The University Of Sheffield.

EEE105
“Electronic Devices”

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

Lecture 2

- Atoms & their electronic states
- Crystals & energy bands
- Insulators, Semiconductors, Metals
- Crystals – sizes and shapes
- Phonons

Atoms

Periodic Table of the Elements

- hydrogen
- alkali metals
- alkali earth metals
- transition metals
- poor metals
- nonmetals
- noble gases
- rare earth metals

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Ti	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Unn								

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

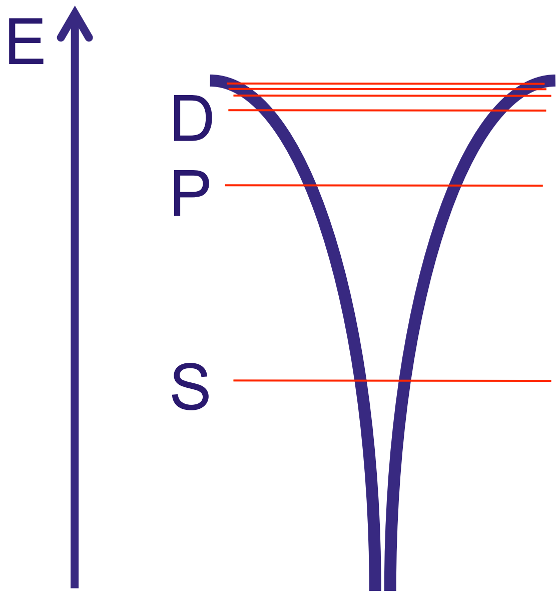
Nucleus (neutrons + protons) surrounded by electrons

Physical understanding
– continued debate
Thomson, Rutherford, Bohr, etc,

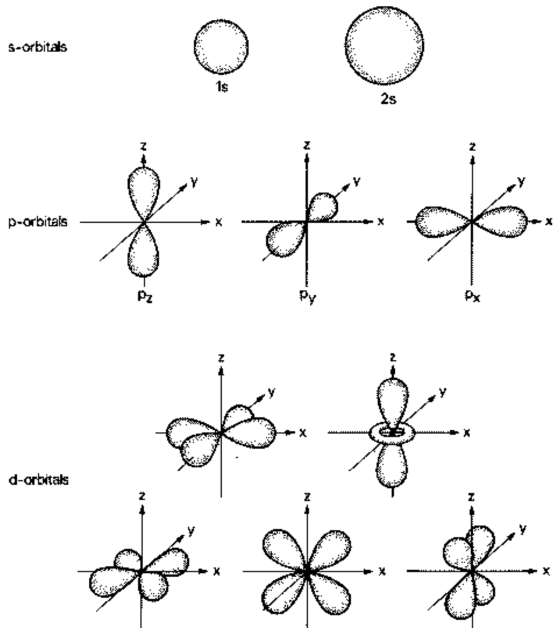
In atomic physics –
consider isolated atoms

Electrostatic potential formed by nucleus

Electronic States



S - 2 electrons 1 orbital
P- 6 electrons 3 orbitals
D- 10 electrons 5 orbitals
F- 14 electrons 7 orbitals



Quantum mechanics →discrete energy levels arranged in shells & orbitals – chemical properties governed by **empty** shells

