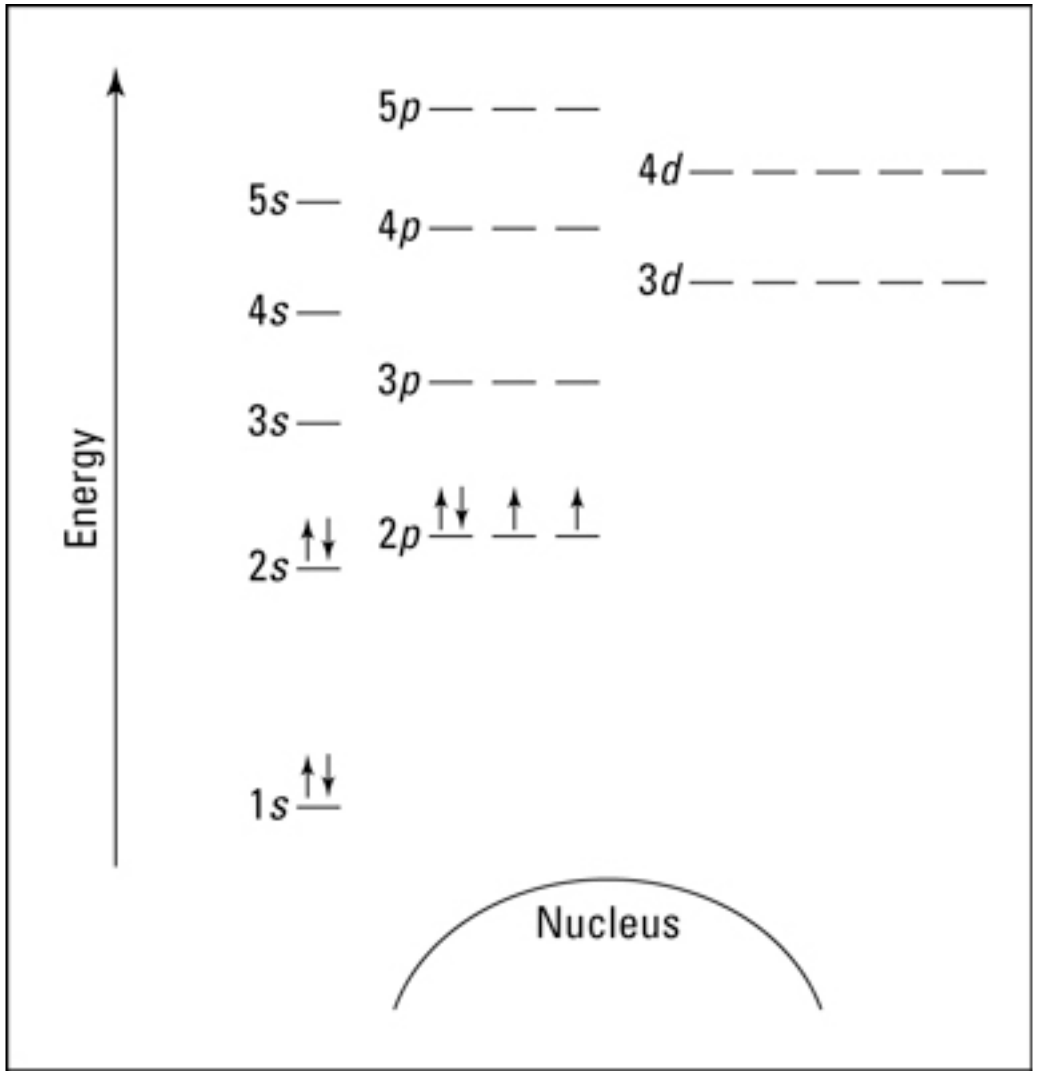
Electrons in materials

(where are they, what is their energy)

Lone atoms

A single atom has electrons in ‘shells’ and ‘sub shells’. Each of these have a distinct energy level. The diagram shows an example of energy levels in an oxygen atom.

