ELECTRONS IN SOLIDS

Lecture 13

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Physics and Astronomy

UCL

5 Electrons in Solids - Overview

5.1 Experimental values

5.1.1 Electrical Resistivity

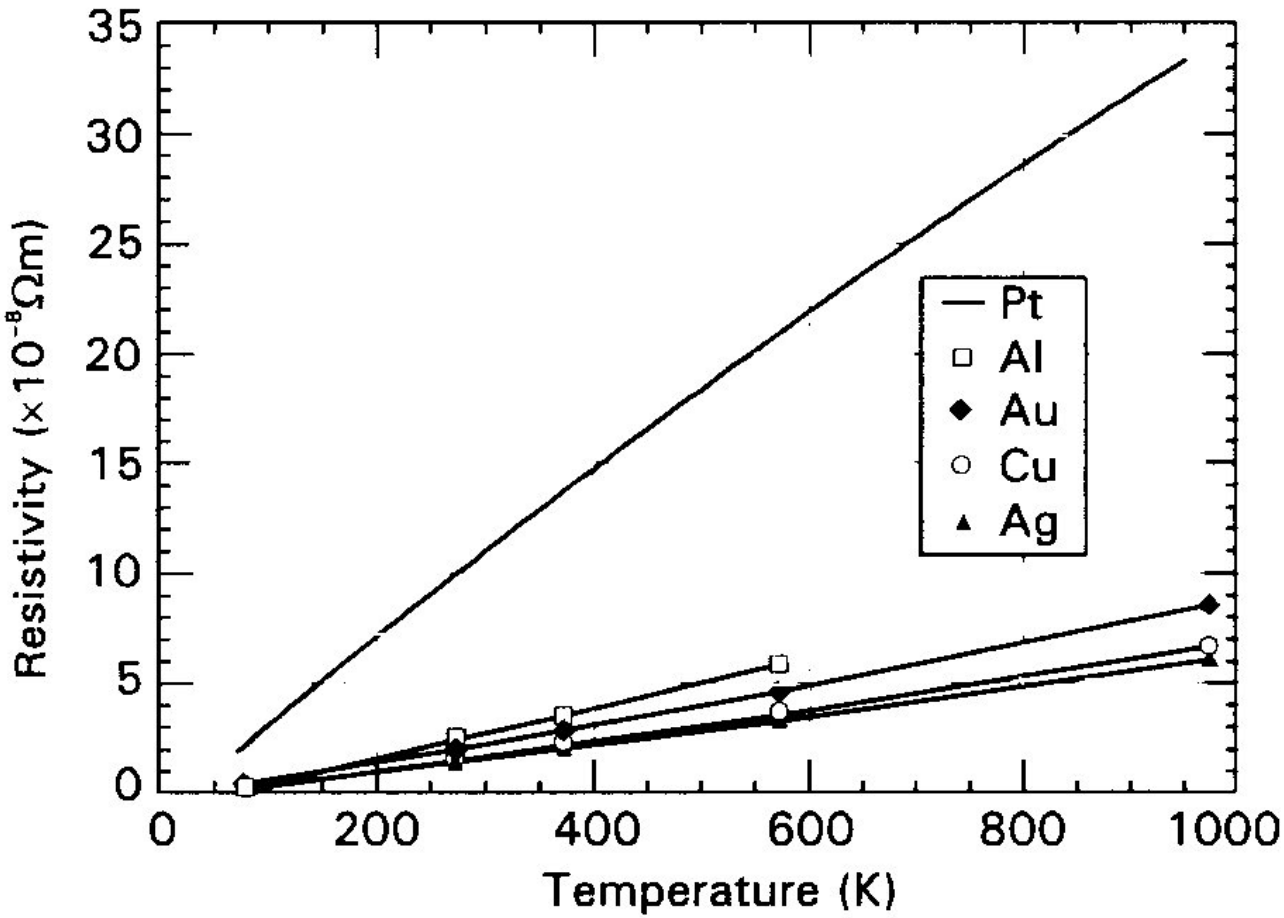
Element	Resistivity (Ωm)	Element	Resistivity (Ωm)
Lithium	8.9×10^{-8}	**Germanium**	0.46
Sodium	4.2×10^{-8}	**Selenium**	10^{-2}
Sodium	4.2×10^{-8}	**Silicon**	10^{-3}
Copper	1.7×10^{-8}	**Tellurium**	4.4×10^{-3}
Silver	1.6×10^{-8}		
Tin	1.1×10^{-7}	**Boron**	1.8×10^{4}
Barium	5.0×10^{-7}	**Phosphorus**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

