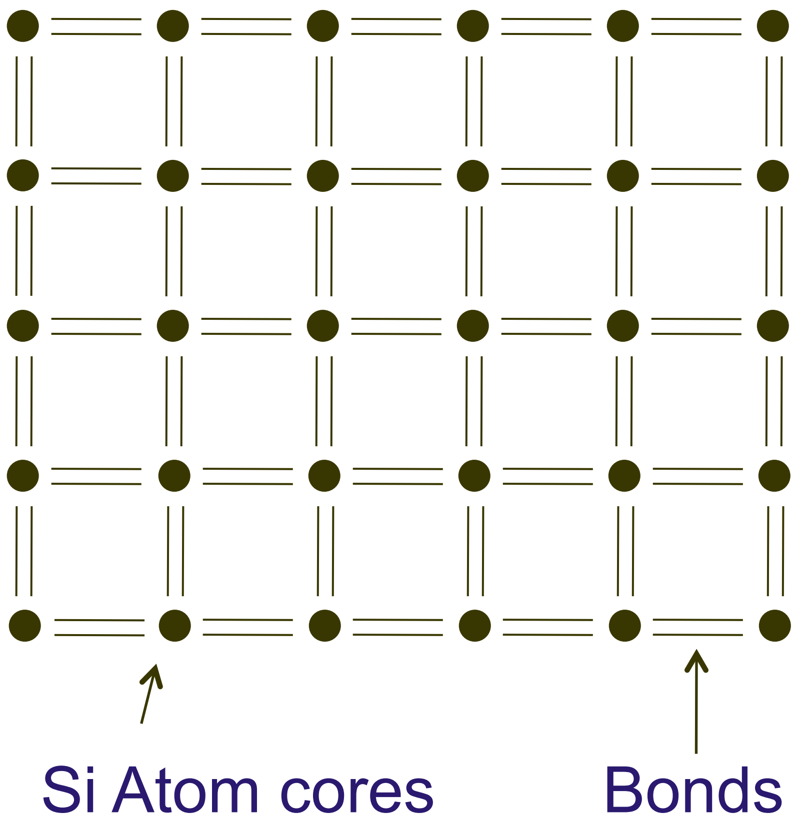
EEE105
"Electronic Devices"

Dr Richard Hogg,
Centre for Nanoscience & Technology, North Campus
Tel 0114 2225168,
Email - r.hogg@shef.ac.uk

Lecture 6

- Holes
- Conduction in intrinsic semiconductors
- Comparison intrinsic semiconductors vs. metals
- Optical excitation of semiconductors

