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Topic 2.5: Lewis Diagrams

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 electron counting and standard diagrams, and Section C mixes everything the way an exam would.

For every species, work in the same order: count the total valence electrons first and write the number down, showing the charge adjustment, then place bonds and lone pairs, then audit the finished diagram by adding up every bonding electron and every lone pair electron and checking that the sum equals your count. A diagram that fails the audit is wrong, however tidy it looks.

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. State what the octet rule says, name the two kinds of electron pair that appear in a Lewis diagram, and state how many electrons a hydrogen atom must be surrounded by in a complete diagram.

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A2. Calculate the total number of valence electrons that must appear in the Lewis diagram of the carbonate ion, CO_3^{2-}, showing the contribution of each part of the formula, including the charge.

A3. The oxygen atom in H_2O is surrounded by two bonding pairs and carries exactly two lone pairs. Using the total valence electron count for H_2O, explain why oxygen cannot carry one lone pair or three lone pairs instead.

A4. A student draws BF_3 with three single bonds, three lone pairs on each fluorine atom, and one lone pair on the boron atom, "because nitrogen has a lone pair in NH_3". Use the total valence electron count for BF_3 to show that the student's diagram is impossible.

A5. Of the elements nitrogen, phosphorus, oxygen and sulfur, which can be the central atom in a Lewis diagram in which the central atom is surrounded by more than eight electrons? Explain why the others can never be, wherever they sit in a diagram.

Section B: Core Practice

B1. Describe, in words, the complete Lewis diagrams of CH_4 and NH_3: for each one give the total valence electron count, the bonds formed by the central atom, the number of lone pairs on the central atom, and the number of electrons surrounding the central atom.

B2. Carbon dioxide, CO_2, has 16 valence electrons. (a) Describe the diagram obtained if carbon is joined to each oxygen by a single bond and each oxygen is then given enough lone pairs for an octet. State how many electrons surround the carbon atom in this diagram. (b) Describe the

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finished Lewis diagram of CO_2, and verify that every atom has an octet and that the diagram uses exactly 16 electrons.

B3. Consider the ammonium ion, NH_4^+. (a) Calculate its total valence electron count, and explain the role of the +1 charge in the calculation. (b) Describe the complete Lewis diagram of the ion, including how the ion's charge is shown. (c) State how many lone pairs sit on the nitrogen atom and how many electrons surround it.

B4. Xenon tetrafluoride, XeF_4, is a neutral molecule. (a) Calculate its total valence electron count. (b) The skeleton has four single bonds and each fluorine is completed to an octet with lone pairs. Calculate how many electrons remain unplaced at that point, and state where they must go. (c) State how many electrons surround the xenon atom in the finished diagram, and name the category this places XeF_4 in.

B5. The chlorite ion, ClO_2^-, can be drawn with chlorine joined to each oxygen by a single bond, in a diagram where every atom has an octet. (a) Calculate the total valence electron count of the ion. (b) Describe this diagram fully: the bonds, the lone pairs on each oxygen, and the lone pairs on chlorine. (c) Audit the diagram: add up all the electrons your description places, and confirm the total.

B6. Beryllium chloride, $BeCl_2$, and boron trifluoride, BF_3, are both stable species whose central atoms lack an octet. (a) Calculate the total valence electron count of each species. (b) For each species, state how many electrons surround the central atom in its correct Lewis diagram. (c) State the name given to this category of octet rule exception, and explain in one sentence why no rearrangement of bonds can give the central atom an octet in either species.

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Section C: Exam Style

C1. The cyanide ion, CN^-, contains carbon and nitrogen joined by a covalent bond. (a) Calculate the total valence electron count of the ion. (b) Show, by counting, that a single bond between the atoms cannot give both atoms an octet with the electrons available. (c) Describe the finished Lewis diagram of CN^-, and verify both the octet of each atom and the total electron count.

C2. The sulfate ion, SO_4^{2-}, has sulfur as its central atom. (a) Calculate the total valence electron count of the ion. (b) Describe the diagram in which sulfur is joined to all four oxygens by single bonds: state the lone pairs on each oxygen, the electrons surrounding sulfur, and audit the total. (c) Describe the alternative diagram in which sulfur forms two double bonds and two single bonds: state the lone pairs on each kind of oxygen, the electrons surrounding sulfur, and audit the total again. (d) Explain why this alternative is available for SO_4^{2-} but the same trick cannot be used to give the central atom an expanded shell in CO_3^{2-}.

C3. The nitrate ion, NO_3^-, has nitrogen as its central atom. (a) Calculate the total valence electron count of the ion. (b) Nitrogen is joined to each oxygen by a single bond, and each oxygen is completed to an octet with lone pairs. Count the electrons placed by this procedure, and state how many electrons surround the nitrogen atom at this stage. (c) Describe how the diagram is finished, and give the lone pair count on each oxygen in the finished diagram. (d) State the total number of lone pairs in the finished diagram, and audit the diagram's total electron count.