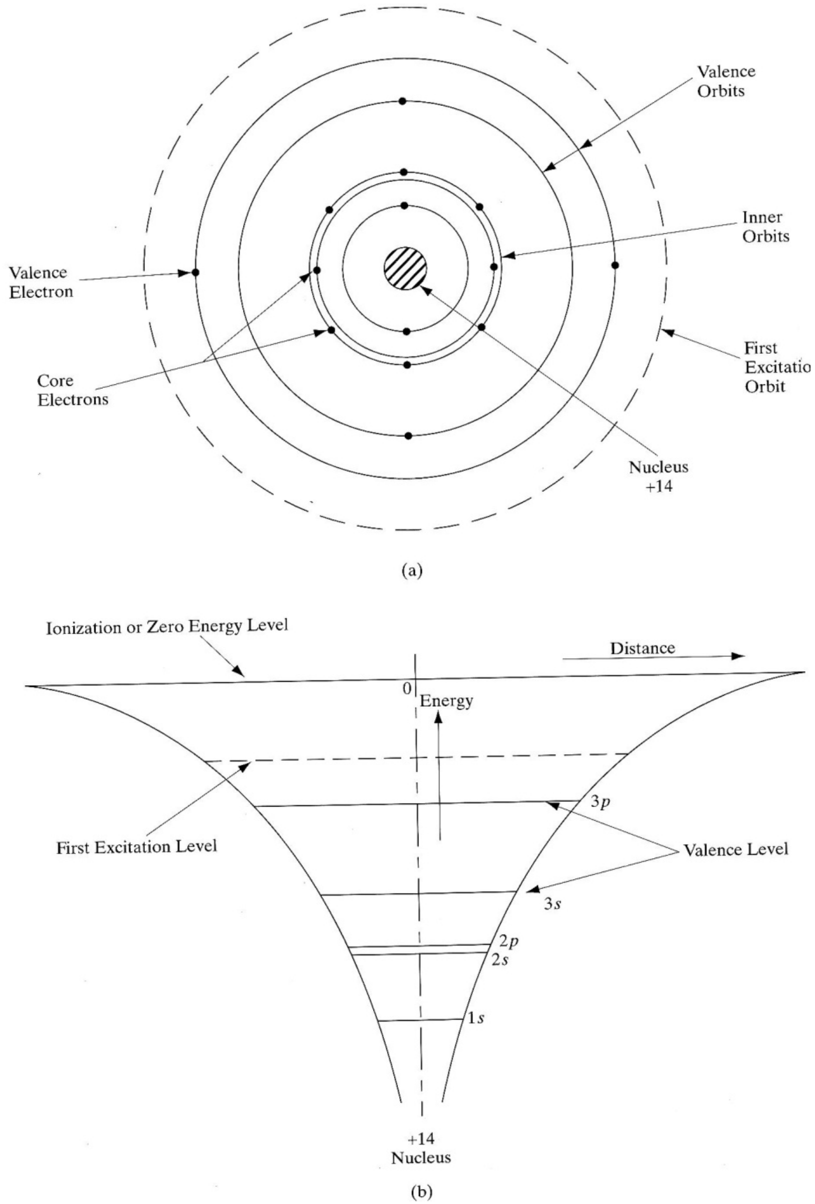
The University Of Sheffield.