Semiconductor Materials

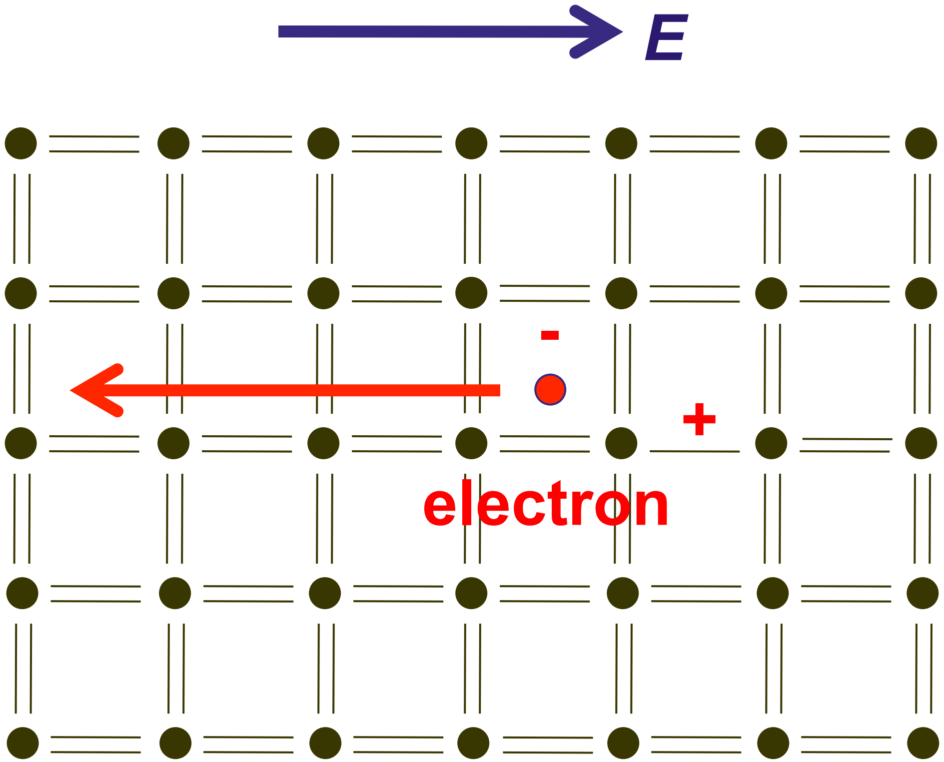


Semiconductors generally covalently bonded

For Si – 4 outer electrons "shared" with neighbours to fill the electronic shell (and minimise energy)

n.b. 3D shape (2D representation for paper/ screen!)

