ELECTRONS IN SOLIDS

Lecture 13

A.H. Harker
Physics and Astronomy
UCL

5 Electrons in Solids - Overview

5.1 Experimental values

5.1.1 Electrical Resistivity

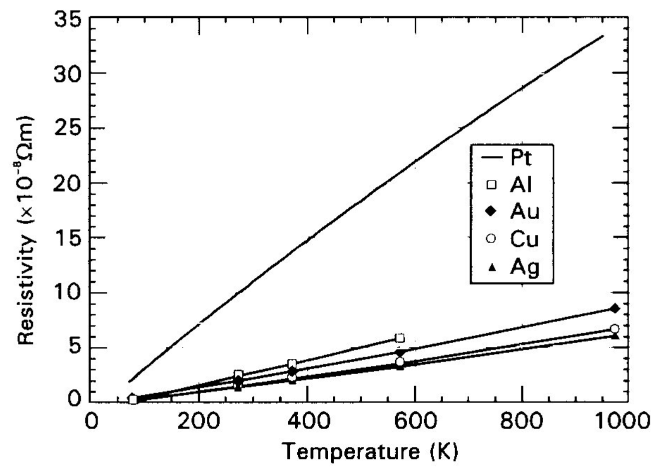
Element	Resistivity (Ωm)	Element	Resistivity (Ωm)
Lithium	8.9×10^{-8}	Germanium	0.46
Sodium	4.2×10^{-8}	Selenium	10^{-2}
Sodium	4.2×10^{-8}	Silicon	10^{-3}
Copper	1.7×10^{-8}	Tellurium	4.4×10^{-3}
Silver	1.6×10^{-8}		
Tin	1.1×10^{-7}	Boron	1.8×10^{4}
Barium	5.0×10^{-7}	Phosphorus	10^{9}
Manganese	1.9×10^{-6}	C (diamond)	10^{11}

Divide materials into:

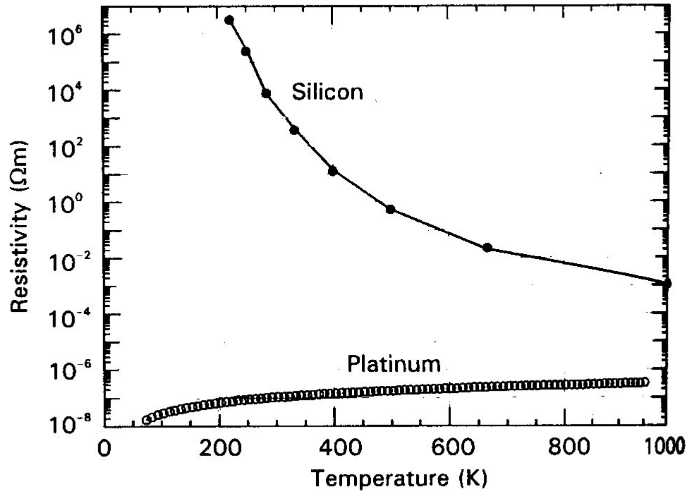
- ***metals* resistivities between 10^{-8} and 10^{-5} Ωm;**
- ***semiconductors* resistivities between 10^{-5} and 10 Ωm;**
- ***insulators* resistivities above 10 Ωm;**
- ***superconductors* have unmeasurably small resistivities**

all at room temperature.
Note the enormous range of values.

The temperature variations are also very different:



For most metals, $\rho \propto T$.



Semiconductors (and insulators) have much stronger temperature dependence of ρ – and in the opposite direction with T.

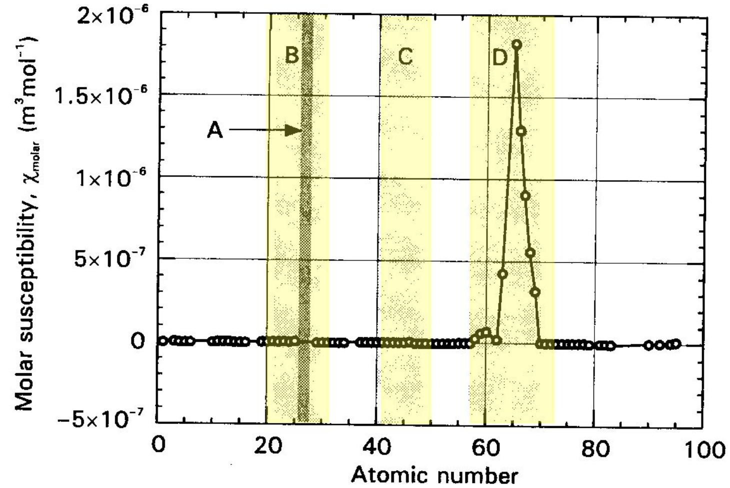
We might expect some sort of ’law of mixtures’ for alloys, but

