EEE118
"Electronic Devices and Circuits"

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Aims, Objectives

- Introduction to physical properties of metals, insulators, semiconductors
- Understand the operation of electronic devices at the level of electrons (and holes)
- Present the terminal characteristics of devices
- Understand how these devices behave and how they are used in electronic circuit applications

Policy

- Lecture material is available on the teaching resources web-site here:

  http://hercules.shef.ac.uk/eee/teach/resources/eee118/eee118.html

- Course hand-out will be available at the beginning of term and at lecture 10 only
- Problem classes – discuss lecture material with demonstrators and attempt problem sheets. <u>These classes are compulsory</u>
- I am available outside formal contact times by appointment (email ahead)
- No queues 1 day before the exam please!

Study time associated with a Module

The University requires that a module (EEE118 in this case) represents ~200 hours of work!

- Lectures = 48
- Problem classes = 24
- Exam = 3
- Total Contact Time = 75

<u>This means you have to do ~125 hours of study on your own</u>

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Self Study

- **When? –** advice is:

Try to spread the work over a long time period to allow concepts to "sink in" – a few hours per week during term time, following the points introduced in the lectures and trying the problem sheets outside the session so that you can ask question during the session.

- **How? –** advice is:

Do problem sheets, read books, discuss with fellow students and look at old exam papers and solutions. There are also a variety of external sources of information on the internet to help you with concepts.

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Lecture 1

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

Not Examinable

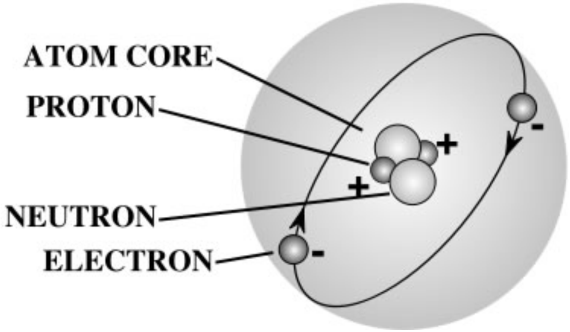
Atoms

Periodic Table of the Elements

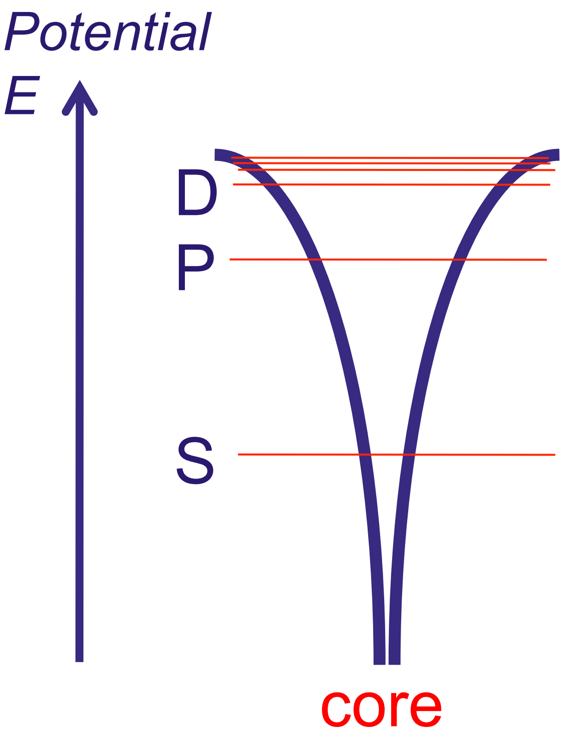
- hydrogen
- alkali metals
- alkali earth metals
- transition metals
- poor metals
- nonmetals
- noble gases
- rare earth metals