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Answer Key

A1. The octet rule states that atoms in a molecule tend to be surrounded by eight valence electrons, with each shared pair counting toward the total of both atoms it joins. The two kinds of pair are the bonding pair, shared between two atoms and drawn as a line (or a pair of dots between them), and the lone pair, held by a single atom and drawn as a pair of dots on that atom. Hydrogen is the standing exception to the octet: its shell holds only two electrons, so a hydrogen atom is complete when it is surrounded by 2 electrons, the pair of its single bond, and it never carries a lone pair.

A2. Carbon contributes 4 valence electrons. Each oxygen contributes 6, and there are three oxygens: 3 × 6 = 18. The 2− charge means the ion owns two extra electrons: +2. Total: 4 + 18 + 2 = 24 valence electrons. All 24 must appear in the finished diagram of CO_3^{2-}.

A3. H_2O has 6 + 1 + 1 = 8 valence electrons in total. The two O−H bonds spend 4 of them, leaving 8 − 4 = 4 electrons, which form exactly two lone pairs on oxygen. One lone pair would place only 4 + 2 = 6 electrons in the diagram, leaving 2 of the 8 unaccounted for. Three lone pairs would place 4 + 6 = 10 electrons, two more than the molecule owns. The count fixes the number: two lone pairs, and oxygen is surrounded by 4 bonding + 4 lone pair electrons = 8, an octet.

A4. BF_3 owns 3 + (3 × 7) = 24 valence electrons. The student's diagram places 6 electrons in the three bonds, 3 × 6 = 18 in the fluorine lone pairs, and 2 more in the lone pair on boron: 6 + 18 + 2 = 26 electrons. That is 2 more than the 24 the molecule owns, so the diagram is impossible. Boron in BF_3 has no lone pair; it is surrounded by only the 6 bonding electrons.

A5. Phosphorus and sulfur. Both are in period 3, and a central atom in period 3 or below can be surrounded by more than eight electrons, as phosphorus is in PCl_5 (10) and sulfur is in SF_6 (12). Nitrogen and oxygen are in period 2, whose valence shell, n = 2, holds a maximum of eight electrons. No arrangement of bonds and lone pairs can put more than eight electrons around a period 2 atom, so nitrogen and oxygen can never carry an expanded shell, as central atoms or anywhere else.

B1. CH_4: total 4 + (4 × 1) = 8 electrons. Carbon forms four single bonds, one to each hydrogen; there are no lone pairs anywhere, and carbon is surrounded by 8 electrons. NH_3: total 5 + (3 × 1) = 8 electrons. Nitrogen forms three single bonds to the three hydrogens and carries one lone pair; nitrogen is surrounded by 6 bonding + 2 lone pair electrons = 8, and each hydrogen is surrounded by 2. The two diagrams differ by exactly the lone pair that ammonia's nitrogen keeps and methane's carbon does not have.

B2. (a) The two single bonds spend 4 electrons, and giving each oxygen an octet means three lone pairs on each oxygen, spending 12 more: all 16 electrons are placed. Carbon, however, is surrounded by only the 4 bonding electrons, half an octet, so this diagram is unfinished even

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though the electron total is already exhausted. (b) Move one lone pair from each oxygen into the C−O bond beside it, creating two double bonds, O=C=O. Each oxygen now has two lone pairs and is surrounded by 4 bonding + 4 lone pair electrons = 8; carbon is surrounded by the 8 bonding electrons. Audit: bonding electrons 8, lone pair electrons 8 (two pairs on each oxygen), total 8 + 8 = 16, exactly the count, with an octet on every atom.

B3. (a) Nitrogen contributes 5 and the four hydrogens contribute 4 × 1 = 4, giving 9; the +1 charge means one electron has been removed from the neutral total, so the ion owns 9 − 1 = 8 valence electrons. (b) Nitrogen sits at the centre joined to each of the four hydrogens by a single bond; there are no lone pairs on any atom; the whole structure is enclosed in square brackets with the + charge written outside, at the upper right. (c) Nitrogen carries zero lone pairs. It is surrounded by the 8 bonding electrons of its four bonds, a complete octet, and each hydrogen is surrounded by 2.

B4. (a) Xenon contributes 8 and each fluorine 7: 8 + (4 × 7) = 36 valence electrons. (b) The four bonds spend 8 electrons. Completing each fluorine's octet takes three lone pairs per fluorine: 4 × 6 = 24 electrons. Placed so far: 8 + 24 = 32, leaving 36 − 32 = 4 electrons. They cannot go on the fluorines, which already have octets, so they go on the central xenon as two lone pairs. (c) Xenon is surrounded by 8 bonding electrons + 4 lone pair electrons = 12. XeF_4 is an expanded octet species, possible because xenon is in period 5, well below period 2.