Resistivities at room T in $\Omega\mathrm{m} \times 10^8$

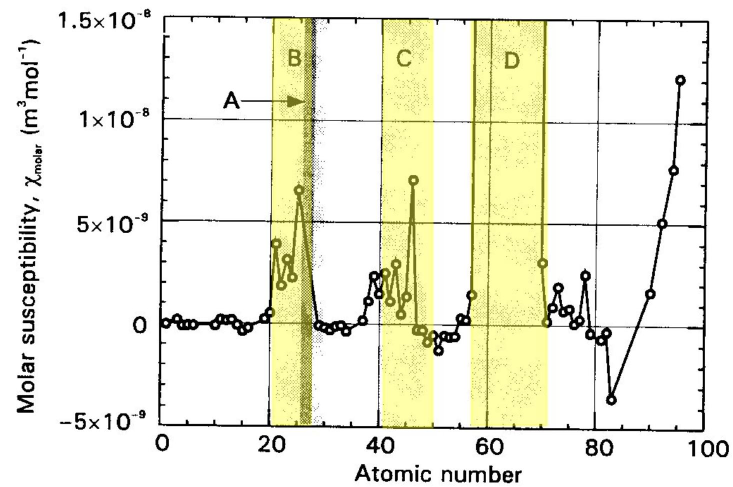
Component1	Alloy	Component2
Cu	Cu(Zn)	Zn
1.55	6.3	5.5
Pt	Pt(10% Ir)	Ir
9.8	25	4.7
Pt	Pt(10% Rh)	Rh
9.8	19	4.3

Adding a trace of low-resistivity Ir to Pt has *increased* the Pt’s resistivity.

Magnetic properties



Yellow regions are ferromagnetic Fe, Co, Ni (A); first transition series (B), second transition series (C) and lanthanides (D) – all elements with part-filled inner electron shells.



Yellow regions are ferromagnetic Fe, Co, Ni (A); first transition series (B), second transition series (C) and lanthanides (D) – all elements with part-filled inner electron shells.

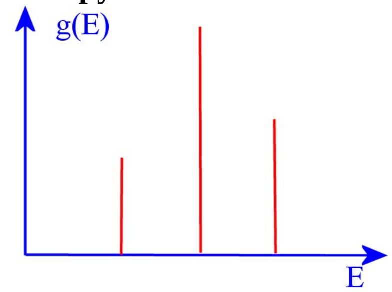
We need to explain

- **the *diamagnetism* which is always present;**
- ***paramagnetism* seen in metals and other materials**
- ***ferromagnetism***
- **magnetic effects on resistivity**
- **special magnetic properties (perfect diamagnetism) of superconductors**

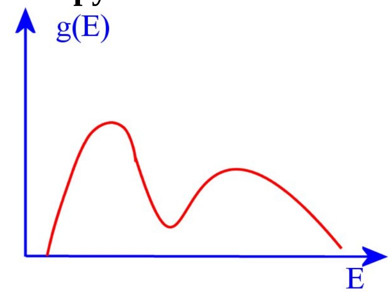
Miscellaneous properties

- **Work function and contact potentials of metals**
- **Extra specific heat above $3R$ per mole**
- **Optical properties**
  - **transparent – clear and coloured**
  - **opaque**
  - **metallic – silvery or coloured**
- **thermionic emission (electrons ’boil off’)**
- **field emission**
- **high thermal conductivity of metals**
- **plasma frequency of metals**
- **x-ray spectra of solids**
- **thermoelectricity**

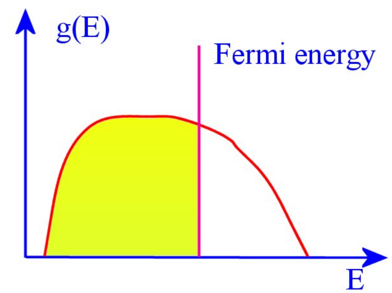
We are going to introduce the *band theory* of electrons in solids. Just as electrons in atoms occupy certain allowed levels:



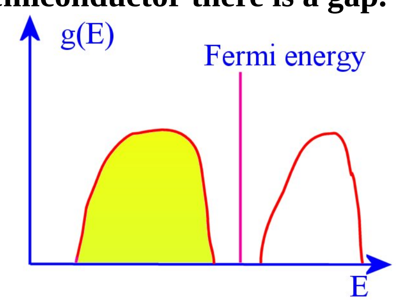
so electrons in solids occupy *bands* of allowed states:



In a metal there is no gap between the occupied and unoccupied states:



In an insulator or semiconductor there is a gap.



Note that the distinction between metals and insulators/semiconductors is definite: in metals there is no gap in the density of states at the Fermi energy at $T = 0$, in the others there is; the difference between semiconductors and insulators is quantitative, and depends on the *size* of the gap. Semiconductors have band gaps ranging up to 2 eV or less – insulators have larger gaps. Intuitively, it is obvious that we can 'do things to' the electrons, such as accelerate them, with little difficulty in a metal, but in semiconductors and insulators we have to promote them across the gap first.