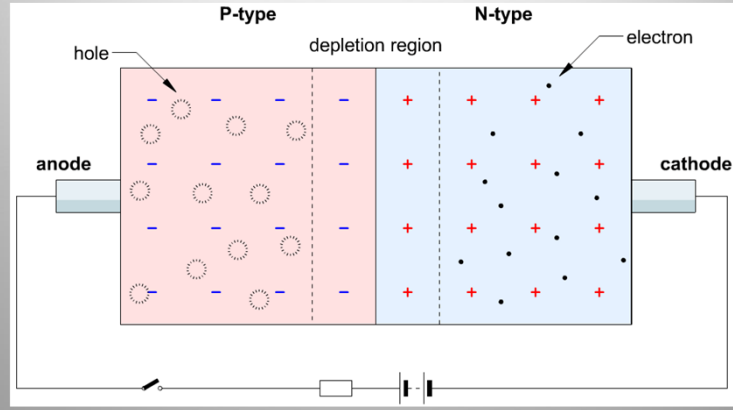
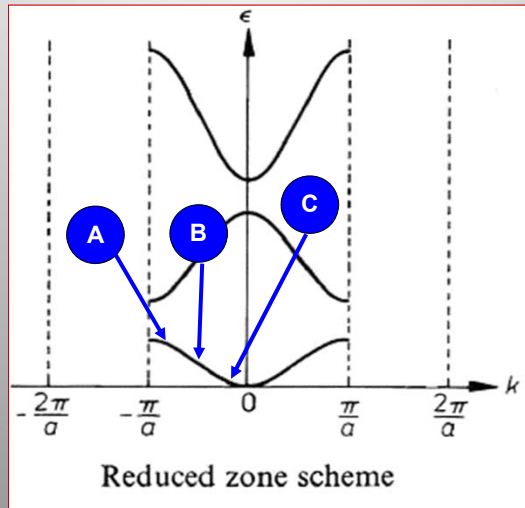


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Manchester University



PHYS432  
**Materials Physics**

Quiz question 5:



## p-n junction

- Consists of two semiconducting regions of opposite type with a common interface
- Many technological apps:
  - rectification, isolation, V-dependent capacitor
  - solar cells, photodiodes, light emitting diodes (LEDs), laser diodes
  - Basic element of bipolar junction transistors (BJTs) and field effect transistors (FETs)

## Contact Potential – two unlike metals

- **Work function** = minimum energy required to remove an e<sup>-</sup> from a metal
- CPD, = **contact potential difference** =  $\Delta\phi$ , develops across the junction (M2 is at higher potential than M1)
- $\Delta\phi$  is T dependent (thermocouples)
- **Kelvin method** (a nulling method) can be used to determine work function of unknown metal

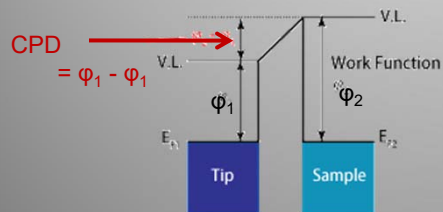
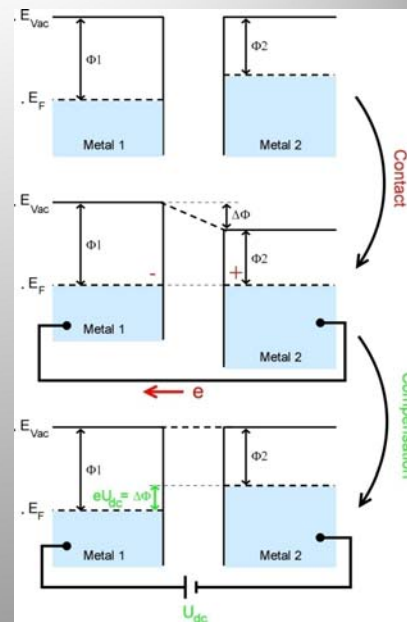