Divide materials into:

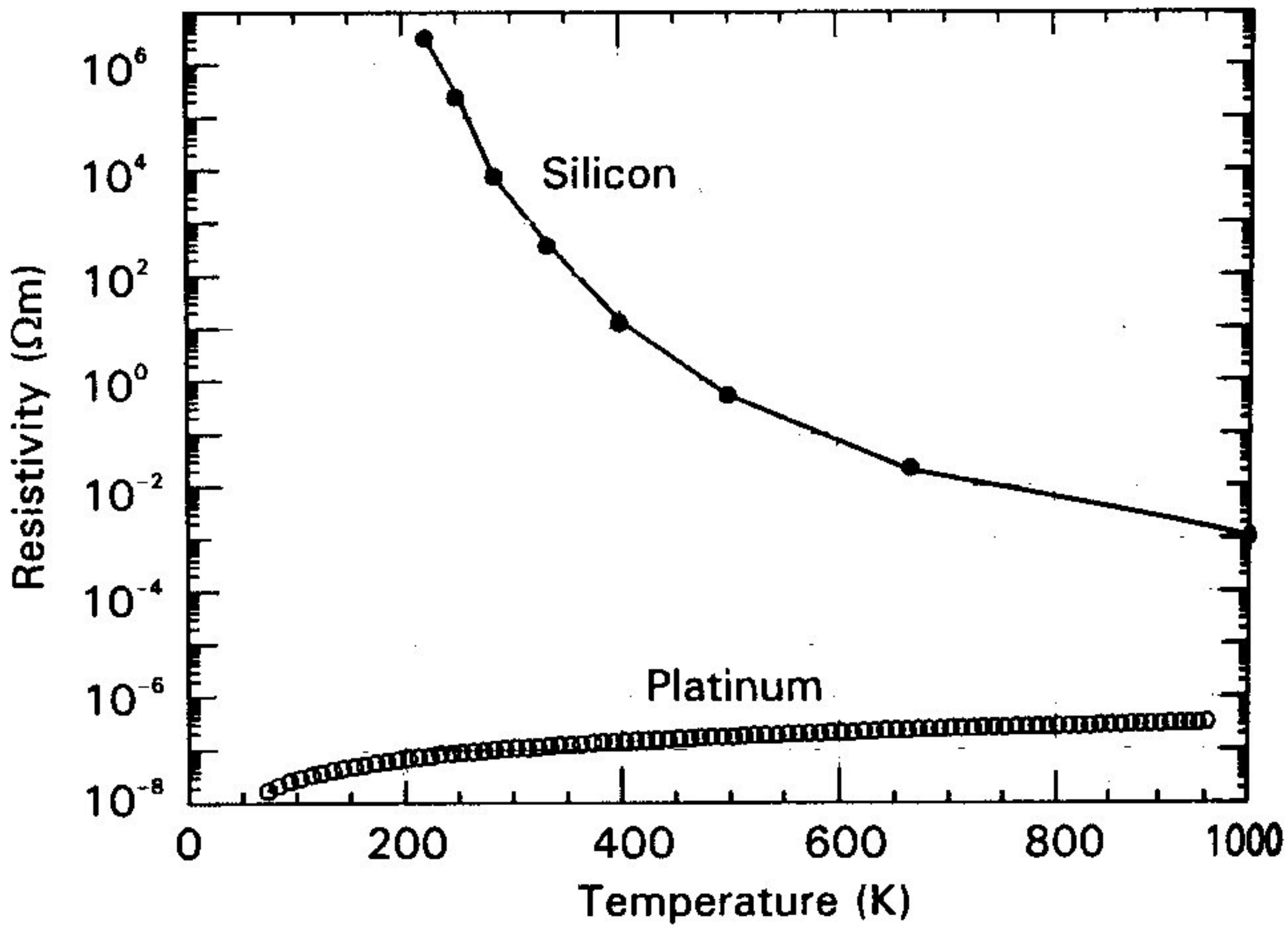
- ***metals*** **resistivities between** 10^{-8} **and** 10^{-5} $\Omega\mathrm{m}$**;**
- ***semiconductors*** **resistivities between** 10^{-5} **and** 10 $\Omega\mathrm{m}$**;**
- ***insulators*** **resistivities above** 10 $\Omega\mathrm{m}$**;**
- ***superconductors*** **have unmeasurably small resistivities**

