

Topic 2.2: Intramolecular Force and Potential Energy

Revision Notes · AP Chemistry

UNIT 2 · COMPOUND STRUCTURE AND PROPERTIES

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The Potential Energy Curve

Bring two atoms slowly toward each other and track the potential energy of the pair. Far apart, they barely interact and the energy is near zero. As they approach, each nucleus attracts the other atom's electrons, and the energy falls.

At one specific distance the energy reaches its minimum. That distance is the bond length, and the depth of the minimum below zero is the bond energy: the energy that must be supplied to pull the atoms completely apart again.

Push the atoms closer than the bond length and the energy climbs steeply. The nuclei repel each other, and the electron clouds repel too; at short range the repulsions overwhelm the attractions. A bond is the compromise position where the total force balances at the lowest possible energy.

Reading the curve. Every potential energy diagram in this topic is read the same way: horizontal position of the minimum gives bond length; vertical depth of the minimum gives bond strength. A deeper well means a stronger bond. A well whose minimum sits further left means a shorter bond.

Bond Order, Bond Length and Bond Energy

Two atoms can share one, two or three pairs of electrons: a single, double or triple bond. The number of shared pairs is the bond order.

More pairs, stronger and shorter. Additional shared pairs pull the nuclei closer together and hold them harder. For the same pair of atoms, bond energy rises and bond length falls as bond order increases. Carbon to carbon: a single bond is about 348 kJ/mol and 154 pm; a double bond about 614 kJ/mol and 134 pm; a triple bond about 839 kJ/mol and 120 pm.

The pattern is a useful prediction tool. Given two bonds between the same atoms, the one with the higher bond order is shorter and stronger, always. Given bonds of the same order between different atoms, shorter usually means stronger: H–F (92 pm) is much stronger than H–I (161 pm), because the small fluorine atom lets the nuclei approach closely, where the attractions are intense.

What Sets Bond Length Between Different Atoms

Bond length is roughly the sum of the two atoms' radii, so atomic size is the first factor: bonds to hydrogen are short, bonds to iodine are long.

The second factor is the pull each nucleus exerts on the shared pairs. A small atom with a high effective nuclear charge (fluorine is the extreme) drags the bonding electrons and the other nucleus in close, shortening and strengthening the bond. This is Coulomb's law applied inside the molecule, the same principle that ran Unit 1.

Potential Energy in Ionic Bonding

The same energy thinking explains the ionic lattice. Bringing a cation and an anion together releases energy as their attraction grows, and a whole lattice releases a great deal: the lattice energy is the energy given out when gaseous ions pack into the solid (equivalently, the energy needed to separate the solid into gaseous ions).

Lattice energy follows Coulomb's law, as in Topic 2.1: it increases with the product of the ion charges and decreases with the distance between ion centres. That is why the potential energy minimum for MgO is far deeper than for NaCl, and why small ions like Li^+ and F^- produce unusually stable lattices.

Comparing Curves on One Diagram

Exam questions overlay two potential energy curves and ask which bond is which. Work the two readings separately.

If curve A's minimum is deeper than curve B's, bond A is stronger and needs more energy to break. If curve A's minimum sits at a smaller distance, bond A is shorter. The two readings often point to the same bond (stronger bonds are usually shorter), but they are independent facts: read depth for strength, position for length, and never infer one from the other without saying so.

For bonds between different atoms, the curve with its minimum further right belongs to the pair with the larger atoms. For the same atoms at different bond orders, the deeper, left shifted curve is the higher order bond.

Traps That Cost Marks in Topic 2.2

Confusing bond energy with the energy of the atoms. Bond energy is a difference: the depth from the minimum up to the separated atoms at zero. A deep minimum means the bonded state is very stable and the bond is strong; it does not mean the atoms themselves "contain" that energy.

Saying a double bond is twice as strong as a single bond. The trend is real but not proportional: $C=C$ at about 614 kJ/mol is well short of twice $C-C$ at 348. Each added pair contributes less than the one before, partly because the pairs repel each other.

Reading the wrong axis for the wrong quantity. On a potential energy curve, length is horizontal and strength is vertical. Answers that claim a bond is stronger because its minimum is further left have mixed the two; position is length, depth is strength.

Forgetting the repulsive wall. Asked why atoms do not simply collapse together, the answer is the steep rise at short distance: nuclear repulsion (and electron cloud repulsion) grows faster than the attractions as the atoms close in, so the energy minimum, not contact, is the stable point.

Applying bond order comparisons across different atom pairs carelessly. Triple beats single for the same two atoms. Across different pairs, size competes with order: compare lengths and energies as separate data rather than assuming the higher order bond always wins on both.

Key Relationships to Remember

- Potential energy curve: minimum position = bond length; depth of minimum = bond energy (energy to separate the atoms)
- Bond order up $\rightarrow$ bond length down, bond energy up (for the same pair of atoms)
- Bond length $\approx$ sum of atomic radii; small, high $Z(\text{eff})$ atoms form shorter, stronger bonds
- Energy is released when a bond forms and required, in the same amount, when it breaks
- Lattice energy follows Coulomb's law: larger ion charges and smaller ions give a deeper potential energy minimum and a more stable lattice

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