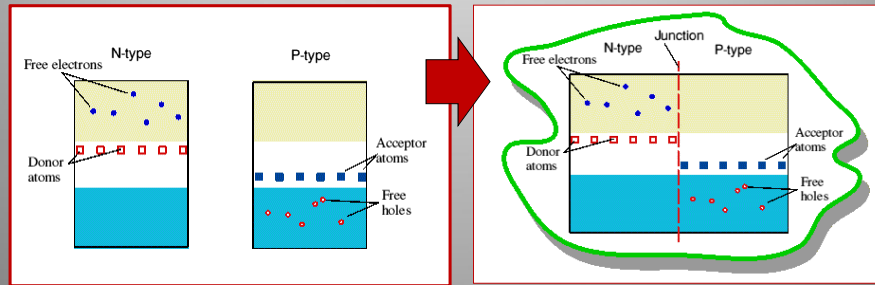
Fig. 1 Band diagram of tip and sample



## A first look at the p-n junction

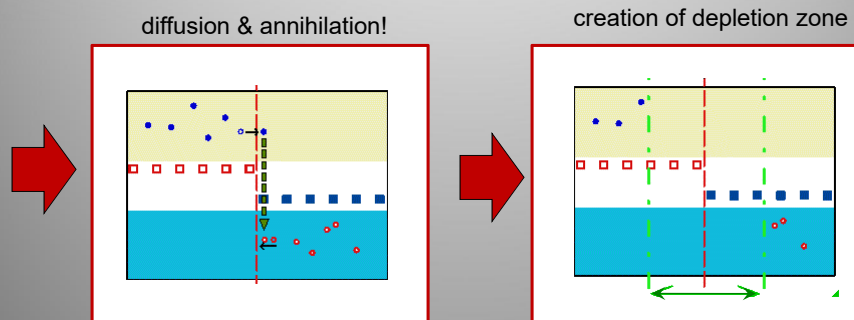
- Imagine joining together the two different types of SC (perfectly, so XTAL structure varies smoothly at border!)
- Interesting things happen at the junction!

*This is not the way p-n junctions are actually formed!*



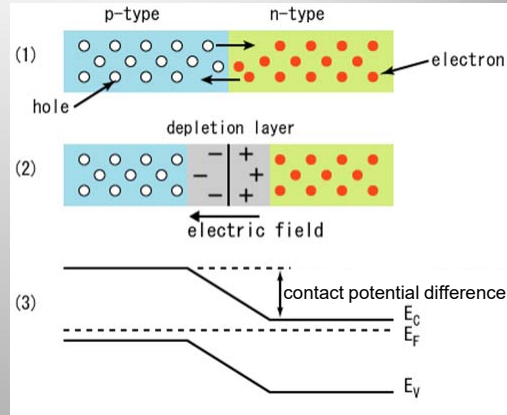
## A first look at the p-n junction

- There are drift and diffusion currents in the materials
- A “built-in” voltage difference between the conduction bands of the two materials occurs as the Fermi energies align.



## p-n junction

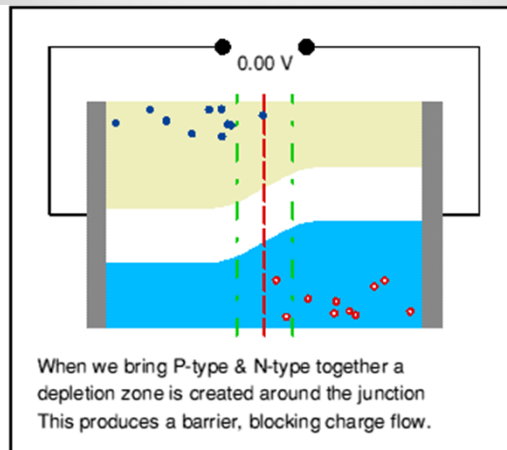
- Formation of depletion layer & CPD
- Diffusion of majority carriers + recombination creates depletion layer