Silicon Atom

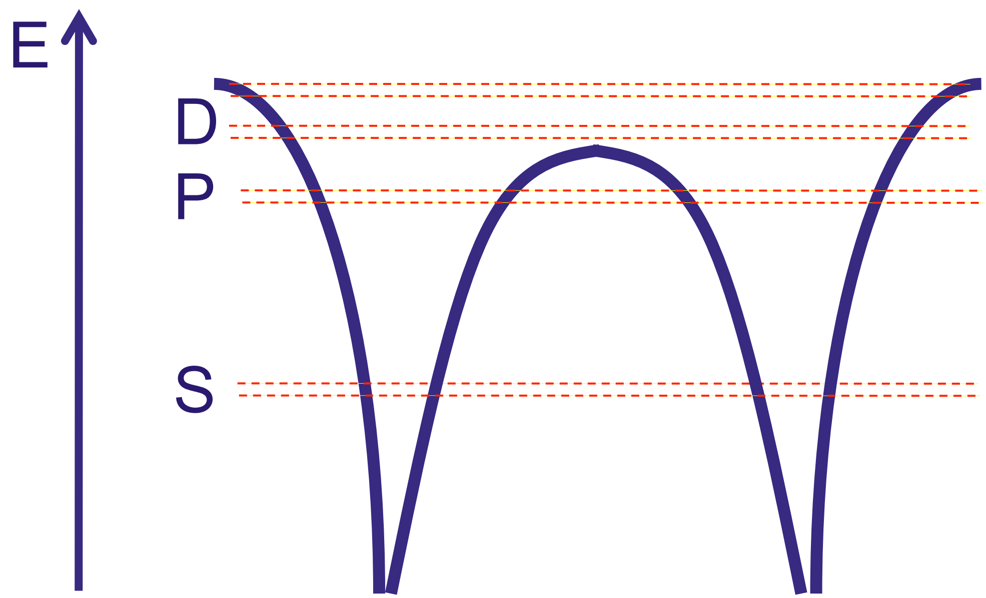
Core electrons of little interest

Outer electrons are the important ones chemically and electrically

Si has 4 outer electrons



Two atoms interacting e.g. H_2

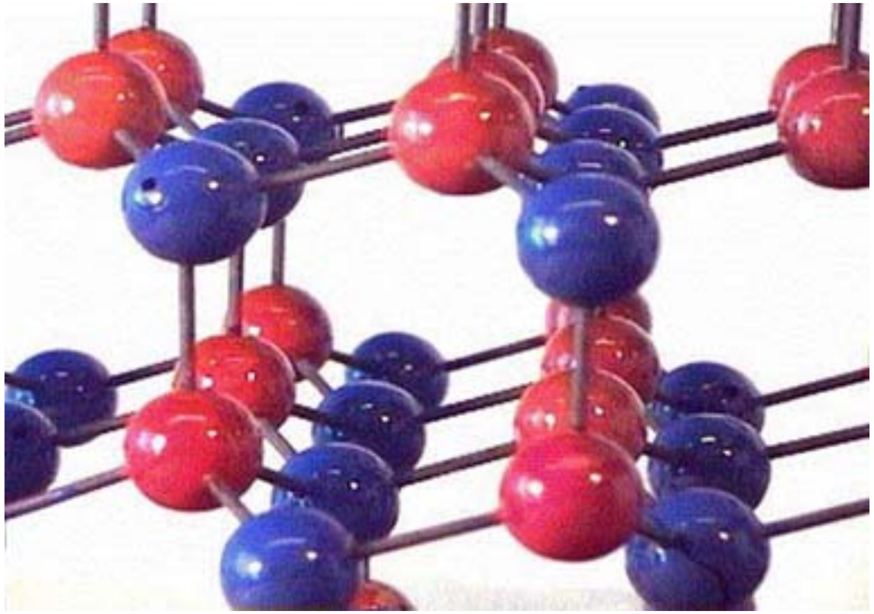


Quantum mechanics (Pauli exclusion principle) does not allow identical states

→the two states split

How about in a crystal?

Crystals

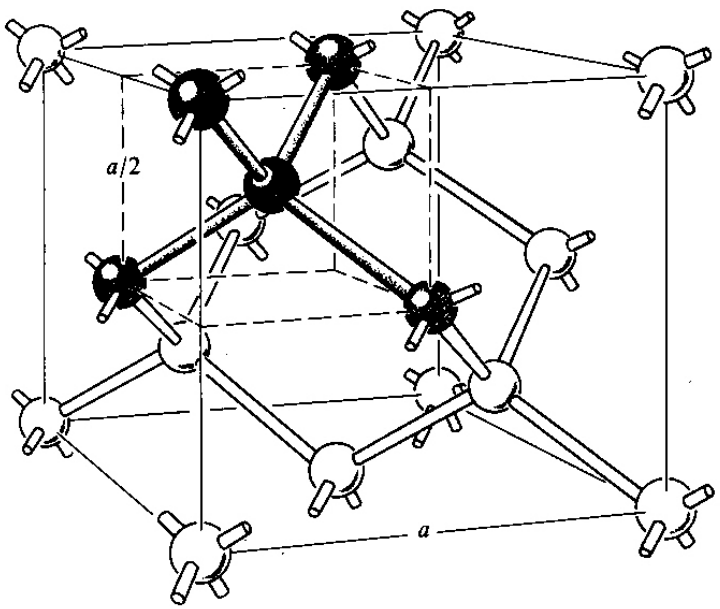


Lattice constant ~0.3-0.5nm

Either ionic or covalent bonding results in highly periodic array of atoms

New properties
-electronic
-structural strength
-vibrational properties (e.g. how thermal energy is transmitted)