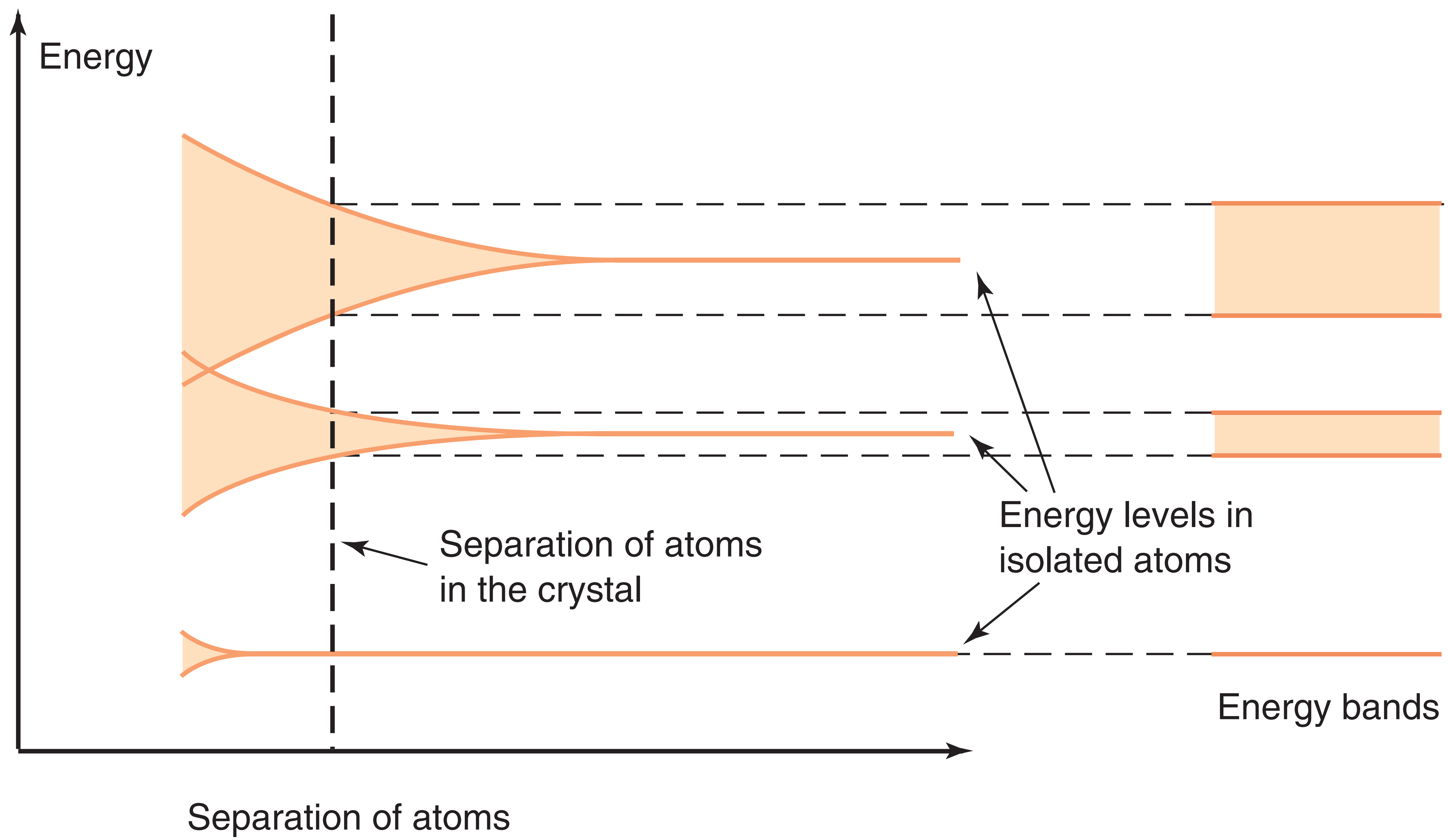


http://media.wiley.com/Lux/65/167865.image2.jpg

According to the Pauli exclusion principle, no two electrons can have the same energy (and this is easily achievable for single lone electrons).

