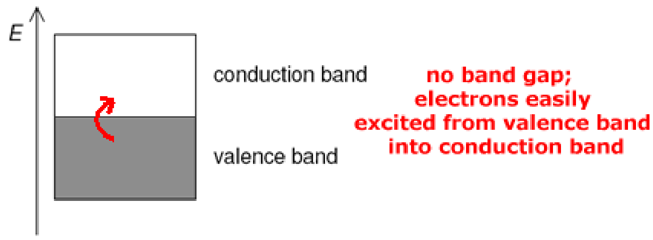
Answers to Exercise 5.2
Conductors, Insulators and Semiconductors

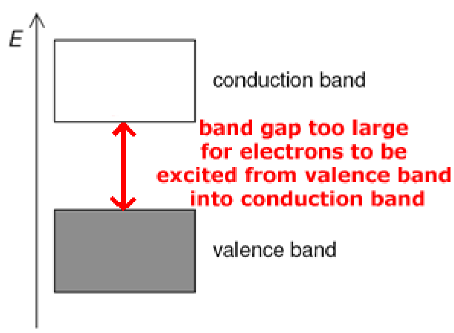
1. In a metal, the energy gap between the valence band and conduction band is very small (sometimes zero). As such, electrons in the valence band are easily excited into the conduction band when a potential is applied, allowing current to flow. Current is the movement of electrons[*] in an unbound state[†] such as the electrons excited into the conduction band.



[*] *In physics, the convention is to talk about current as the movement of positive charges – essentially the movement of the holes left behind when the electrons move in the opposite direction. In chemistry, we prefer to talk about the movement of electrons directly. It may sound like your physics and chemistry professors are talking about different things, but they're not.*

[†] *An unbound state is a state (orbital) which is so close in energy to other states* ***that have space for more electrons****. Thus, the electron is not "bound", but can freely move to those other states (and back again).*

2. In an insulator, the energy gap between the valence band and conduction band is large. As such, applying a potential will not usually provide enough energy to excite electrons from the valence band into the conduction band. In an insulator, the electrons are therefore in a bound state[†] (the valence band) and cannot move to other states (orbitals), so current does not flow.



[†] *A bound state is a state (orbital) that is not close in energy to any other states* ***that have space for more electrons****. As such, electrons in it are "bound", unable to move freely.*

3.

(a) Doping is only necessary to make an extrinsic semiconductor. An intrinsic semiconductor is a material that is a semiconductor without any alteration.

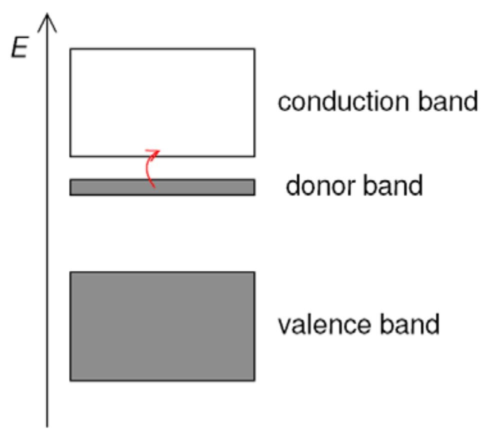
*The term **<u>intrinsic semiconductor</u>** literally means the material is **<u>intrinsically</u>** a semiconductor.*

(b) An **<u>n-type</u>** semiconductor refers to an extrinsic semiconductor made by doping with a material with extra valence electrons. Thus, the current flows primarily due to movement of **<u>n</u>**egative electrons in the conduction band.

A **<u>p-type</u>** semiconductor refers to an extrinsic semiconductor made by doping with a material with less valence electrons. Thus, the current flows primarily due to the movement of **<u>p</u>**ositive "holes" in the valence band.

(c) In all extrinsic semiconductors, the role of the dopant is to decrease the band gap by introducing an additional band.

In an n-type semiconductor, the dopant introduces a donor band. The donor band contains electrons, but it is higher in energy than the valence band. Thus, the relevant band gap becomes the gap between the donor band and the conduction band. Because this is smaller than the gap between the valence band and conduction band, it requires less energy to excite an electron from the donor band into the conduction band. Once in the conduction band (an unbound state), these electrons can move freely, allowing current to flow.



In a p-type semiconductor, the dopant introduces an acceptor band. The acceptor band is a source of 'holes' (that electrons can be excited into). Thus, the relevant band gap becomes the gap between the valence band and the acceptor band. Because this is smaller than the gap between the valence band and the conduction band, it requires less energy to excite an electron from the valence band into the acceptor band. This leaves 'holes' in the valence band which can be 'filled' by other electrons. Thus, current can flow.