Crystalline Solids



Most semiconductors
-covalent bonding
-diamond lattice
-Referred to as Zinc blende for compound semiconductors

Unit Cell of lattice constant “a” – smallest unit which can be repeated to make the crystal

8 atoms per unit cell for diamond

Density

Atoms/Unit Volume- Depends on crystal structure
For Diamond structure =$8/a^3$

$$Density = \frac{\left(\frac{Atoms}{Volume}\right)\left(\frac{Kg}{Mole}\right)}{\left(\frac{Atoms}{Mole}\right)}$$

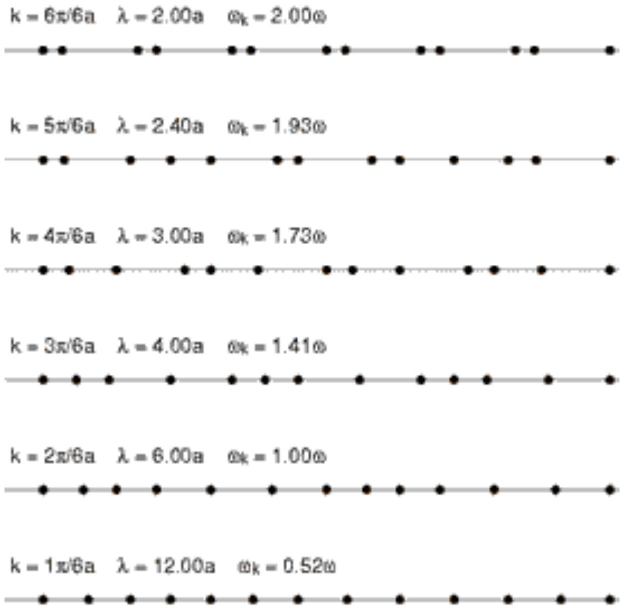
Kg/Mole

– atomic number

Number of atoms per mole