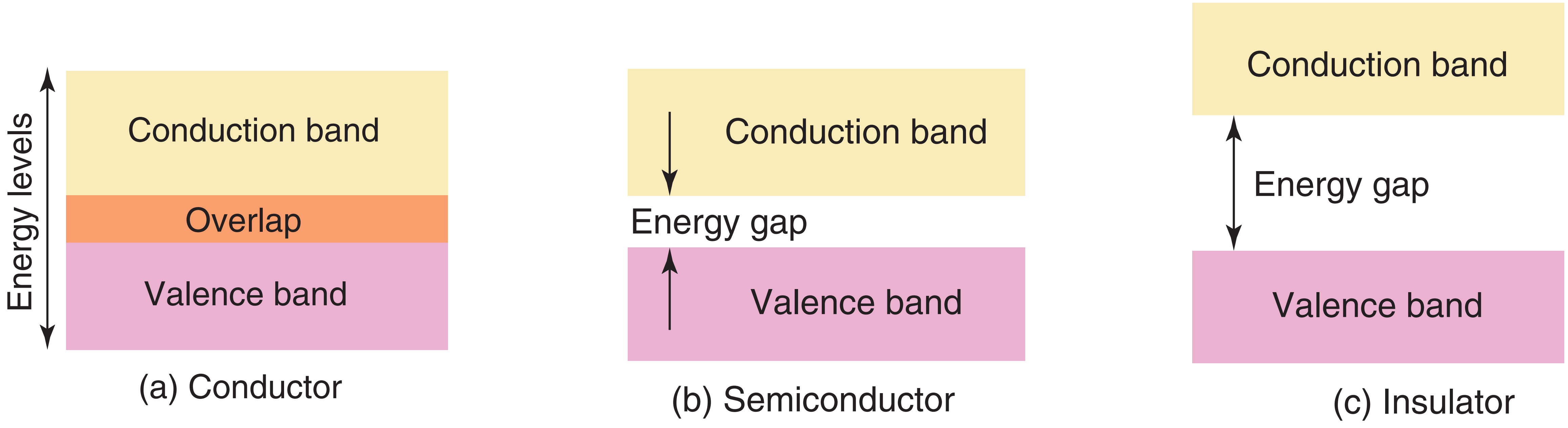
Nearby atoms

When multiple, identical atoms are brought near together in a solid, there is a smearing of the energy levels so that none occupy the same energy state.



continued...

- This smearing causes electrons to occupy 'bands' of energy instead of specific energy levels. The outer shell of electrons forms the **valance** band.
- Electrons which can freely move through the solid are said to occupy a different energy band, known as the **conduction** band.
- We can classify conductors, insulators and semi conductors by their band structures and the energy gaps between these structures.



A conductor has electrons which can **easily move** between the conduction and valance bands, whereas this gap is **too large** for electrons to bridge in insulators.

Semiconductors have a small band gap (which can be bridged in certain conditions).