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

The temperature variations are also very different:



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



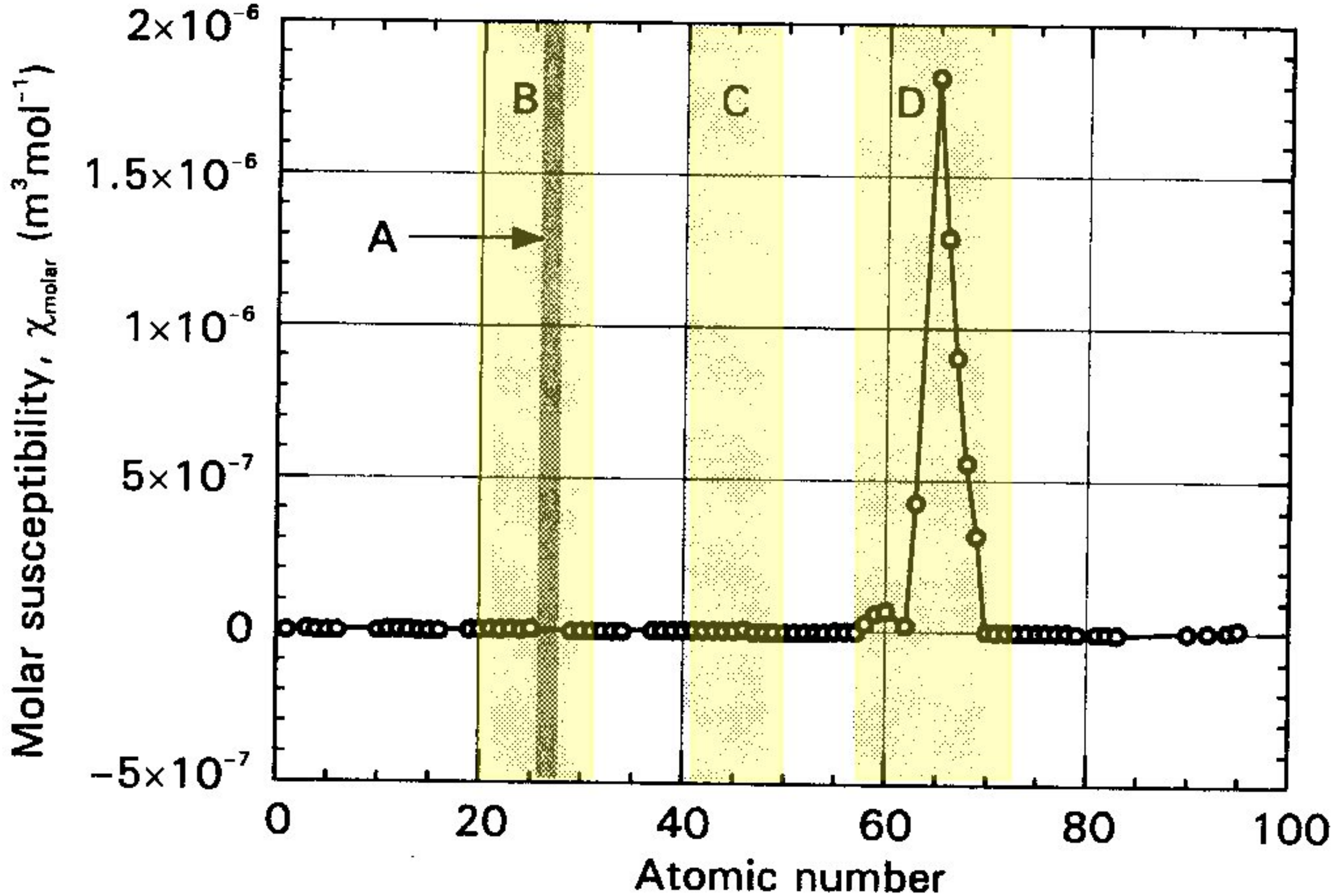
Semiconductors (and insulators) have much stronger temperature dependence of ρ – and in the opposite direction with T.