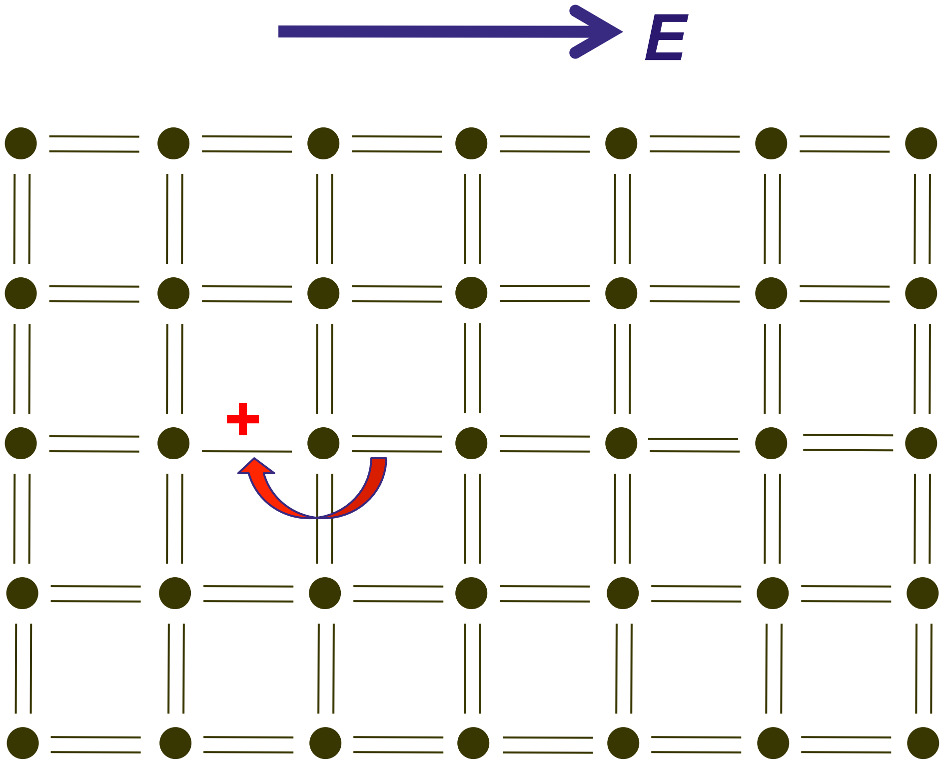
Conduction Processes



Conduction electron has –ve charge

Charge must be conserved so it leaves a +ve "hole"
-An unfilled electron state

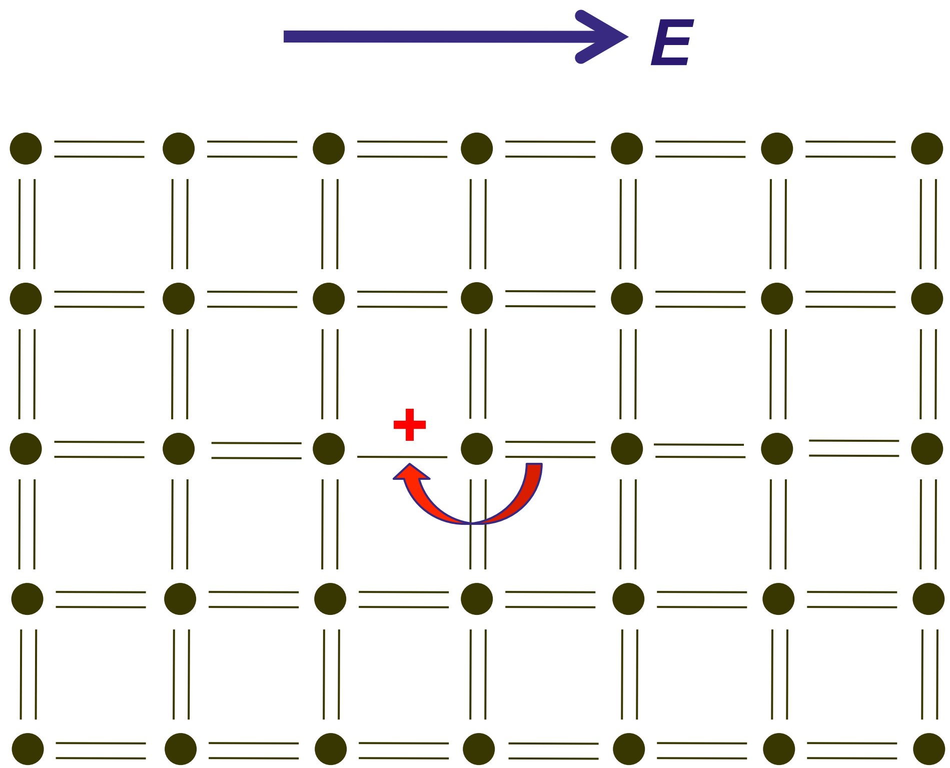
What about the "Hole"???



An electron at a neighbouring bond can move to the empty state

The positive charge moves

What about the “Hole”???



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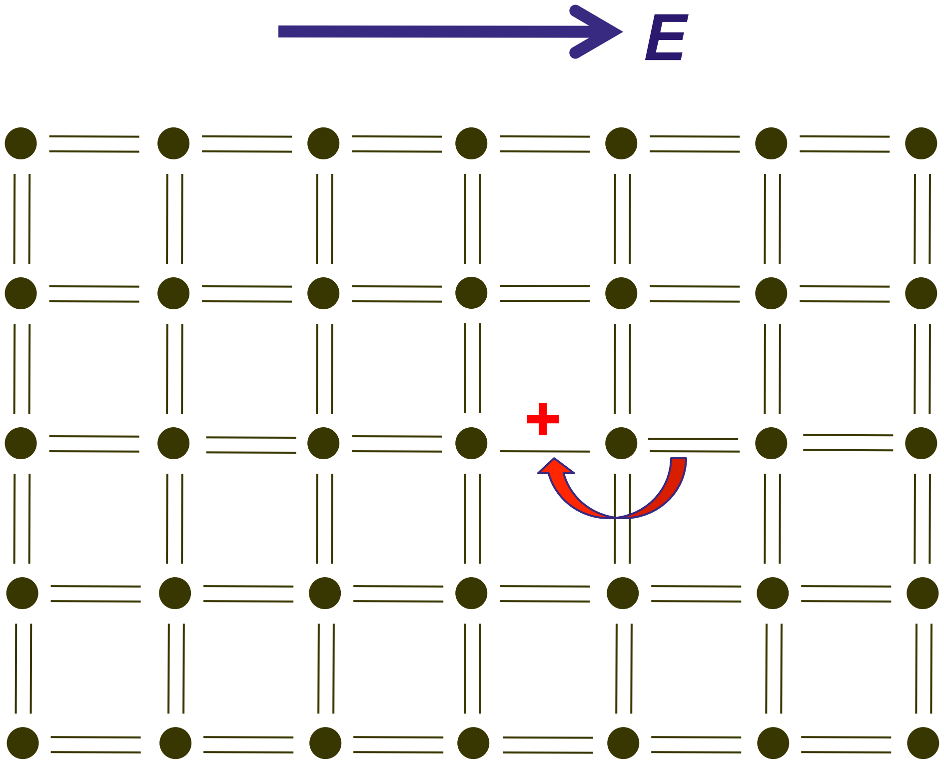