Jacaranda *Physics 2*, 3rd Ed. p345

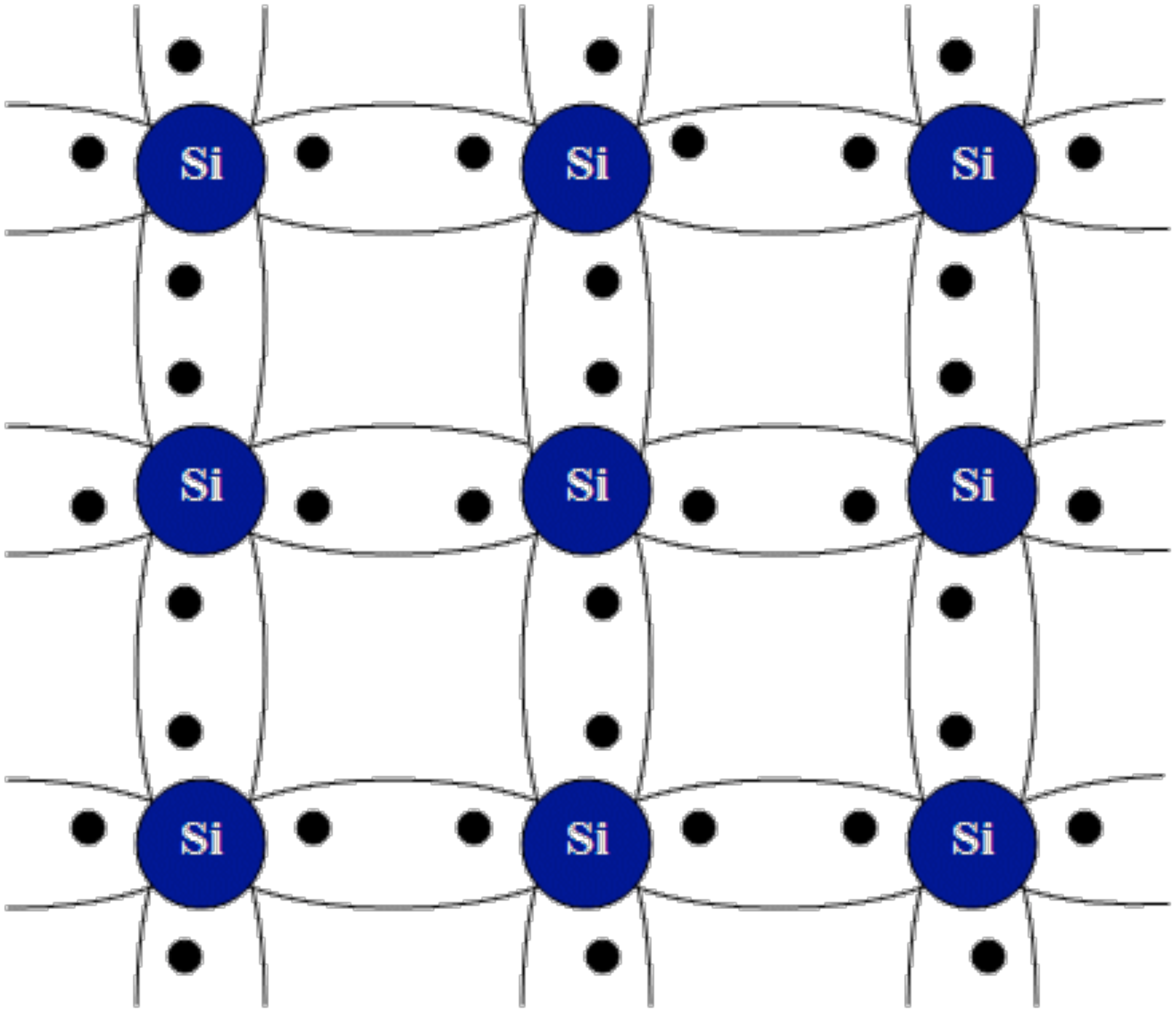
Semiconductors

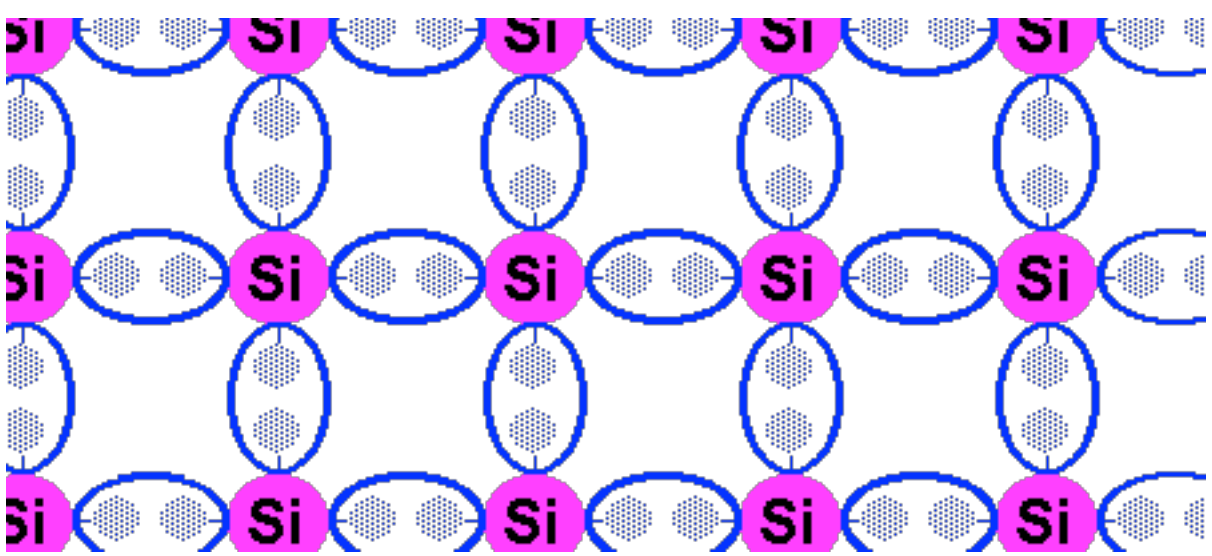
- Conductors are usually metal and contain free (unbound) electrons which are able to conduct electricity through the material.
- Semiconductors are much more similar to insulators in which electrons are part of specific covalent and ionic bonds.
- However, semiconductors are ‘weak insulators’ because the electrons can still be released from such bonds into the conduction band.

Semiconductors cont...

- Semiconductors are normally made from group 4 elements on the periodic table - these have 4 valence electrons. The most common is silicon (germanium has also been used).
- The silicon atoms form a 'diamond cubic' crystal structure, where each valence electron is shared with another nearby silicon atom.