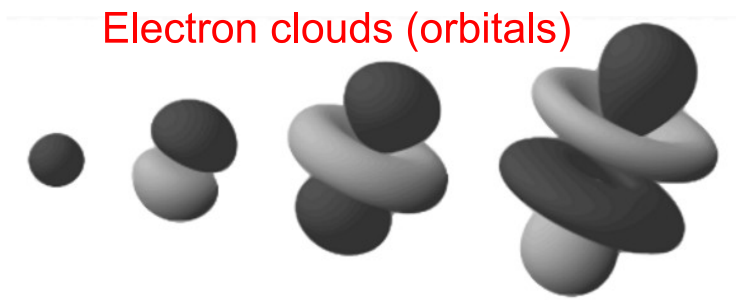
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 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



Potential energy diagram and Electronic States





Quantum mechanics →
Electrons in the atom occupies discrete energy levels arranged in groups (shells & orbitals) – chemical properties governed by outer shells

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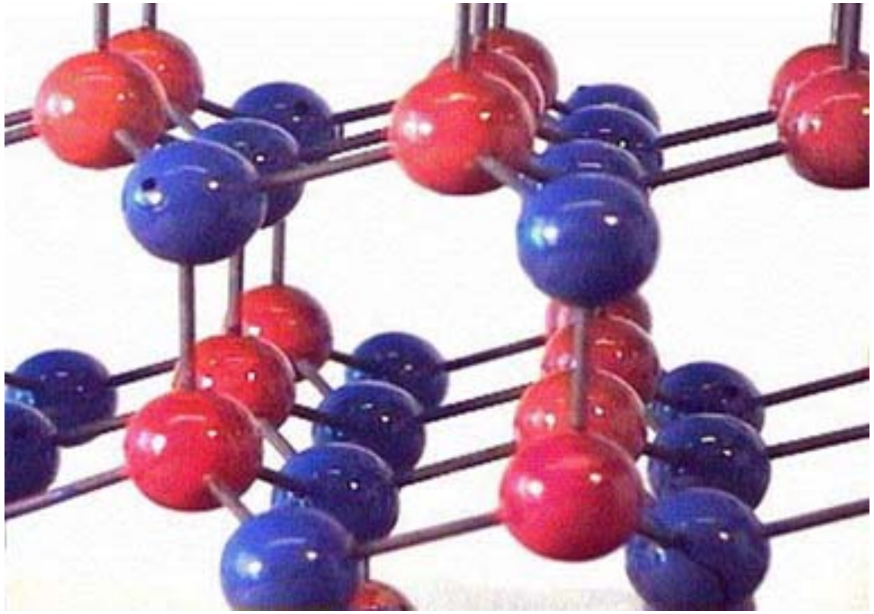
Crystals – atoms bound together

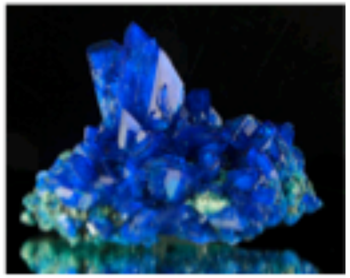


Bonds can be formed between atoms – shared electrons to fill outer shells (covalent bond)

Treating the system as isolated atoms no longer valid

Atomic spacing ~0.3-0.5nm (0.3-0.5 x 10^{-9}m)

Familiar Crystals

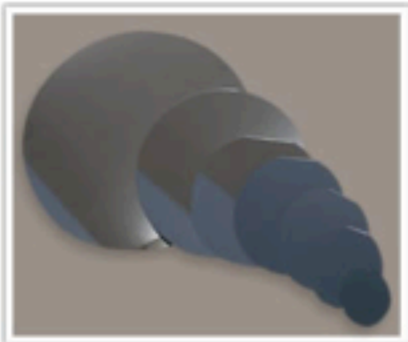


You may even have grown your own…

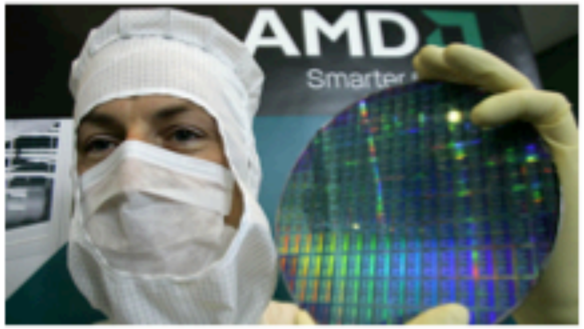
Semiconductors are Crystals

This is a single crystal of silicon

From which we slice wafers (also single crystals)