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

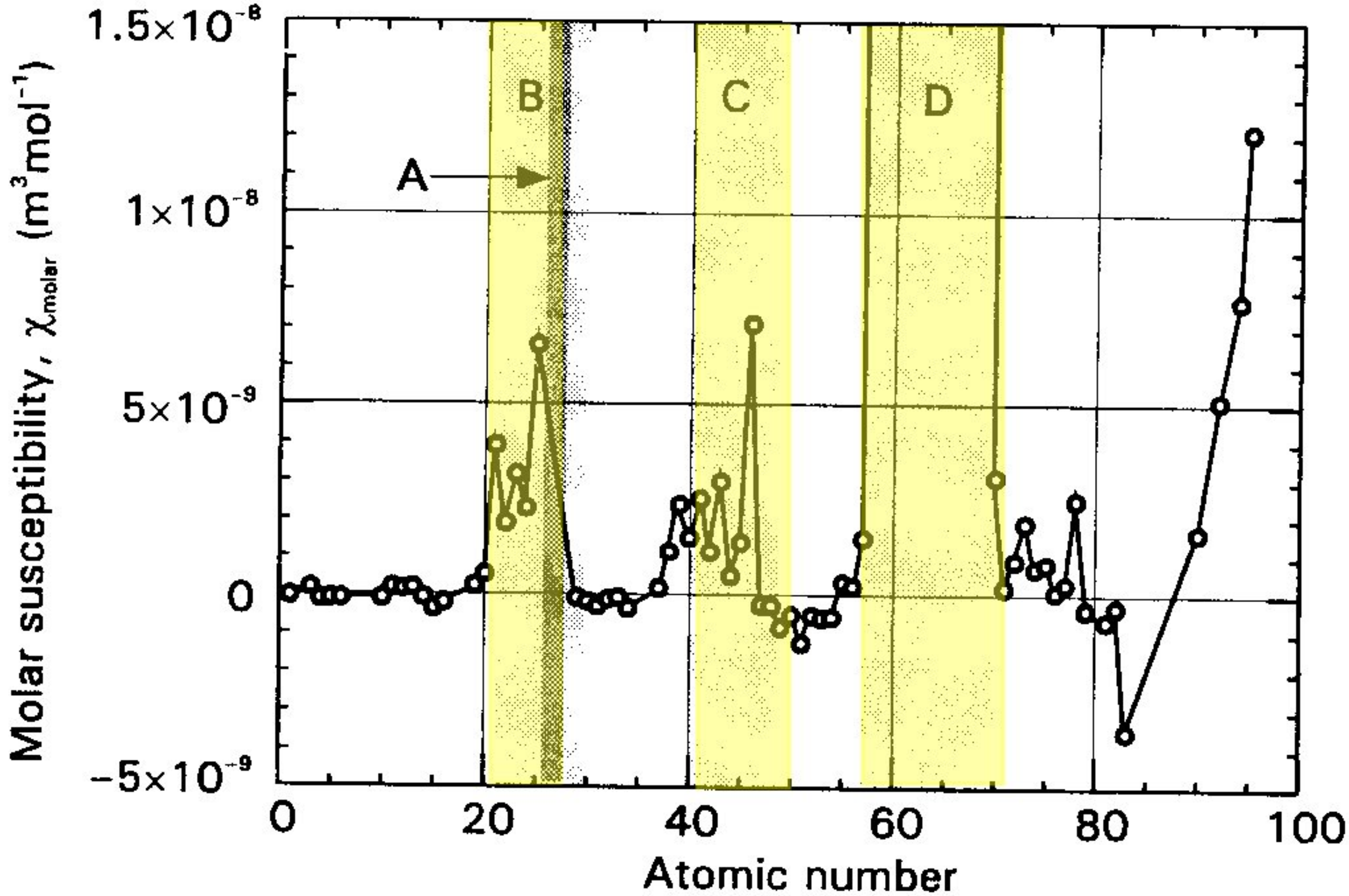
Resistivities at room T in $\Omega\mathrm{m} \times 10^8$		
Component1	**Alloy**	**Component2**
Cu	**Cu(Zn)**	**Zn**
1.55	**6.3**	**5.5**
Pt	**Pt(10% Ir)**	**Ir**
9.8	**25**	**4.7**
Pt	**Pt(10% Rh)**	**Rh**
9.8	**19**	**4.3**