B5. (a) Chlorine contributes 7, the two oxygens contribute 2 × 6 = 12, and the 1− charge adds 1: 7 + 12 + 1 = 20 valence electrons. (b) Chlorine is joined to each oxygen by a single bond. Each oxygen carries three lone pairs, giving each oxygen 2 bonding + 6 lone pair electrons = 8. The chlorine carries two lone pairs, so chlorine is surrounded by 4 bonding + 4 lone pair electrons = 8: every atom has an octet. (Chlorine can also be drawn with a double bond to one oxygen, an expanded diagram; judging between valid diagrams belongs to the formal charge work of Topic 2.6.) (c) Audit: bonding electrons 2 × 2 = 4; oxygen lone pairs 2 × 6 = 12; chlorine lone pairs 4. Total: 4 + 12 + 4 = 20, exactly the counted total.

B6. (a) $BeCl_2$: 2 + (2 × 7) = 16 electrons. BF_3: 3 + (3 × 7) = 24 electrons. (b) In $BeCl_2$, beryllium forms two single bonds and is surrounded by 4 electrons. In BF_3, boron forms three single bonds and is surrounded by 6 electrons. (c) These are incomplete octets, also called electron deficient centres. No rearrangement can complete either octet because the totals run out: completing the chlorine or fluorine octets spends every electron the species owns, and converting lone pairs into extra bonds would break the terminal atoms' octets instead, so the central atom's shortage cannot be repaired from inside the diagram.

C1. (a) Carbon contributes 4, nitrogen 5, and the 1− charge adds 1: 4 + 5 + 1 = 10 valence electrons. (b) A single bond spends 2 electrons. Giving each atom an octet would then need three lone pairs on carbon (6) and three on nitrogen (6): 2 + 6 + 6 = 14 electrons, but the ion owns only 10. A single bond therefore cannot satisfy both octets; 4 electrons' worth of lone pairs must instead be shared, meaning the bond order must rise. (c) Finished diagram: the atoms are joined

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by a triple bond, and each atom carries one lone pair, with the whole ion in square brackets and the − charge outside. Octets: carbon is surrounded by 6 bonding + 2 lone pair electrons = 8, and nitrogen likewise by 8. Audit: bonding 6 + lone pairs 4 = 10, exactly the counted total.

C2. (a) Sulfur contributes 6, the four oxygens contribute 4 × 6 = 24, and the 2− charge adds 2: 6 + 24 + 2 = 32 valence electrons. (b) Four single bonds spend 8 electrons. Each oxygen carries three lone pairs, spending 4 × 6 = 24. Sulfur is surrounded by the 8 bonding electrons, a plain octet, and there are no lone pairs on sulfur. Audit: 8 + 24 = 32, exactly the total. (c) Convert one lone pair on each of two oxygens into a second bond to sulfur. The two double bonded oxygens now carry two lone pairs each, and the two single bonded oxygens still carry three each. Sulfur is surrounded by 2 × 4 + 2 × 2 = 12 electrons: an expanded octet. Audit: bonding electrons 12 (two double bonds of 4 and two single bonds of 2), lone pair electrons (2 × 4) + (2 × 6) = 20; 12 + 20 = 32, the same total, as it must be: nothing was added, electrons were only moved from lone pairs into bonds. (d) Sulfur is in period 3, so its valence shell can hold more than eight electrons and an expanded diagram is legal. Carbon in CO_3^{2-} is in period 2, whose shell holds at most eight, so carbon can never be surrounded by 10 or 12 electrons; carbonate's diagram must keep carbon at an octet, and any double bond drawn in it is paid for by the single fixed total of 24 electrons, not by expansion.

C3. (a) Nitrogen contributes 5, the three oxygens contribute 3 × 6 = 18, and the 1− charge adds 1: 5 + 18 + 1 = 24 valence electrons. (b) The three single bonds spend 6 electrons, and completing each oxygen's octet takes three lone pairs per oxygen, 3 × 6 = 18 electrons: 6 + 18 = 24, so every electron is placed. Nitrogen is surrounded by only the 6 bonding electrons, short of an octet, so the diagram is not finished even though the total is exhausted. (c) Move one lone pair from one oxygen into the N−O bond beside it, making one double bond. The double bonded oxygen now carries two lone pairs; the other two oxygens still carry three lone pairs each; nitrogen carries no lone pair and is now surrounded by 8 electrons. (d) Lone pairs in the finished diagram: 2 + 3 + 3 = 8 lone pairs. Audit: bonding electrons 4 + 2 + 2 = 8; lone pair electrons 8 × 2 = 16; total 8 + 16 = 24, exactly the counted total, with an octet on every atom.

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Next Worksheet: Topic 2.6 Resonance and Formal Charge

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