From which we make electronic circuits and microprocessors…



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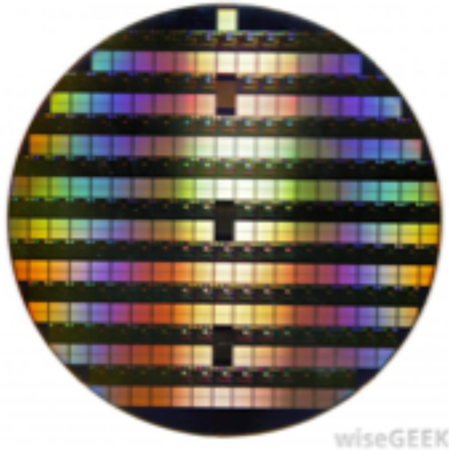
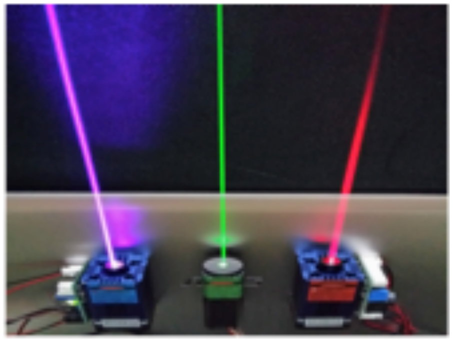
Semiconductor Devices



In this course we will learn about the devices formed from these crystals…

Electronics



Lasers

LEDs

Solar Cells

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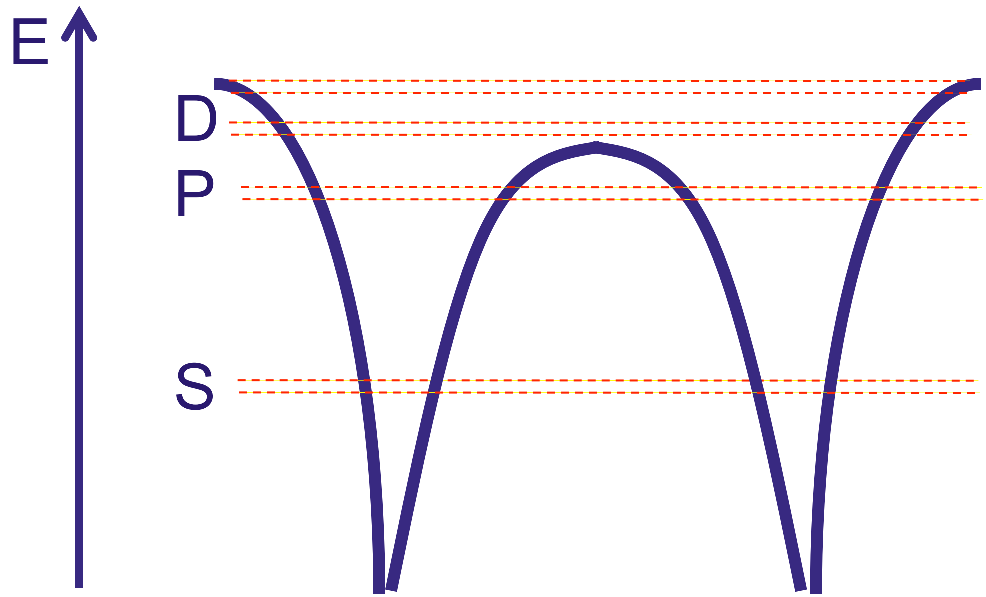
Two atoms interacting



