

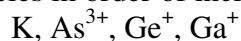
ANSWER KEY**Part 1. Multiple Choice (14 marks total)**

For each numbered statement below, circle the letter that corresponds to the best answer. There is only one correct answer per question. Each question answered correctly is worth 2 marks.

1. Which of the following compounds has a non-hydrogen atom that does not obey the octet rule?

- (a) arsenic trichloride
- (b) carbon dioxide
- (c) sulfur hexafluoride
- (d) ammonia
- (e) hydrazine (N_2H_4)

2. Arrange the following species in order of increasing size:



- (a) $\text{As}^{3+} < \text{Ga}^+ < \text{Ge}^+ < \text{K}$
- (b) $\text{Ga}^+ < \text{As}^{3+} < \text{Ge}^+ < \text{K}$
- (c) $\text{Ge}^+ < \text{K} < \text{Ga}^+ < \text{As}^{3+}$
- (d) $\text{As}^{3+} < \text{Ge}^+ < \text{Ga}^+ < \text{K}$
- (e) $\text{As}^{3+} < \text{Ge}^+ < \text{K} < \text{Ga}^+$

3. Which one of the following statements is true?

- (a) Lithium does not react with water.
- (b) Sodium metal is mined in Northern Canada.
- (c) The electron affinity of rubidium is smaller in magnitude than that of sodium.
- (d) The chemical bonds between rubidium atoms in rubidium metal are ionic.
- (e) The reaction of cesium with water releases oxygen gas.

4. What is the oxidation state of Cr in $(\text{NH}_4)_2\text{Mg}(\text{CrO}_4)_2 \cdot 6\text{H}_2\text{O}$?

- (a) +2
- (b) +3
- (c) +4
- (d) +5
- (e) +6

5. Which of the following elements has 4 neutrons in the nucleus of its most abundant isotope?

- (a) He
- (b) Li
- (c) Be
- (d) B
- (e) C

6. Molecules that have this shape are always polar.

- (a) see-saw
- (b) trigonal planar
- (c) octahedral
- (d) linear
- (e) tetrahedral

7. Which of the following is expected to exist as an isolable molecule?

- (a) C_4H_2
- (b) H_3O
- (c) N_2H_6
- (d) F_4
- (e) PH_6

Part 2. Short Answer Questions

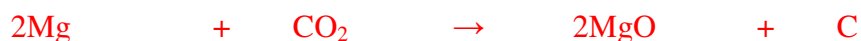
6 marks 1. For this question, consider only the following elements as possible answers:

Li, Na, K, Rb, Cs
Be, Mg, Ca, Sr, Ba

For each part, give the symbol from the above list that makes the statement correct.

- (a) Cs has the lowest first ionization energy.
- (b) Be forms an oxide with the largest lattice energy.
- (c) Na can form a compound with molar mass 78 g mol^{-1} that contains the peroxide ion.

6 marks 2. (a) Write a balanced equation for the reaction of magnesium with carbon dioxide.



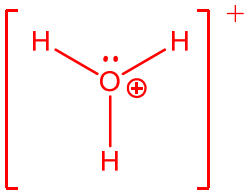
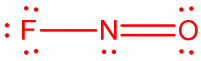
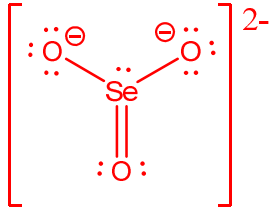
(b) Write a balanced equation for the reaction of barium oxide with oxygen.




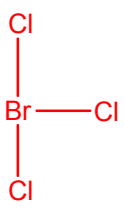
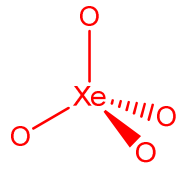
(c) Lithium metal reacts with nitrogen at room temperature to form lithium nitride (Li_3N). Sodium metal does not react with nitrogen under the same conditions. Provide a rationale for the difference of the reactivity of lithium and sodium with nitrogen.

The lattice energy of lithium nitride is greater than that of sodium nitrate because Li^+ is much smaller than Na^+ . As a result, Li_3N is a much more stable compound.

- 12 marks** 3. (a) Draw the best Lewis structure for each of the following molecules or ions. Draw only one structure when resonance is possible. Write any non-zero formal charges on the appropriate atoms, show all lone pairs of electrons as pairs of dots and all bond pairs as lines.