-Avagadro's number = $6x10^{23}$

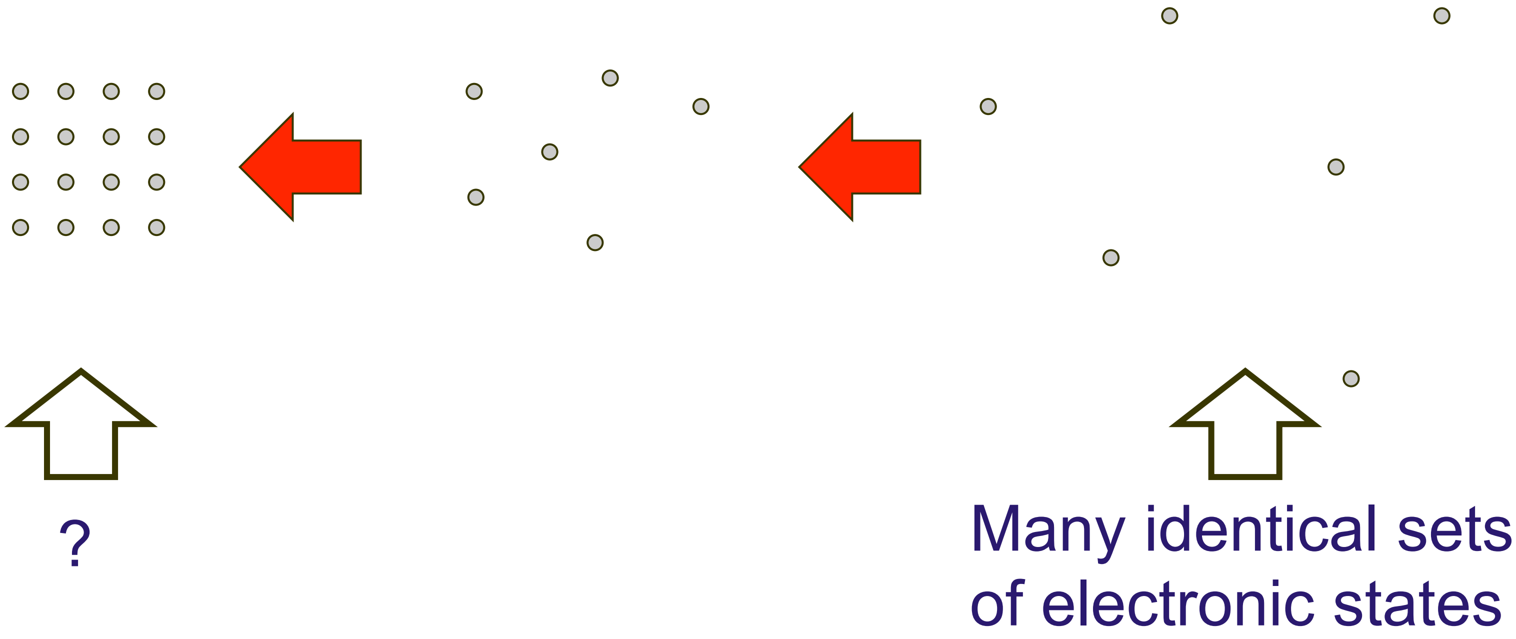
Thermal Energy in a Crystal



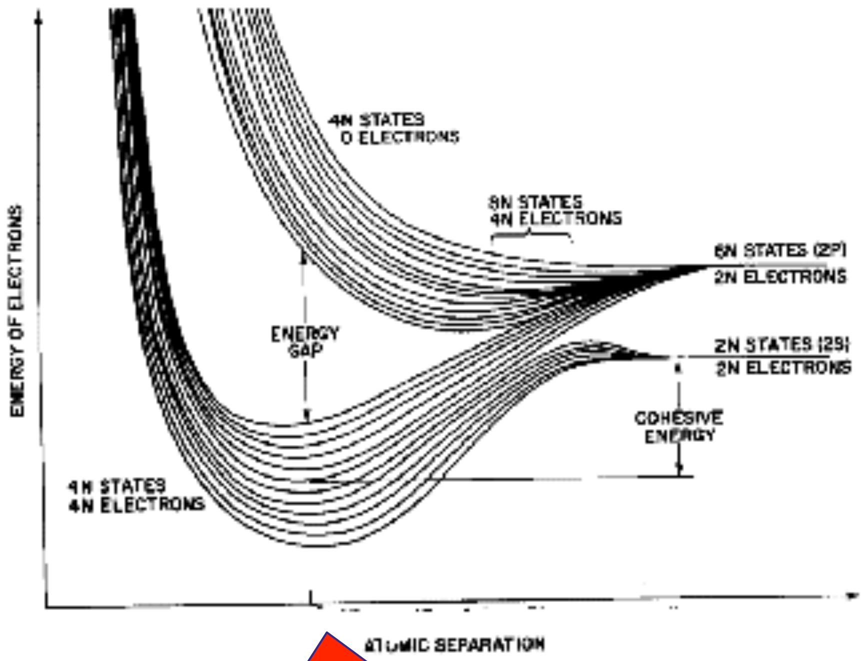
- The crystal can be considered as weights connected by springs
- The allowed modes of vibrations can be considered as a particle travelling through the crystal (they have energy and momentum)
- Similarly to electrons (charge), and photons (light), lattice vibrations are quantized into "phonons"

Thought Experiment

Imagine compressing a very dilute gas of atoms
– what happens to outermost shell which is partially filled