Two atoms sharing outer electrons – covalent bond

Energy levels split

By the way, this is not just a quantum mechanical effect, it applies classically to two coupled oscillators. Watch this video…

https://www.youtube.com/watch?v=CguKKl9mX2s

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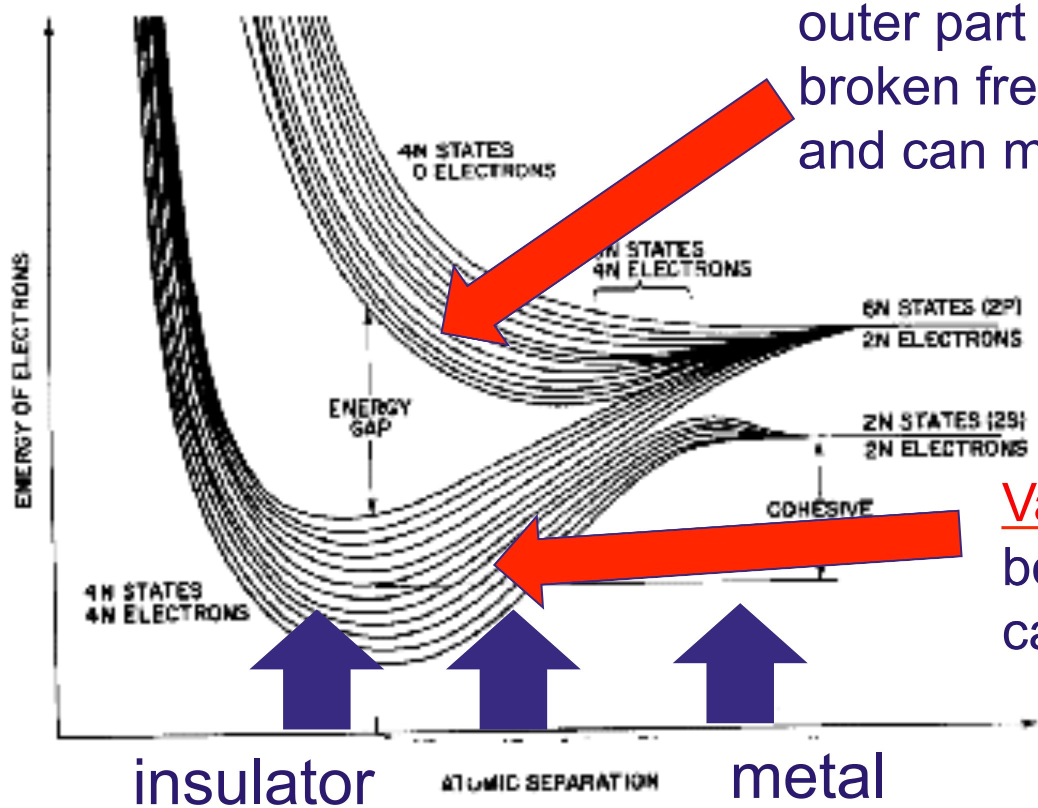
Energy Bands

What happens when we have many atoms in a crystal?



Conduction Band – electrons on the outer part of the atoms here have broken free from the crystal bond and can move about in the crystal