<http://www.acsu.buffalo.edu/~wie/applet/pnformation/pnformation.html>

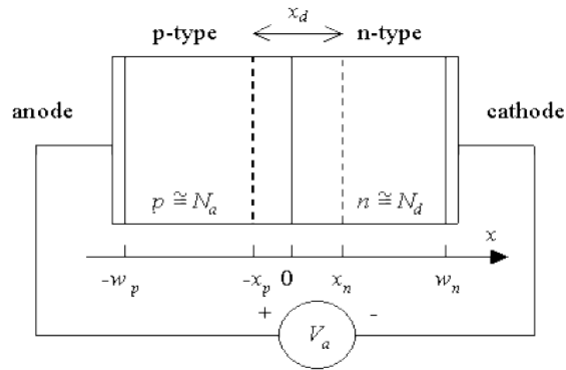
[http://www.yenka.com/freecontent/attachment\\_action?quick=14r&att=2923](http://www.yenka.com/freecontent/attachment_action?quick=14r&att=2923)

## p-n junction



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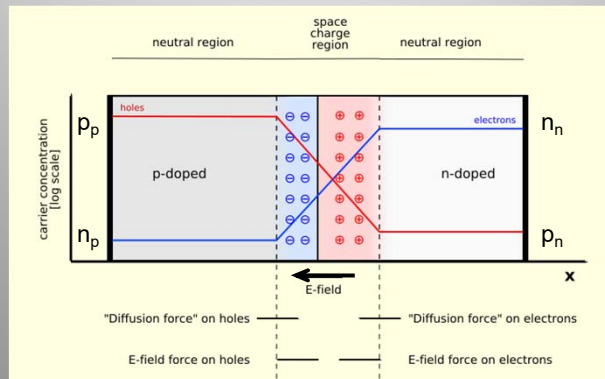
## p-n junction

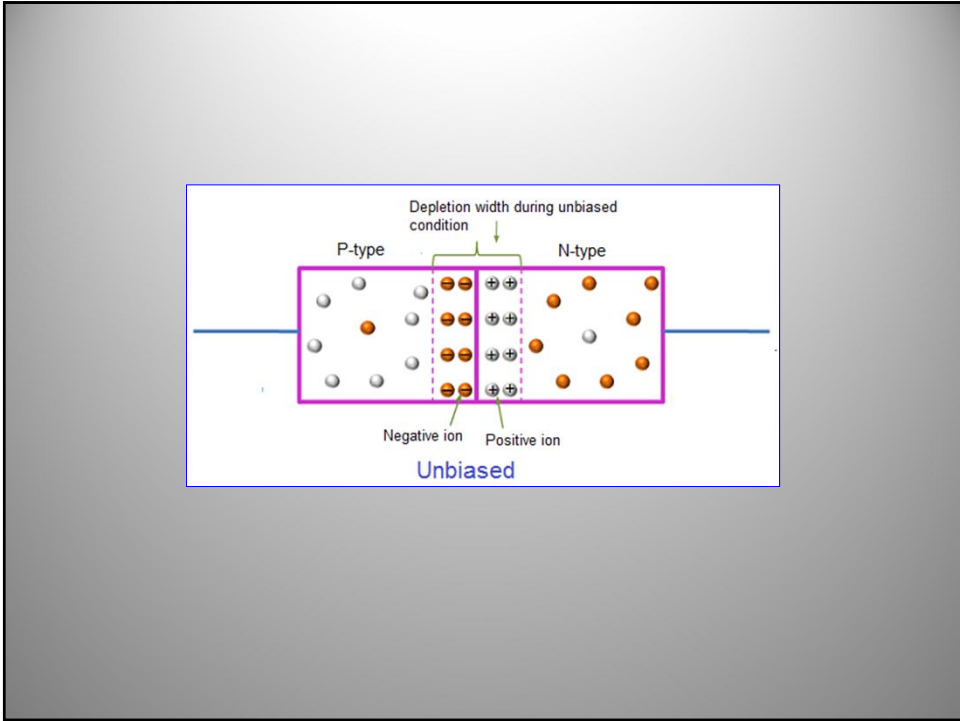
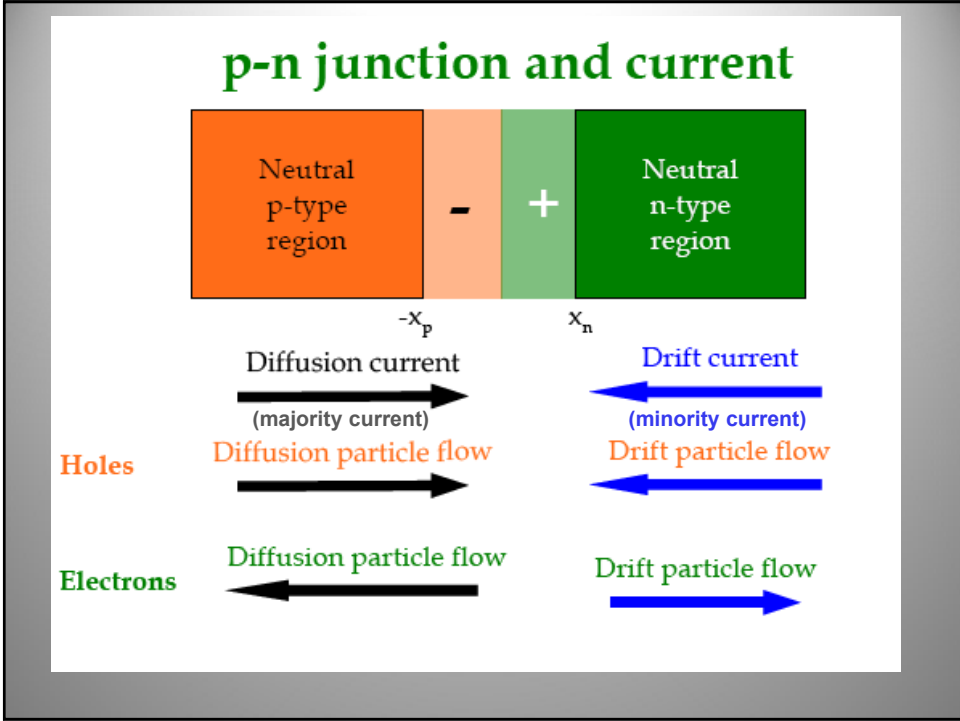