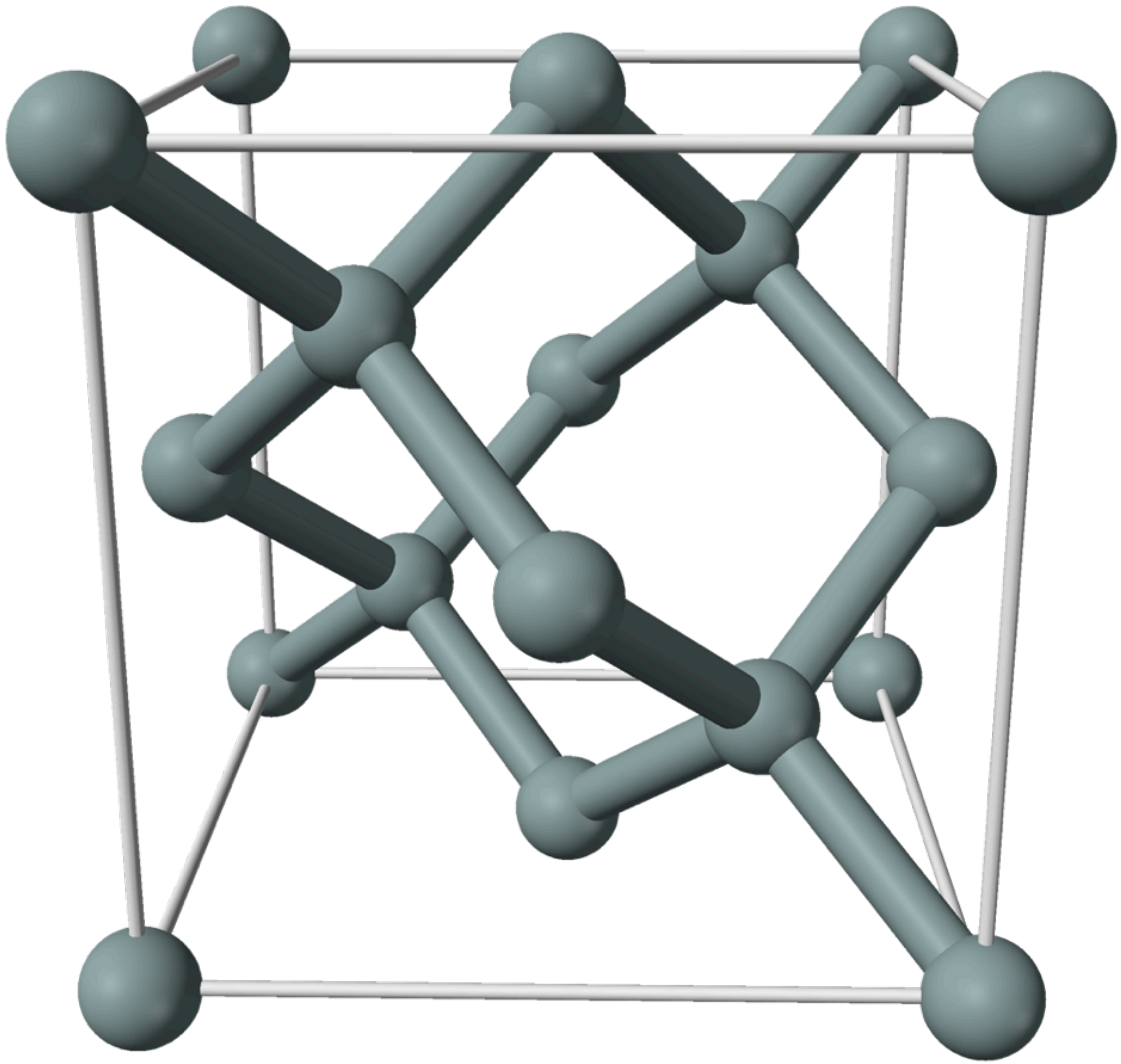
http://cac-science8.wikispaces.com/file/view/periodic_table2.png/32894291/periodic_table2.png





Silicon **bonding** structure. Covalent bonds are formed where electrons are shared.

http://www.pfk.ff.vu.lt/lectures/funkc_dariniai/images/silicon3.gif
http://www.alpcentauri.info/Silicon_covalent_bond.gif



Silicon **crystal** structure

atomic spacing =0.54nm

http://upload.wikimedia.org/wikipedia/commons/f/f1/Silicon-unit-cell-3D-balls.png

Semiconductors cont...