Valence Band – electrons bound into atom bonds and can't move about

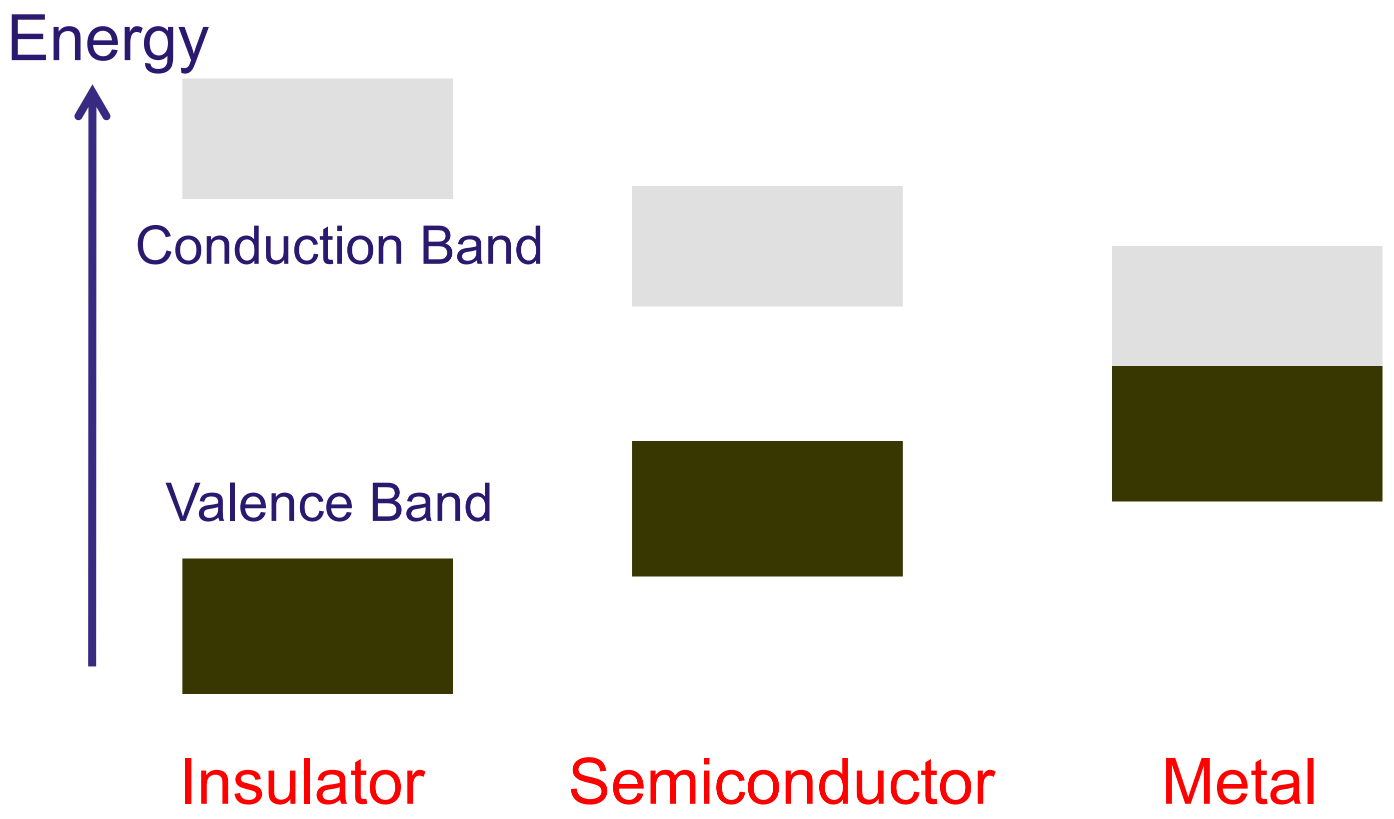
insulator

semiconductor

metal

Classification of Solids

- can simplify previous picture



Insulators

- Insulators – large amount of energy is required to promote electrons from the valence band to the conduction band i.e. break one of the bonds and free an electron
- e.g. NaCl (salt), Al_2O_3 (aluminium oxide), C (diamond)
- Used as dielectrics in capacitors, insulation between conductors etc

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Metals

- Valence and conduction bands overlap - electrons essentially free to move – good conductors
- e.g Cu (copper), Au (gold), Fe (iron), Al (aluminium)
- Used for conducting electrical current, inductors, antennae, etc

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Semiconductors – the main focus of this module

- Electrons bound in valence band but moderate amounts of energy e.g. heat or an incident light photon can provide enough energy to promote an electron to the conduction band
- e.g. Si (silicon), Ge (germanium), GaAs (gallium arsenide), InP (indium phosphide), GaN (gallium nitride)
- Used in transistors, diodes, microprocessors, memory chips, light emitting diodes (LEDs), lasers etc

