- What factors determine the lattice energy of an ionic crystal? 3

> - **The size of the cations and anions: the smaller the ions are, the higher the lattice energy.**
> - **The charges on the cations and anions: the higher the charges on the ions, the higher the lattice energy.**
> - **The crystal structure: broadly, the higher the number of anions around each cation (and vice versa), the higher the lattice energy.**

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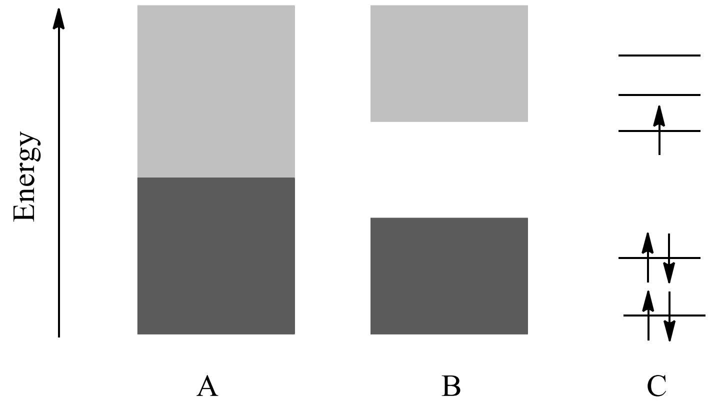
Marks 5

- The diagram below shows the band structure of two solid elements, A and B. Dark grey denotes filled electron energy levels, light grey denotes unfilled levels. Also shown are the atomic energy levels (valence electron orbitals only) of another element, C.



Describe the electrical properties of elements A and B, explaining your reasoning.

A is a conductor. As there is no energy gap between them, electrons can easily be promoted from the filled to the unfilled electron energy levels. They are hence free to move if a voltage is applied.

B is an insulator. There is a large energy gap between the filled and unfilled electron energy levels. As the electrons can't get to the unfilled levels (the conductance band), B is unable to conduct.

If a small amount of element C is deliberately added to each of A and B, describe what effect this will have on the electrical properties of each. Give reasons.

There is no effect on A. There is no effect on the energy levels so electrons can still be promoted easily into the conductance band.

B will become an n-type semi-conductor. The extra electrons are forced into the conductance band and are free to move when a voltage is applied. There are not very many of these extra electrons, so the result is a material which can conduct some current, but not a lot.

Marks 4

- Explain what is meant by the term "band gap".

In a solid, there are very many energy levels for the electrons. Each "band" is made up of a large set of energy levels.

If these sets are separated in energy, then there is a "band gap".

Commonly, "band gap" refers to the energy difference between the top energy level in the conductance band and the bottom energy level valence band. It is small in conductors (*e.g.* metals) and large in insulators (*e.g.* diamond).

The band gap of the semiconductor gallium(II) sulfide is 2.53 eV. What range of wavelengths (in nm) would you expect this material to absorb?

As 1 eV = 1.602×10^{-19} J, 2.53 eV is equivalent to:

$(2.53 \times 1.602 \times 10^{-19})$ J = 4.053×10^{-19} J

This is the smallest energy it will absorb. Using $E = \frac{hc}{\lambda}$, this corresponds to a wavelength of:

$$\lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34}\ \mathrm{J\ s})(2.998 \times 10^{8}\ \mathrm{m\ s^{-1}})}{4.053 \times 10^{-19}\ \mathrm{J}} = 4.90 \times 10^{-7}\ \mathrm{m} = 490.\ \mathrm{nm}$$

As 2.53 eV is the smallest energy it will absorb, this corresponds to the longest wavelength it will absorb. It will absorb wavelengths shorter than 490. nm.

For reference, the relationship between colours and wavelengths is as follows:

violet	blue	green	yellow	orange	red
400–450	450–490	490–560	560–590	590–630	630–700 nm

Predict the colour of a single crystal of GaS according to a human observer when it is illuminated with white light. Explain your answer.

From above, it will absorb wavelengths shorter than 490. nm, corresponding to the absorption of violet-blue light. The human observer will see white light with these colours removed: the complementary colour will be yellowy orange.

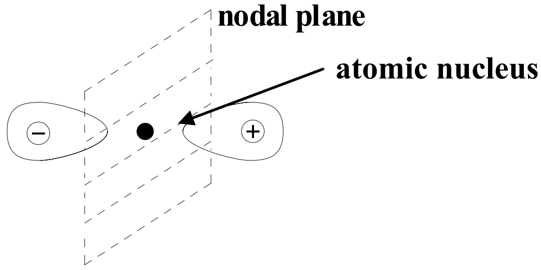
	Marks
• Pure silicon is an insulator. Explain, with band structure diagrams, how doping pure silicon with a small amount of aluminium can turn it into a p-type semiconductor.	4

The band gap in pure Si (between the full valence band and the empty conductance band) is large. Normal thermal energy does not give the electrons enough energy to make the jump and so Si is an insulator.

Replacing some Si atoms with Al (or other Group 13 element), means that the valence band will not be completely occupied with electrons. The gaps act as positive holes and allow the material to act as a semiconductor of the p-type.

Si doped with Al

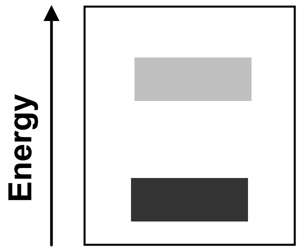
• Sketch the wave function of a 2*p* orbital as a lobe representation. Clearly mark all nodes (spherical and/or planar) and nuclear positions.	2



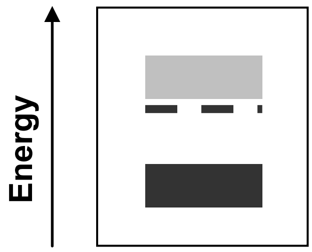
- Pure silicon is an insulator. Explain, with sketches of band structure diagrams, how 'doping' pure silicon with a small amount of phosphorus can turn it into an 'n-type' semiconductor.

Marks 2

Silicon is an insulator as the energy gap between the full valence band (shown in black below) and the empty conduction band (shown in grey below) is large:

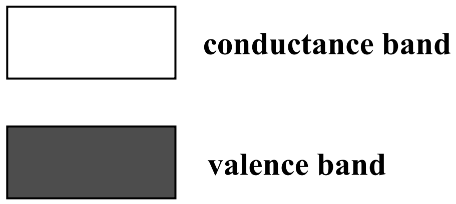


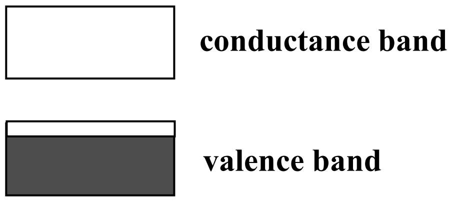
Phosphorus has one extra electron compared to silicon. These occupy energy levels just below the bottom of the conduction band (shown as a dotted line below). Some electrons from these localised electronic states are thermally excited into the conduction band, where they become mobile and act as (negative) charge carriers.



Marks
3

- Pure silicon is an insulator. Explain how incorporation of a small amount of nearby elements can bring about 'p-type' semiconduction. Explain your choice of dopant and use diagrams as required.





Si doped with Ga

The band gap in pure Si (between the full valence band and the empty conductance band) is large. Normal thermal energy does not give the electrons enough energy to make the jump and so Si is an insulator.

As Si has 4 electrons per atom, replacing some Si atoms with Ga (or other Group 13 element), means that the valence band will not be completely occupied with electrons. The gaps act as positive holes and allow the material to act as a semiconductor of the p-type.

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