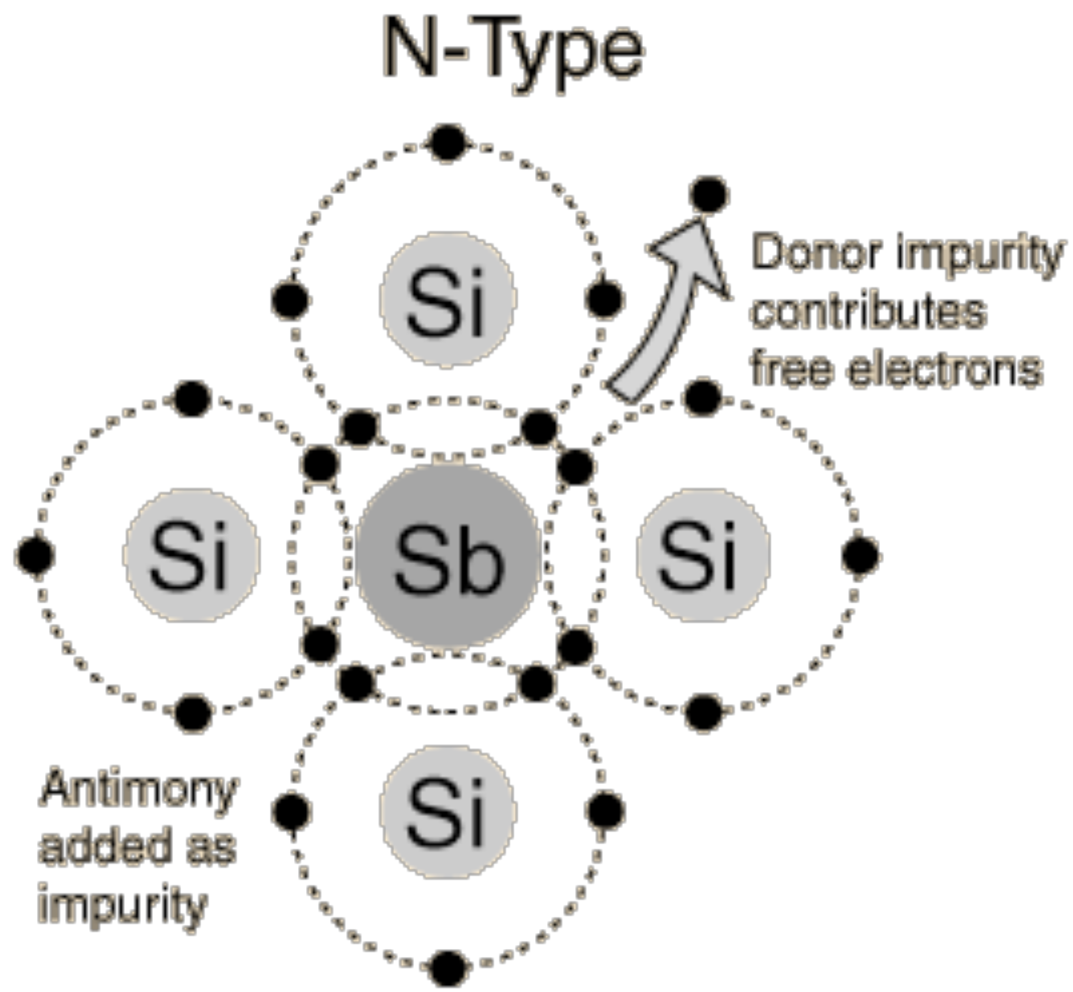
- If an electron is excited from the valence band into the conduction band (by thermionic processes, or incident radiation etc), it leaves behind a 'hole' in the valence band.
- The 'hole' can move through the material in the valence band because electrons move to fill it, leaving a hole elsewhere.
- So both the 'hole' and the conduction band electron are free to move through the material. Their direction will be determined by a potential difference (holes to negative, electrons to positive)

Doping

- A very common way of altering the electrical properties of a semiconductor is to add ‘dopant’ atoms into the uniform (silicon) crystal structure.
- The effect of doping is to introduce new energy levels between the conduction and valence bands. This is a bit like a ‘ladder’, helping electrons move between the two levels.
- The dopant atoms only have to be present in very small quantities to change the electrical behaviour of the semiconductor (1 in 200,000 atoms). There are two types of doped semiconductors:

