

Topic 2.2: Intramolecular Force and Potential Energy

Worksheet · AP Chemistry

Unit 2 · Compound Structure and Properties

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How to Use This Worksheet

Work through the sections in order. Section A checks the ideas, Section B builds fluency with bond data and energy curves, and Section C mixes everything the way an exam would.

For every curve question, read the two features separately: the horizontal position of the minimum is the bond length, and the depth of the minimum is the bond energy. Say which feature you used for each conclusion.

Do not look at the answer key until you have attempted every question. The key gives full working, so compare your method, not just your final answer.

Section A: Recall and Concepts

A1. Describe what happens to the potential energy of two hydrogen atoms as they are brought together from a large distance to form H_2 , and identify the point on the curve that represents the bond length.

A2. Explain why the potential energy rises steeply when two bonded atoms are pushed closer together than the bond length.

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A3. Define bond energy, and state its relationship to the energy released when the same bond forms.

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A4. State how bond length and bond energy change as bond order increases from single to double to triple, for bonds between the same two atoms.

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A5. A student says "a double bond is exactly twice as strong as a single bond because it has twice the electrons." Correct the claim, using the C—C (348 kJ/mol) and C=C (614 kJ/mol) values.

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Section B: Core Practice

B1. The H—F bond is 92 pm long with a bond energy of 567 kJ/mol. The H—I bond is 161 pm long with a bond energy of 299 kJ/mol. State the pattern these two bonds show, and explain it in terms of atomic size and attraction.

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B2. Put the three carbon to carbon bonds (single 154 pm, double 134 pm, triple 120 pm) in order of increasing bond energy, and justify the order.

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B3. Two potential energy curves are drawn for H–Cl and H–Br. The H–Br curve's minimum is shallower and sits at a larger distance than the H–Cl minimum. State which bond is longer, which is stronger, and the feature of the curve you read for each answer.

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B4. N₂ has a triple bond and a bond energy of about 945 kJ/mol; O₂ has a double bond and a bond energy of about 498 kJ/mol. Explain why the comparison supports the bond order pattern even though the atoms differ.

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B5. A bond has a potential energy minimum of –431 kJ/mol relative to separated atoms (the value for H–Cl). State how much energy is needed to break one mole of these bonds, and how much is released when one mole of the bonds forms from separated atoms.

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B6. State, with a reason, which of F₂ (159 kJ/mol, 142 pm) and Cl₂ (243 kJ/mol, 199 pm) breaks the usual "shorter means stronger" pattern, and give the standard explanation for the exception.

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Section C: Exam Style

C1. The potential energy curve for the bond in a diatomic molecule X₂ has its minimum at 110 pm with a depth of 945 kJ/mol. A second molecule Y₂ has its minimum at 121 pm with a depth of 498 kJ/mol. (a) State which molecule has the longer bond and which has the stronger bond. (b) Suggest the bond order in each molecule, given that both are formed from Period 2 elements. (c) Explain why the stronger bond is not simply the shorter bond by the same percentage.

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C2. Consider the ionic solids NaCl and MgO. The potential energy of the MgO lattice is much lower (more negative) relative to its separated gaseous ions than that of NaCl. (a) State what this tells you about the relative lattice energies. (b) Explain the difference using Coulomb's law, covering both variables. (c) Predict two physical properties in which MgO will exceed NaCl as a direct consequence.

C3. A student plots a potential energy curve for H_2 and draws the energy falling steadily as the atoms approach, reaching its lowest point when the nuclei touch, with no rise at short distance. (a) Identify the two features of the real curve the drawing gets wrong. (b) Explain the physical cause of the missing feature, naming the repulsions involved.

Answer Key

A1. At large separations the atoms barely interact and the potential energy is close to zero. As they approach, the attraction of each nucleus for the other atom's electrons lowers the energy steadily. The energy passes through a minimum and then rises sharply at very short distances. The minimum is the stable bonded state, and the internuclear distance at that minimum is the bond length (74 pm for H₂).

A2. At very short range the two positive nuclei repel each other strongly, and the electron clouds also repel. These repulsions grow faster than the attractions as distance falls (the nuclear repulsion follows an inverse square in distance), so the total energy climbs steeply. The bond length is the balance point where attraction and repulsion cancel at minimum energy.

A3. Bond energy is the energy that must be supplied to break one mole of the bond and separate the atoms completely (to the zero of potential energy). Bond formation is the exact reverse journey down the same curve, so forming one mole of the same bonds releases exactly the same amount of energy.