Formation of Energy Bands



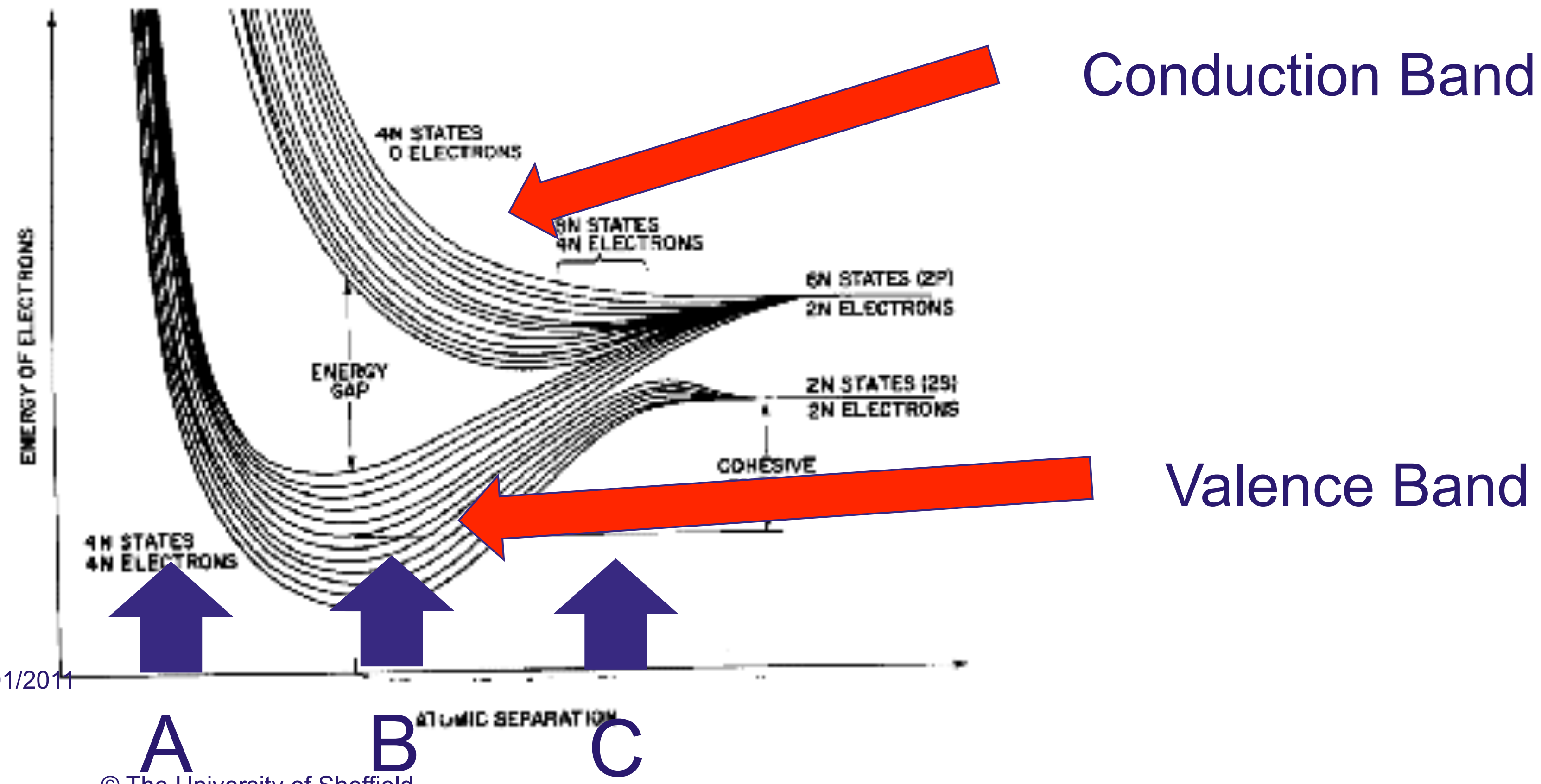
Transition from -

Isolated atomic levels

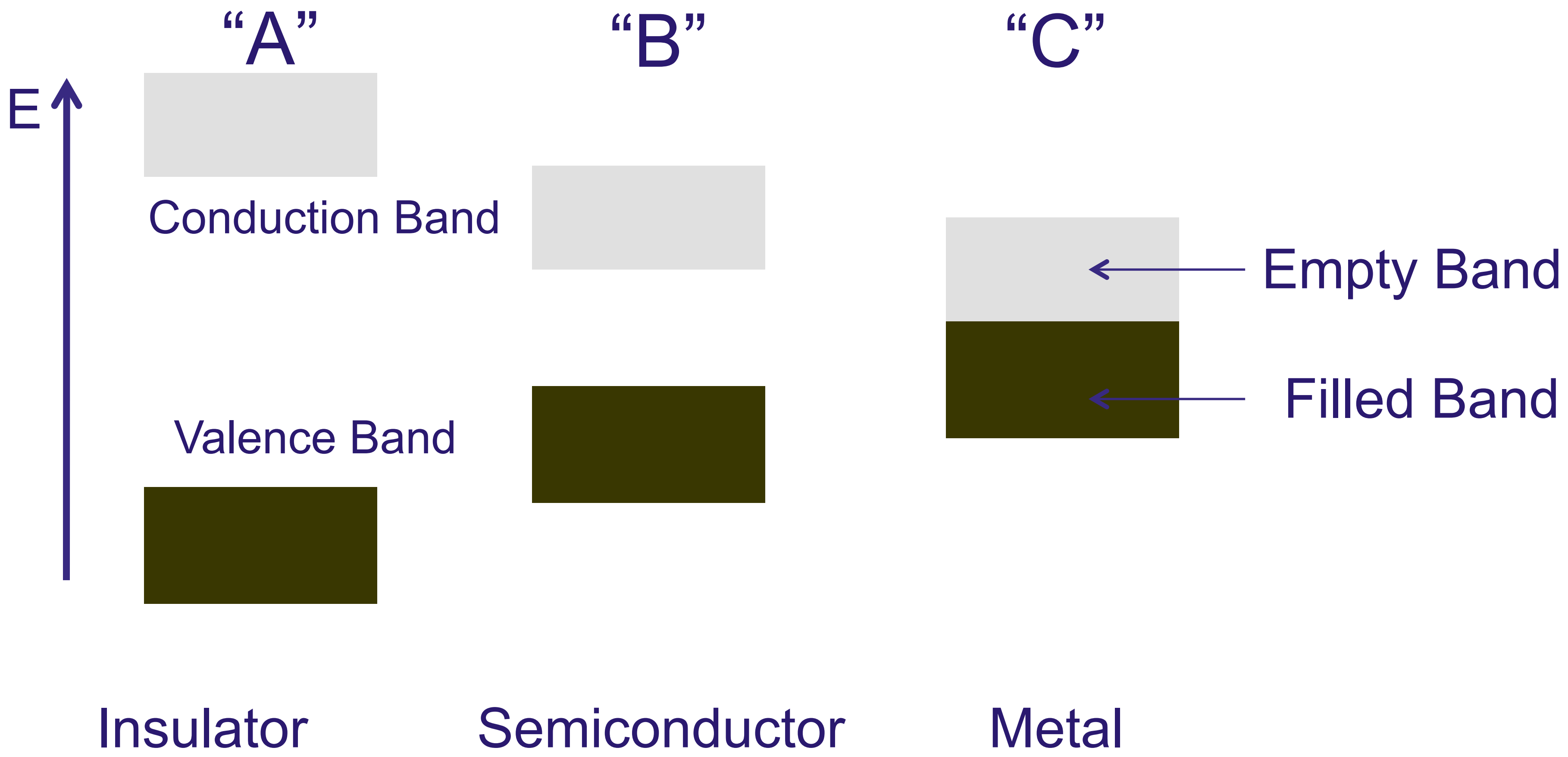
To-

Energy bands of a crystal

Energy Bands – Regimes



Classification of Solids

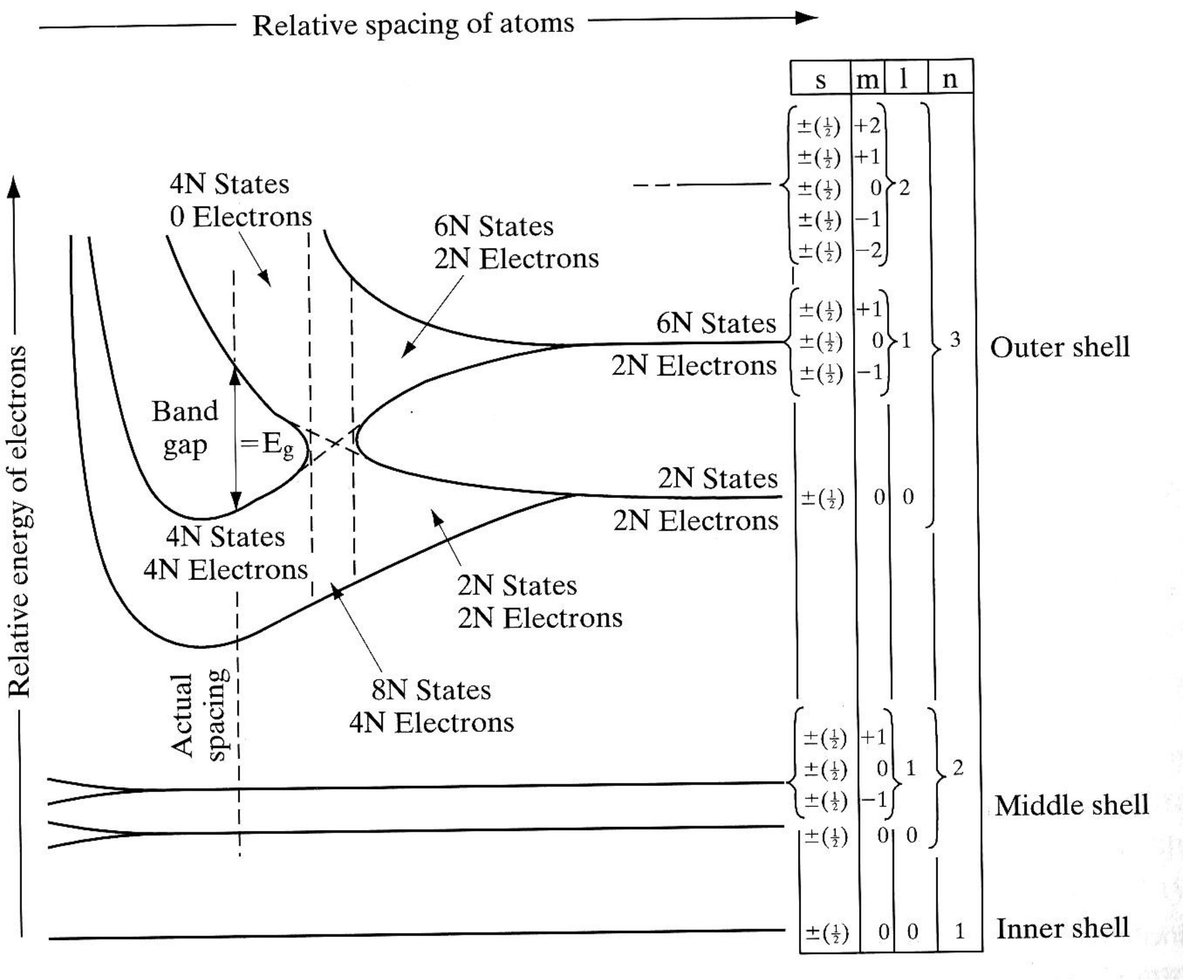


For Silicon

Outer electrons modified from many isolated atoms with degenerate electron states to bands of electron states

Band-gap formed between **valence band** and **conduction band**

Core electrons essentially unmodified (not of interest anyway!)



Insulators

- Insulators –electrons in bands for which a large amount of energy is required to promote them to the conduction band – essentially the charge remains in the chemical bonds
- e.g. NaCl, C (diamond)
- Used as dielectric in capacitors, insulation between conductors

Metals

- Electrons essentially free to move
- e.g Cu, Au, Fe, Al,
- Used for wires, inductors, antennae, etc

Semiconductors

- Electrons bound in bands but moderate amounts of energy e.g. Due to heat or an incident photon can promote an electron to the conduction band.

- Used in transistors, diodes

- Group IV elements like Si, Ge,

compound semiconductors” e.g. III-Vs, GaAs, InP,

Summary

- A crystalline solid has electronic levels in bands, contrasting the discrete energy levels of isolated atoms
- Most semiconductors have a diamond (Si, Ge) or Zinc blende structure which has 8 atoms per unit cell.
- The thermal energy in a crystal is quantized and these quanta are called phonons
- These solids may be classified broadly into 3 types, with the presence and relative magnitude of a band-gap determining the classification
- This classification may be somewhat “grey” depending upon e.g. Temperature