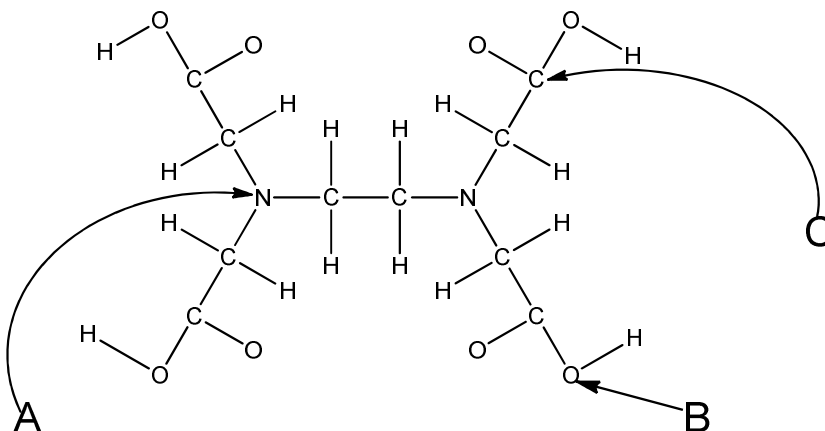
$[\text{H}_3\text{O}]^+$ 	NOF (N is the central atom) 	$[\text{SeO}_3]^{2-}$ 
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- (b) Complete the following table by drawing the perspective diagram and specifying the molecular shape for each molecule. The central atom is underlined. In the last column, clearly write “YES” if the molecule is polar, or “NO” if it is not polar.

Formula	Perspective Diagram	Molecular Shape	Is the molecule polar?
<u>Se</u> Cl ₄		See-saw	Yes
<u>Br</u> Cl ₃		T-Shaped	Yes
<u>Xe</u> O ₄		Tetrahedral	No

6 marks

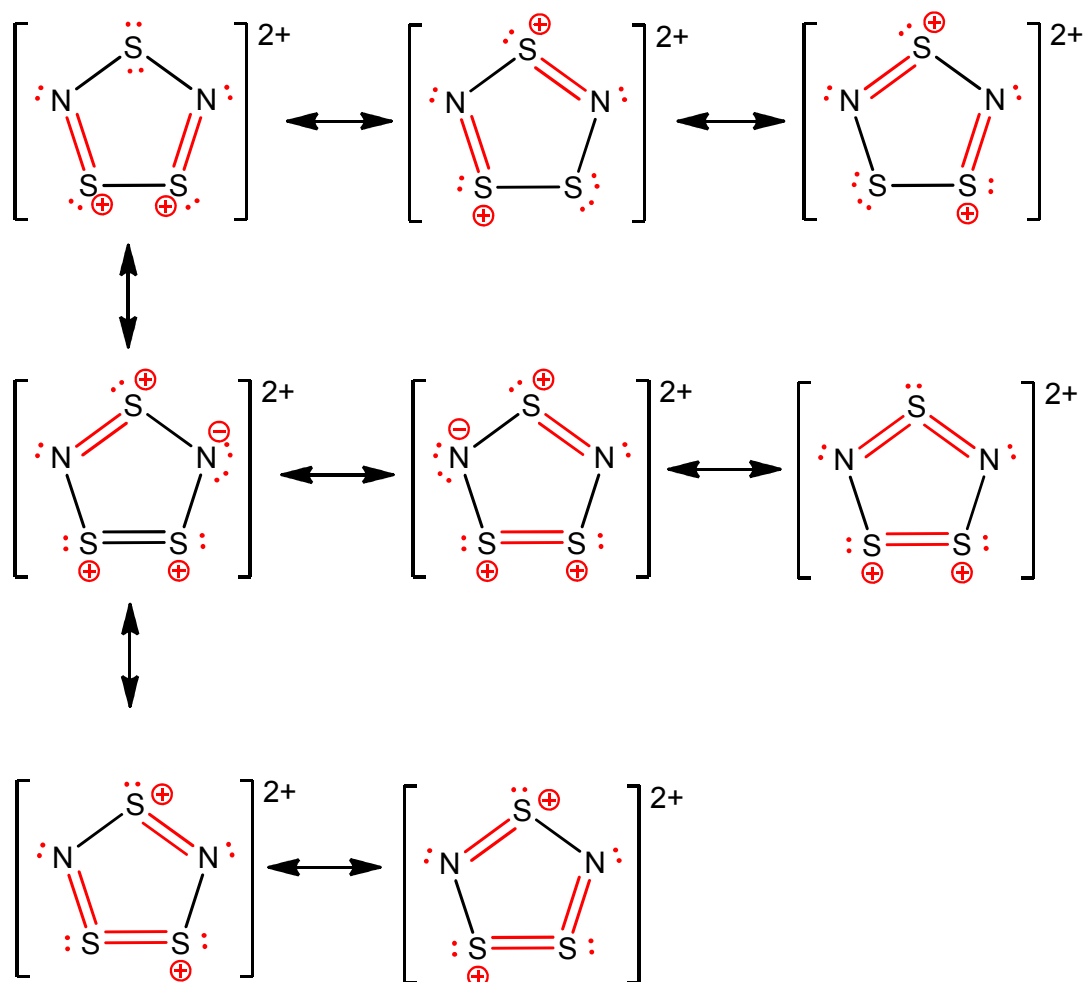
4. EDTA (ethylenediamine tetraacetic acid) is a common food additive. EDTA traps metal impurities in food that result from modern-day food manufacturing. Once trapped by EDTA, the metal-EDTA complex is excreted from the body. The following diagram shows the skeletal structure of EDTA. Answer parts (a) – (f) concerning the molecule below by circling the best answer.