A4. As bond order increases, bond length decreases and bond energy increases. Each additional shared pair pulls the two nuclei closer together (shorter) and the greater total attraction means more energy is needed to separate them (stronger).

A5. The values refute "exactly twice": twice 348 would be 696 kJ/mol, but C=C is 614 kJ/mol, about 1.8 times, not 2. The second shared pair does add attraction, but the pairs of electrons also repel each other, and the second pair is held in a geometry set by the first, so each added pair contributes less extra strength than the one before.

B1. The pattern: the shorter bond is the much stronger bond. Fluorine is a very small atom, so in H–F the nuclei sit close together where the attraction between them and the shared electrons is intense; the bond is short and strong. Iodine is large, the nuclei are far apart in H–I, attractions are weaker at that distance, and the bond is long and weak.

B2. Single < double < triple in bond energy. Bond energy rises with bond order for the same atom pair, and the lengths confirm the order: 154 > 134 > 120 pm is the length order, which is the reverse of the energy order (348, 614, 839 kJ/mol).

B3. H–Br is longer: its minimum sits at the larger internuclear distance (position on the horizontal axis). H–Cl is stronger: its minimum is deeper (vertical depth), so more energy is needed to climb out of the well to separated atoms.

B4. The atoms are neighbours in the same period, so size differences are small and the dominant difference is bond order: N₂'s triple bond shares three pairs and O₂'s double bond shares two. The near doubling of bond energy with the extra shared pair, between atoms of comparable size, is the

bond order effect: more shared pairs, stronger and shorter bond (N_2 is 110 pm, O_2 is 121 pm, consistent with the same pattern).

B5. Breaking one mole of $\text{H}-\text{Cl}$ bonds takes +431 kJ (energy must be supplied to climb from -431 to 0). Forming one mole of $\text{H}-\text{Cl}$ bonds from separated atoms releases 431 kJ (the system falls from 0 to -431). The two values are equal in size and opposite in sign because they are the same journey in opposite directions.

B6. F_2 is the exception: it is shorter than Cl_2 but weaker. The standard explanation: fluorine atoms are so small that the non-bonding electron pairs (lone pairs) on the two atoms are forced close together and repel strongly, weakening the bond. In Cl_2 the atoms are larger, the lone pairs are farther apart, the repulsion is smaller, and the bond is stronger despite being longer.

C1. (a) Y_2 has the longer bond (minimum at 121 pm against 110 pm). X_2 has the stronger bond (minimum depth 945 against 498 kJ/mol). (b) X_2 's very high bond energy with a short length indicates a triple bond (the values match N_2 exactly). Y_2 's intermediate depth and length indicate a double bond (the values match O_2). Both assignments fit the bond order pattern: three shared pairs give a shorter, stronger bond than two. (c) Length and energy are separate features of the curve. Length is set by where the minimum sits (mainly atomic sizes and order), energy by the depth of the well (total attraction minus repulsions). Their percentage changes need not match because they measure different things; only the direction of the pattern (higher order: shorter and stronger) is guaranteed.

C2. (a) MgO has the larger lattice energy: its bonded state sits much lower relative to separated ions, so much more energy is released on forming the lattice (and required to break it). (b) Charge: MgO 's ions are +2 and -2 (charge product 4) against NaCl 's +1 and -1 (product 1), so attractions are about four times stronger at equal distance. Distance: Mg^{2+} and O^{2-} are both smaller than Na^+ and Cl^- , so the ions approach more closely, strengthening the attraction further by the inverse square. Both Coulomb variables act in the same direction, so the lattice energy difference is large. (c) Melting point (MgO about $2,850^\circ\text{C}$, NaCl 801°C) and hardness (or lattice enthalpy, or the energy needed to vaporize/dissociate the solid): both reflect the extra energy needed to pull the more strongly attracted ions apart.

C3. (a) Two errors: the real curve has a minimum at a finite distance (74 pm for H_2), not at contact; and the real curve rises steeply at distances shorter than the bond length instead of continuing to fall. (b) The rise is caused by repulsion that dominates at short range: the two positively charged nuclei repel each other electrostatically, and the two electron clouds repel as they are forced to overlap. As the atoms close in, these repulsions grow faster than the nucleus to electron attractions, producing the steep wall on the left of the minimum.

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