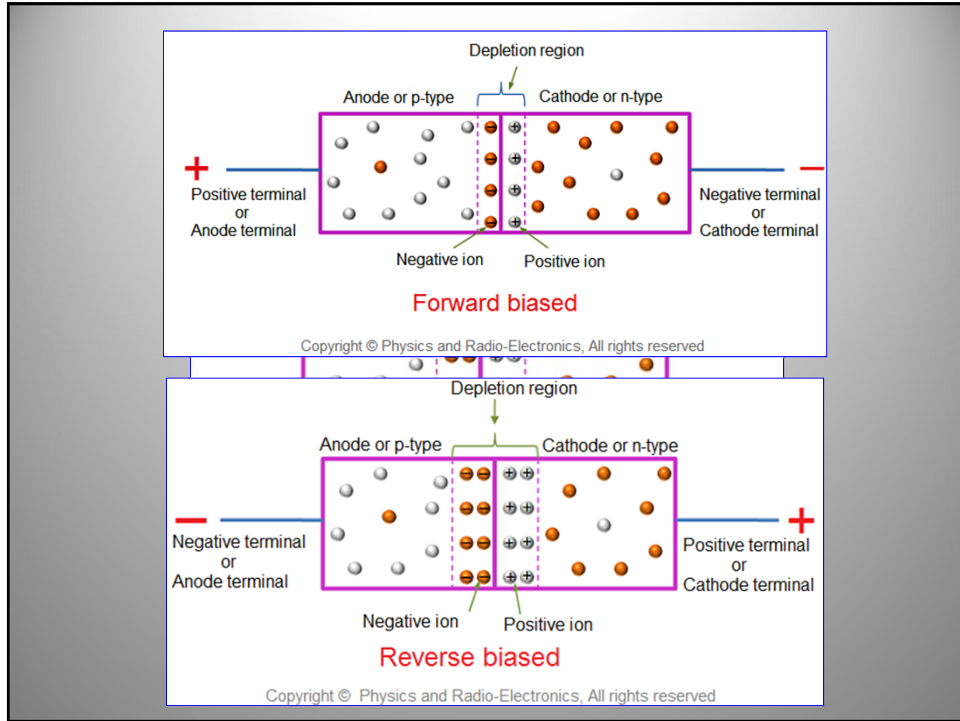
**Abrupt p-n junction** when the doped regions are uniformly doped