<p>a) The molecular shape at the atom labeled A is</p> <p>(i) Tetrahedral (ii) Linear (iii) Trigonal Planar (iv) Bent (v) Trigonal Pyramidal</p>	<p>d) The number of carbon atoms with tetrahedral molecular shape in EDTA is</p> <p>(i) 0 (ii) 2 (iii) 4 (iv) 6 (v) 10</p>
<p>b) The estimated H-O-C bond angle at the atom labeled B is</p> <p>(i) 90° (ii) 120° (iii) 109° (iv) 145° (v) 60°</p>	<p>e) The formal charge on the atom labeled A in the best Lewis structure is</p> <p>(i) -2 (ii) -1 (iii) 0 (iv) +1 (v) +2</p>
<p>c) The estimated O-C-O bond angle at the atom labeled C is</p> <p>(i) 90° (ii) 120° (iii) 109° (iv) 145° (v) 60°</p>	<p>f) The oxidation state of the atom labeled B is</p> <p>(i) -2 (ii) 0 (iii) +2 (iv) +4 (v) none of the above</p>

- 6 marks** 5. The cation $[\text{S}_3\text{N}_2]^{2+}$ is known to exist as a ring with all VSEPR-predicted bond angles $\leq 120^\circ$. Complete the templates below by adding lone pairs and bonds to show five best resonance Lewis structures for $[\text{S}_3\text{N}_2]^{2+}$. Show all lone pairs of electrons as pairs of dots and all additional bonds as lines. Write any non-zero formal charges on the appropriate atoms.

There are eight best structures. Five of the eight best structures should be drawn for full marks.



Space for rough work:

- 5 marks** 6. Barium titanate has piezoelectric properties and is used in commercial products such as microphones and guitar pickups. Its structure consists of a simple cubic lattice of barium atoms where a titanium atom occupies the cubic hole and oxygen atoms occupy the middle of each face of the unit cell.

(a) What is the empirical formula of barium titanate?

Answer:

BaTiO₃

(b) How many oxygen atoms surround each titanium atom in barium titanate?

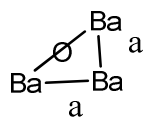
Answer:

6

(c) In barium titanate the radius of the oxygen ions is 1.26 Å, the radius of the barium ions is 1.56 Å and the radius of the titanium ions is 0.74 Å. What is the volume (in Å³) of the unit cell of barium titanate?

There are two ways to determine the edge length, a:

The first is using the face of the cube:



The distance across the face is: $2 \times 1.26 \text{ Å} + 2 \times 1.56 \text{ Å} = 5.64 \text{ Å}$

Using Pythagorean theorem:

$$a^2 + a^2 = (5.64 \text{ Å})^2$$

Solving for a:

$$a = 3.99 \text{ Å}$$

$$\text{Volume of unit cell} = a^3 = (3.99 \text{ Å})^3 = \mathbf{63.4 \text{ Å}^3}$$

The second is using the distance through the body of the cube (across the Ti atom):

$$a = 2 \times 0.74 \text{ Å} + 2 \times 1.26 \text{ Å} = 4.0 \text{ Å}$$

$$\text{Volume of unit cell} = a^3 = (4.0 \text{ Å})^3 = \mathbf{64 \text{ Å}^3}$$

Since a larger volume is calculated using the distance through the body of the cube, the correct volume must be **64 Å³**

Answer:

64 Å³

5 marks

7. A chemist found a bottle of an s-block metal, but the label had worn off so that the metal could not be identified. Under an argon atmosphere (to prevent any reaction with air or moisture), the chemist slowly added 5.00 g of the metal to an Erlenmeyer flask containing 500 g of bromine. A reaction occurred immediately (the flask became hot) and, after the reaction was complete, the excess bromine was evaporated to leave 9.67 g of a white solid.
- (a) Identify the unknown metal with a chemical symbol? You must show your work for credit.

Moles of s-block metal reactant = moles of product

$$\frac{5 \text{ g}}{x \text{ g mol}^{-1}} = \frac{9.67 \text{ g}}{(x \text{ g mol}^{-1} + n(80 \text{ g mol}^{-1}))}$$

If $n = 1$, the product is YBr (where Y is the s-block metal).

Solving for x:
 $x = 85.7 \text{ g mol}^{-1}$

This molecular weight corresponds to the molecular weight of Rb.

If $n = 2$, the product is YBr₂.

Solving for x:
 $x = 171 \text{ g mol}^{-1}$

This molecular weight does not correspond to the molecular weight of any s-block metal.

The unknown is Rb.

- (b) Write a balanced equation for the chemical reaction observed.



End of Examination