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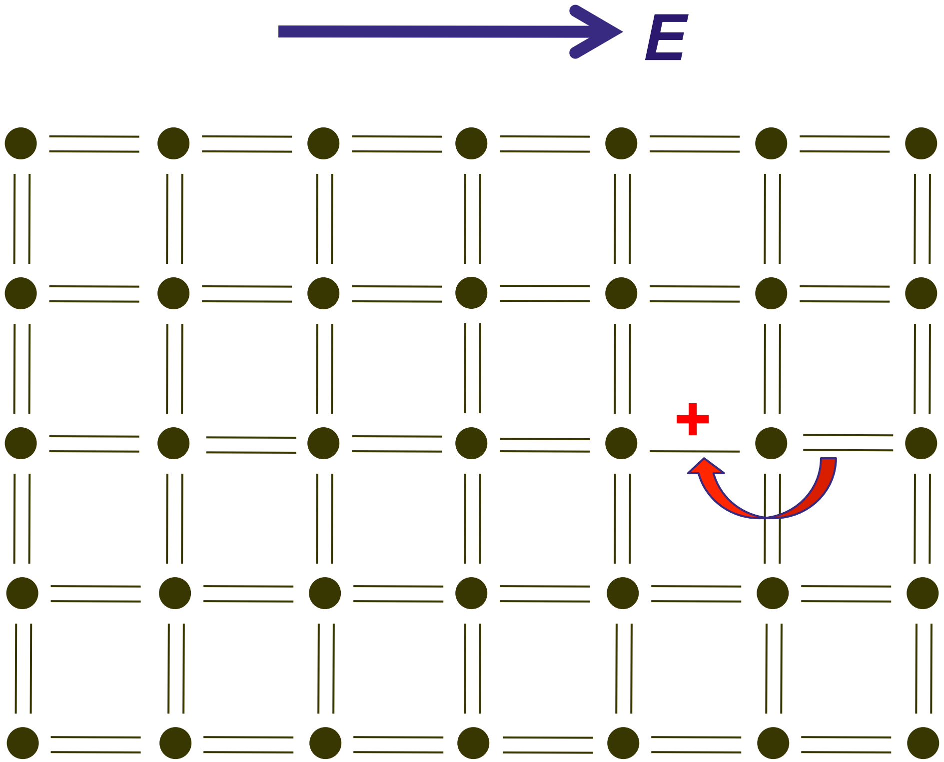


An electron at a neighbouring bond can move to the empty state

The positive charge moves

Holes

- It is convenient to consider the motion of one particle with charge +q through the semiconductor – this is called a "hole"
- Motion similar to that described for electrons – it has an effective mass and a mobility as described previously
- We need to specify m^*_e, m^*_h, μ_e , μ_h
- Motion of hole is in opposite sense to electron under an E-field – net current flows add with regard to current

Intrinsic Semiconductors

- For a pure, intrinsic semiconductor, for every electron excited to the conduction band (free electron) there is one free hole → $n=p=n_{i,}$ Where n= density free electrons, p=density free holes, n_i = intrinsic carrier concentration
- Total density of free carriers is given by $n+p=2n_i$
- Conductivity for intrinsic semiconductor will be

$$\sigma = nq\mu_e + pq\mu_h = n_i q\left(\mu_e + \mu_h\right)$$

Conductors Vs Semiconductors

- Conductors – we have just considered one carrier

– the electron

$$\sigma = nq\mu$$

- Intrinsic semiconductor – we have two charge carriers

– the electron and hole

$$\sigma = nq\mu_e + pq\mu_h = n_i q(\mu_e + \mu_h)$$

Electrons and Holes

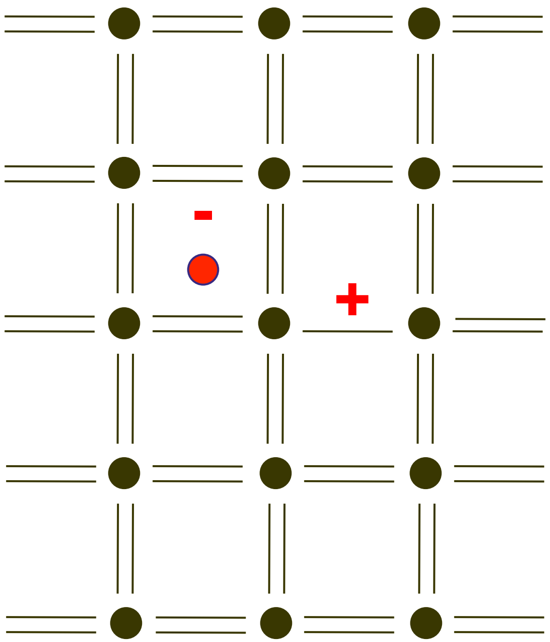
The free conduction electron may give up excess energy and return to the valence band