## The carriers

Carrier particle and concentration		
	majority carriers	minority carriers
n-type	e <sup>-</sup> , n <sub>n</sub>	h <sup>+</sup> , p <sub>n</sub>
p-type	h <sup>+</sup> , p <sub>p</sub>	e <sup>-</sup> , n <sub>p</sub>







## Applications

- Rectification

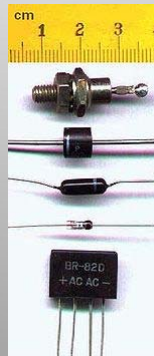
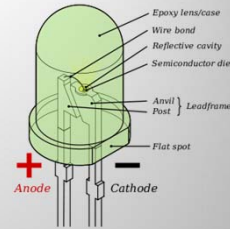
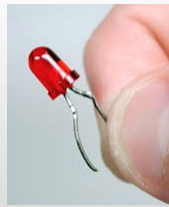


- V regulation



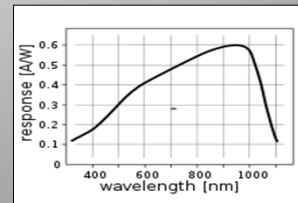
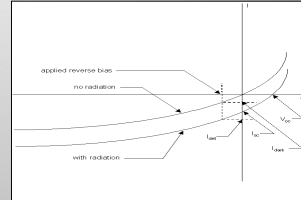
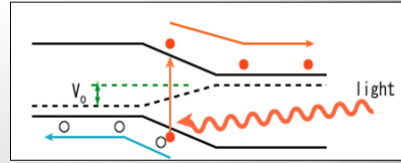
- Photovoltaics

- LEDs



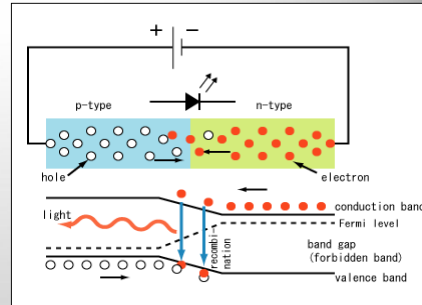
# Photodiode

- A reverse biased diode has a small drift current
- Exposure of the p n junction to light can excite  $e^-$  into the CB (leaving  $h^+$  in VB)
- These particles give rise to a current under influence of the electric field

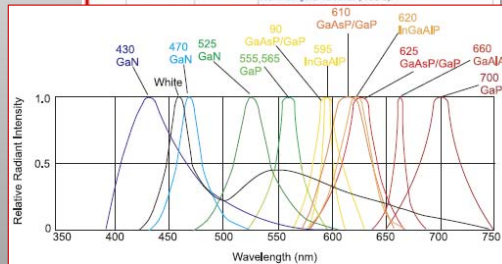


# Light emitting diode

- A forward biased diode can act as an LED
- As  $e^-$  enter the CB in the p region, the recombination process emits radiation (similarly with  $h^+$  in the VB)
- The radiation emitted depends on the band gap, which can be tuned (in direct gap SCs) to specific values of  $h\nu$



Color	Wavelength [nm]	Voltage [V]	Semiconductor Material
Infrared	$\lambda > 760$	$\Delta V \approx 1.9$	Gallium arsenide (GaAs) Aluminum gallium arsenide (AlGaAs) Aluminum gallium arsenide (AlGaAs)



Ultraviolet	$\lambda < 400$	$3.1 < \Delta V < 4.4$	Gallium nitride (GaN) Aluminum nitride (AlN) Aluminum gallium nitride (AlGaN) Aluminum gallium indium nitride (AlGaInN) — (down to 210 nm <sup>2</sup> )
White	Broad spectrum	$\Delta V \approx 3.5$	Blue/UV diode with yellow phosphor



# Semiconductor lasers

- very high doping enhances carrier injection
- population inversion from high bias and  $E_f$  below VB edge
- recombination:  $e^-$  jumping to lower E levels in excited atoms, emitting  $\hbar\omega \sim E_g$ 
  - spontaneous emission from unstable states
  - stimulated **coherent** emission from metastable states
- sandwich between mirrors