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.



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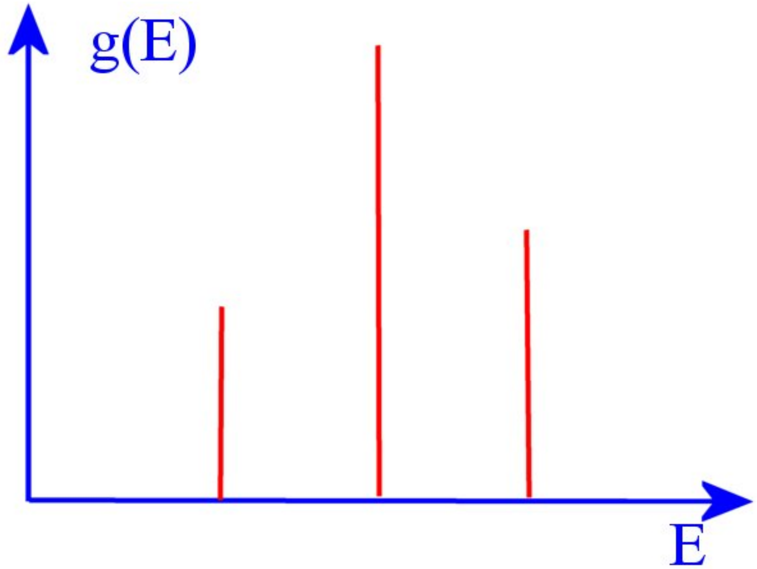
We need to explain