N-type semiconductors

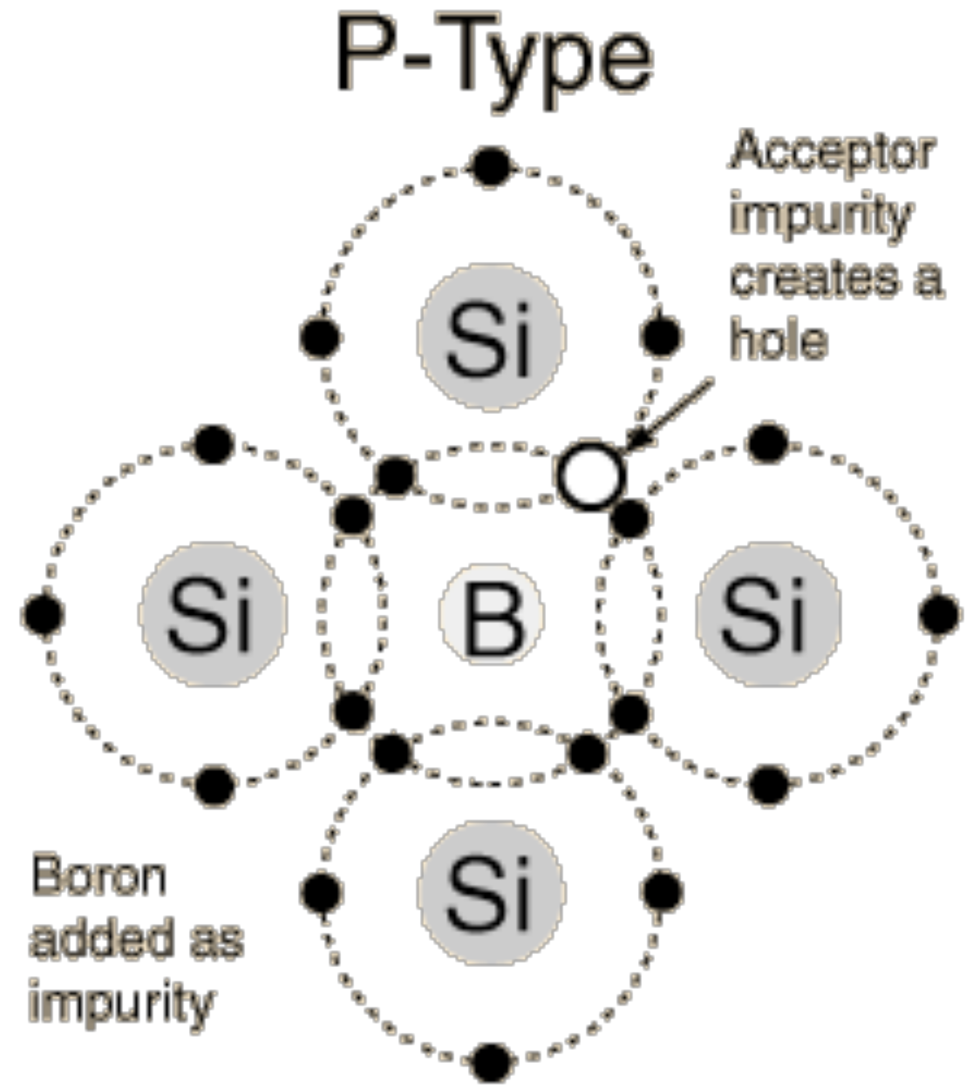
- These are doped with group 5 elements, providing a surplus electron (since they have five valence electrons).
- The extra electron cannot remain in the valence band and so moves to the conduction band.



http://hyperphysics.phy-astr.gsu.edu/hbase/solids/dope.html

P-type semiconductors

- These are doped with group 3 elements, creating an extra ‘hole’ (since they only have three valence electrons).
- The hole allows electrons to move through the material as other electrons ‘fill’ the hole.



http://hyperphysics.phy-astr.gsu.edu/hbase/solids/dope.html

Questions

1. Describe the model we used to demonstrate the propagation of holes and electrons in a semi conductor.
2. Compare qualitatively the number of electrons which are free to drift from one atom to another in semiconductors, conductors and insulators.
3. What normally happens to the resistance of a wire when you heat it?
4. Would you expect a semiconductor such as silicon to behave differently? How?