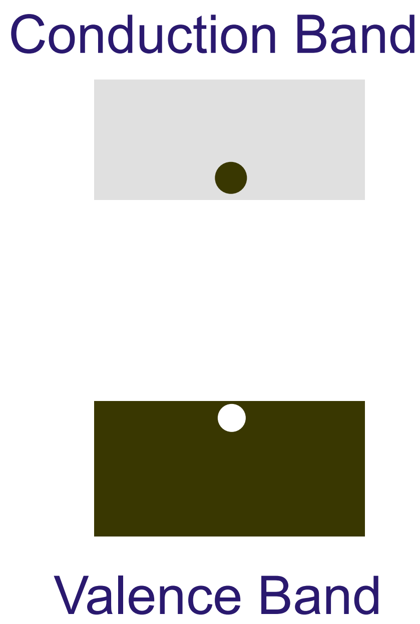
This corresponds to an electron and hole recombining

The excess energy is given up as heat (phonons) or light (photons)

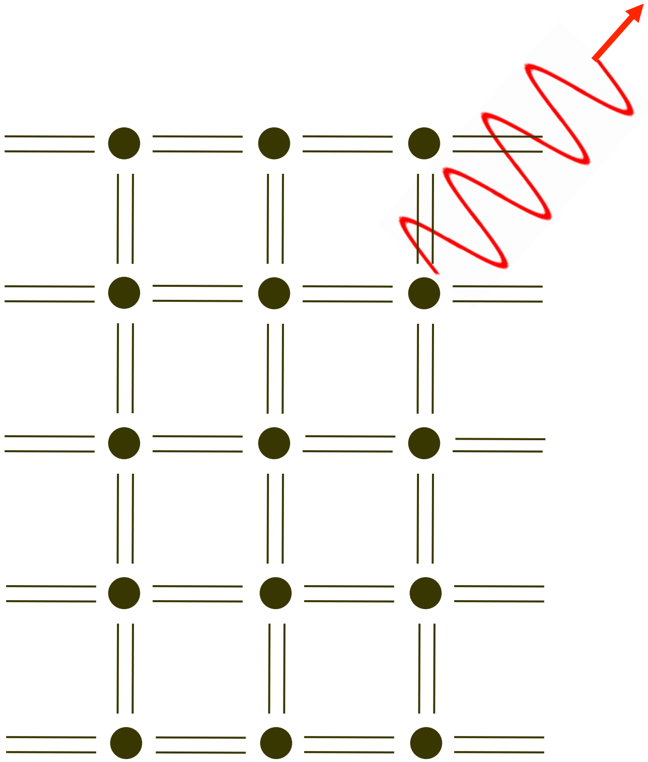
Charge, Energy and Momentum must be conserved