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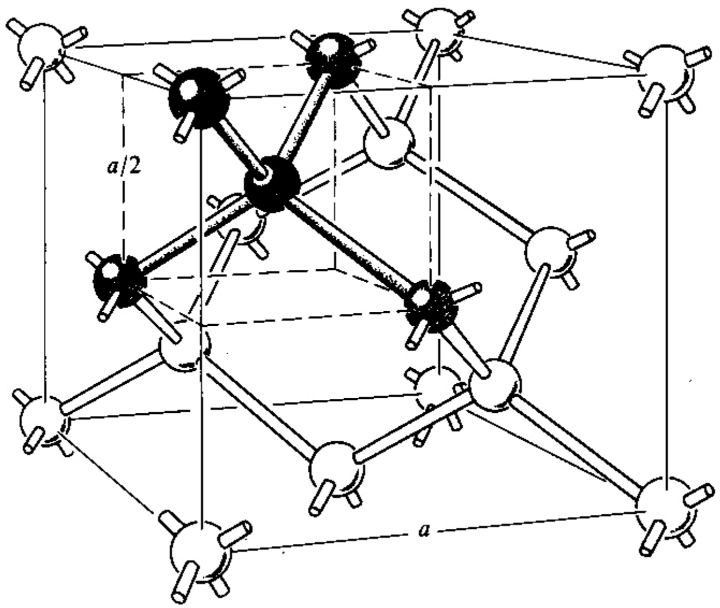
Crystalline Solids



Most semiconductors
- diamond lattice – Ge, Si
- referred to as Zinc Blende for compound semiconductors

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

8 atoms per unit cell on average

How many atoms/m^3 in Si?

- Lattice constant a = 5.4×10^{-10} m
- Diamond lattice (8 atoms per unit cell of side a)

$$\text{Number} = 8/a^3 = 8/(5.4\times10^{-10})^3$$

$$= 5 \times 10^{28}\ \text{Atoms/m}^3$$

$$= 5 \times 10^{22}\ \text{Atoms/cm}^3$$

Semiconductor device engineers often use cm^3 rather than m^3 as a measure of volume.

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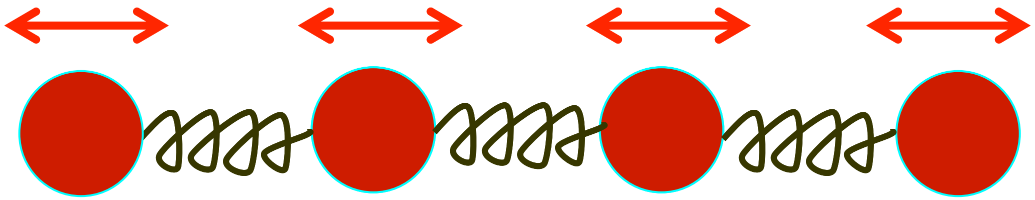
Thermal Energy in a Crystal



- The atoms in a crystal can be considered as weights connected by springs
- Heat energy causes them to vibrate
- Similar to electrons (charge), and photons (light), lattice vibrations are quantized into “phonons”
- Heat energy can cause some of the crystal bonds to break, freeing up electrons into the conduction band

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Summary

- A crystalline solid has 'allowed' electronic energy levels forming bands, contrasting the discrete energy levels of isolated atoms
- These solids may be classified broadly into 3 types, with the presence and relative magnitude of an energy gap (called a band-gap) between the valence band (bound electrons) and the conduction band (free electrons) determining the classification
- This classification may be indistinct depending upon e.g. temperature
- Most semiconductors have a diamond (e.g. Si, Ge) or Zinc Blende (e.g. GaAs) structure which has 8 atoms per unit cell
- The thermal energy in a crystal is quantized and these quanta are called phonons

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