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Topic 2.4: Structure of Metals and Alloys

Revision Notes · AP Chemistry

UNIT 2 · COMPOUND STRUCTURE AND PROPERTIES

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The Electron Sea Model

A solid metal is a regular lattice of positive metal ions surrounded by a sea of delocalized valence electrons. Each metal atom gives its valence electrons to the shared pool, so the electrons move throughout the whole crystal and belong to no single atom.

Why the cations do not fly apart. Positive ions repel each other, yet the structure holds: every cation is attracted simultaneously to the negatively charged sea all around it, and that shared attraction beats the cation to cation repulsion. This electrostatic attraction is the glue of a metal. Unlike an ionic solid, a metal has no anions; unlike a molecular solid, its electrons are not locked inside localized covalent bonds.

Electrical and Thermal Conductivity

Electrical conductivity. Under a potential difference, the delocalized electrons drift through the lattice, carrying charge. The cations stay in their lattice positions; the electrons are the only moving charge carriers. This separates metals from ionic compounds in a single test: a metal conducts as a solid, while an ionic solid cannot, because its ions are locked in place and it has no free electrons.

Melting changes less than students expect: in a liquid metal the cation lattice is disordered, but the sea is still present and mobile, so the liquid keeps most of its conductivity. Ionic compounds conduct when molten for the opposite reason: melting frees their ions.

Thermal conductivity and lustre. The same mobile electrons transfer kinetic energy rapidly through the metal, so electrical and thermal conductivity travel together; they also interact strongly with light and reflect it, giving metals their shine.

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Malleability and Ductility

Hammer a metal and layers of cations slide past each other into new positions. The metal does not break, because metallic bonding is non-directional: the electron sea redistributes around the shifted cations and the attraction is maintained, so the piece changes shape instead of fracturing. Malleability is this behaviour under hammering or rolling into sheets; ductility is the same behaviour when drawn into a wire.

The contrast with ionic solids. Shift a layer in an ionic crystal by one ion position and like charges come face to face, and their repulsion splits the crystal apart. Metals have no alternating charges to misalign, so they deform where ionic solids shatter. Both can have high melting points and both conduct when liquid; solid state conductivity and malleability are the separators.

What Sets the Strength of Metallic Bonding

The attraction between the cations and the sea grows with the number of valence electrons contributed and with the charge on the cations left behind. More electrons in the sea and a higher cation charge mean stronger metallic bonding and, usually, a higher melting point. Sodium contributes one valence electron per atom and forms Na^+, and it melts at 98 °C. Magnesium contributes two and forms Mg^{2+}, and it melts at 650 °C: the extra electron per atom in the sea, combined with the doubled cation charge pulling on it.

Alloys: Deliberately Disrupting the Lattice

An alloy contains two or more elements, at least one of them a metal, and is made because the mixture is more useful than the pure metal: usually harder and stronger, at the cost of some malleability and conductivity. Added atoms break up the perfect regularity of the host lattice, and a distorted lattice resists the sliding of layers, so the alloy is harder; the same disorder scatters the delocalized electrons, so an alloy generally conducts less well than its pure host metal. Classification is by position and size: atoms that replace host atoms give a substitutional alloy, and much smaller atoms in the gaps give an interstitial alloy. On an exam, read the particulate diagram, not a memorized example.

Substitutional Alloys

In a substitutional alloy, solute atoms occupy normal lattice positions in place of solvent atoms. That works only when the two kinds of atom have comparable radii: as a rule of thumb, radii within about 15% of each other can exchange places without wrecking the lattice.

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Brass is the standard example: copper (128 pm) and zinc (134 pm) differ by only 4.7%, so zinc atoms substitute for copper atoms throughout the lattice. Bronze (copper with tin, 140 pm, a 9.4% difference) works the same way, and silver and gold, both 144 pm, substitute perfectly.

Substitution is not free: the replacement atoms are never quite identical to the host atoms, so the lattice is slightly distorted, planes slide less easily, and the alloy is harder and less malleable. Fourteen karat gold is the everyday case. Pure gold is too soft for jewellery, so some of its atoms are replaced by silver and copper atoms of similar size, giving a substitutional alloy hard enough to wear (14 karat means 14 parts gold out of 24: 58.3% by mass).

Interstitial Alloys

In an interstitial alloy the added atoms are far too small to replace host atoms, so they fit into the interstices: the empty spaces between the larger host atoms, which stay in their normal positions.

Steel is the standard example: an iron atom has a radius of 126 pm and a carbon atom 77 pm, about 39% smaller, far outside the comparable size range. The carbon atoms lodge in the holes in the iron lattice and obstruct the movement of the layers, so steel is much harder and stronger than pure iron, and less malleable.

Interstitial atoms add mass without adding much volume, so the alloy is typically slightly denser than the pure metal. The metallic bonding survives: steel keeps its electron sea, still conducts, and still melts. It is a harder metal, not a different kind of solid.

Traps That Cost Marks in Topic 2.4

Naming ions or protons as the charge carriers. In a metal the cations stay in their lattice positions and protons never move. The current is the drift of delocalized electrons, and an answer in which positive charges flow through the wire has the model backwards.

Explaining malleability by weak bonds. Metallic bonds can be extremely strong; tungsten melts above 3,000 °C. Metals bend because their bonding is non-directional and survives layer sliding, not because it is feeble. Ionic solids are the brittle ones.

Classifying an alloy from its ingredients instead of its sizes and positions. Carbon in iron might sound as if it should substitute evenly, but the roughly 39% size gap forces it into the gaps. Zinc in copper sounds like a guest between atoms, but the 4.7% size match makes it substitutional.

Claiming alloying destroys metallic properties. An alloy keeps its electron sea: it still conducts, still has its lattice of cations, and still melts. Alloying reduces conductivity and malleability; it never produces an insulator or a molecular solid.

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Saying alloying increases malleability. Both alloy types distort the lattice and hinder layer sliding, so hardness rises and malleability falls; added atoms are obstacles to sliding, not a lubricant.

Key Relationships to Remember

- Electron sea model: lattice of metal cations in a sea of delocalized valence electrons belonging to no single atom (SAP-3.D.1); the cations stay put because their shared attraction to the sea outweighs their mutual repulsion
- Electrical and thermal conductivity: mobile delocalized electrons, in the solid and in the liquid
- Malleability and ductility: non-directional bonding lets layers of cations slide while the sea keeps them bound; ionic solids shatter because a shifted layer aligns like charges
- Metallic bond strength: rises with valence electrons contributed and cation charge (Na: 1 electron, Na^+, 98 °C; Mg: 2 electrons, Mg^{2+}, 650 °C)
- Substitutional alloy: atoms of comparable radius replace host atoms in lattice positions (SAP-3.D.3; brass: Cu 128 pm, Zn 134 pm, a 4.7% difference); harder and less malleable than the pure metal
- Interstitial alloy: much smaller atoms occupy the gaps between host atoms (SAP-3.D.2; steel: Fe 126 pm, C 77 pm, carbon about 39% smaller); harder, stronger, denser and less malleable
- Read the diagram: atoms in lattice positions means substitutional; small atoms in the holes means interstitial

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Topic 2.4 Quiz: Structure of Metals and Alloys

Topic 2.4 Worksheet

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