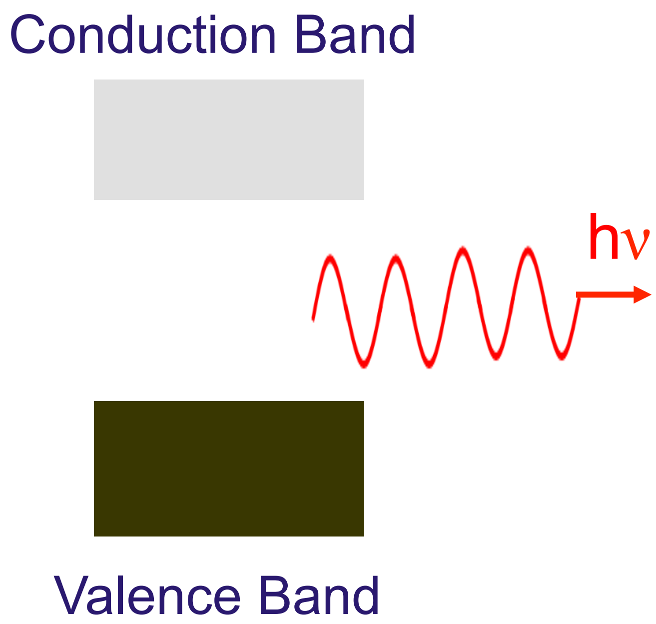
Before e-h Recombination





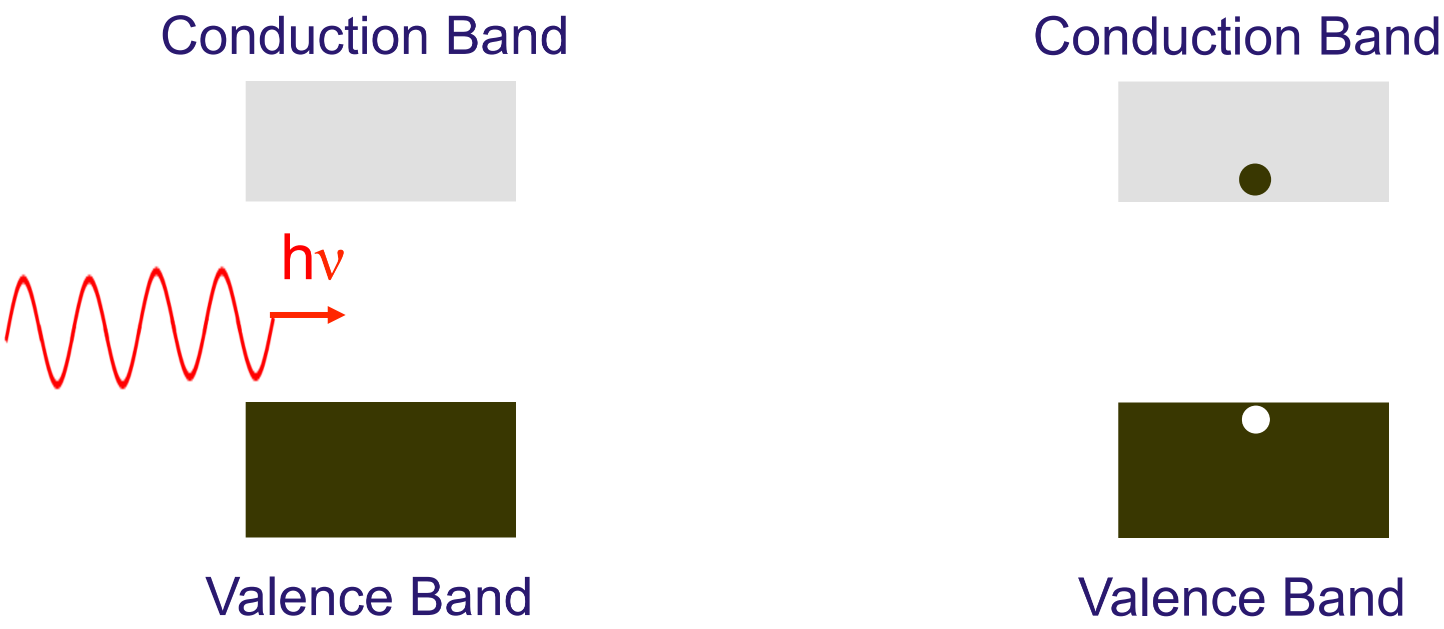
After





Energy $=W_g = E_c - E_v$ is given up to light or phonons

Absorption of Light



Photon with energy greater than the band-gap is annihilated
Energy promotes electron to CB

Summary

- In a semiconductor atoms are covalently bonded in a regular array – in Si each atom has a bond with each of 4 neighbours in a diamond lattice structure
- An electron with enough energy may be promoted to the conduction band and is no longer tied to this bond leaving a +ve charge at the bond (an empty electronic state)
- The conduction electron may move around the crystal

Summary (2)

- The empty electronic state – or +vely charged "hole" may also move around the crystal as a charge carrier similarly to the electron – we now need to consider electron and hole effective masses, mobility, etc
- Conduction in intrinsic semiconductors is made up of both electron and hole transport
- Electrons and holes may recombine, giving up the energy of the conduction electron - to phonons or photons – reverse process (absorption of photon with enmergy > band-gap excites an electron to CB