- **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**

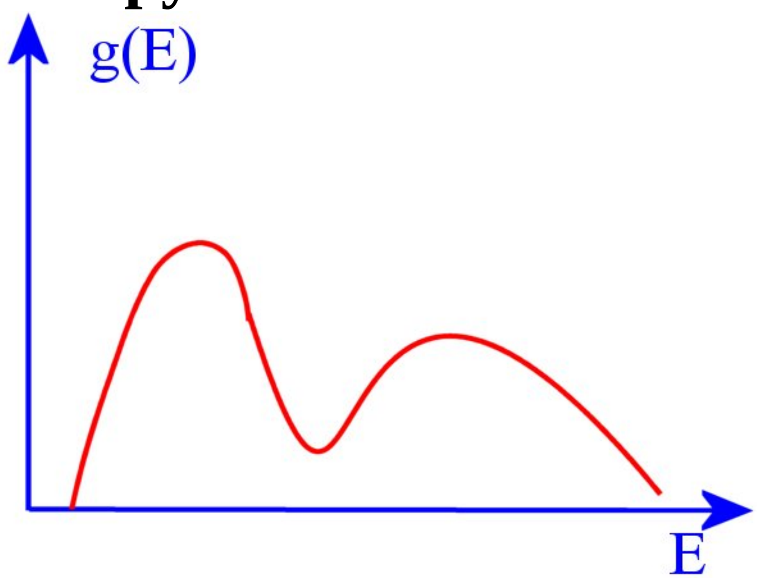
Miscellaneous properties

- **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**

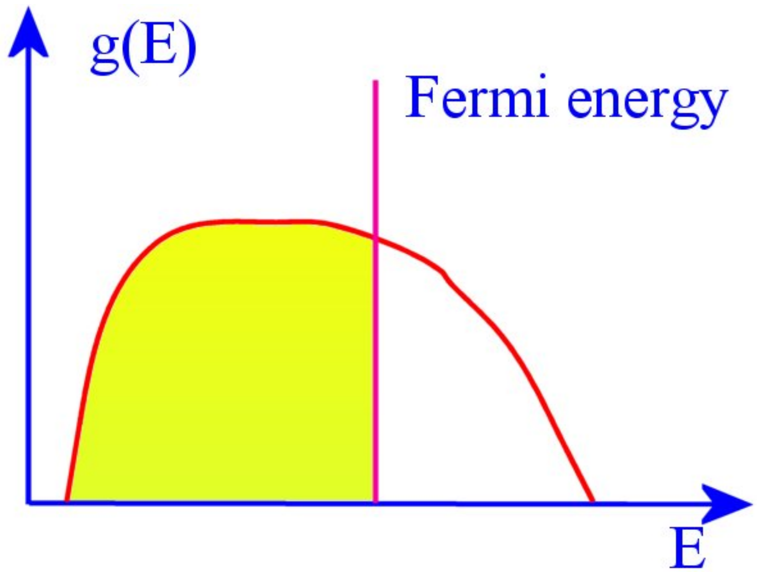
We are going to introduce the *band theory* of electrons in solids. Just as electrons in atoms occupy certain allowed levels:



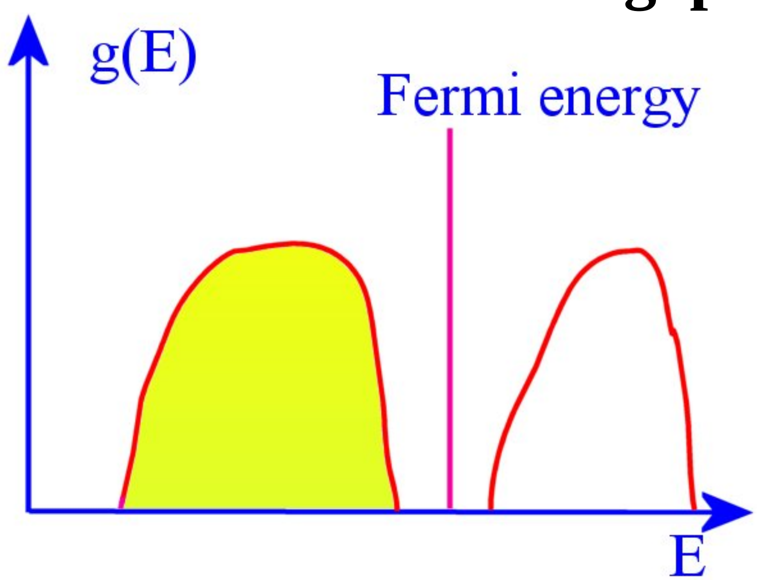
so electrons in solids occupy *bands* of allowed states:



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.