CANADIAN CHEMISTRY CONTEST

CHEMISTRY

TOPIC QUESTIONS

King

CANADIAN CHEMISTRY OLYMPIAD | OLYMPIADE DE CHIMIE DU CANADA

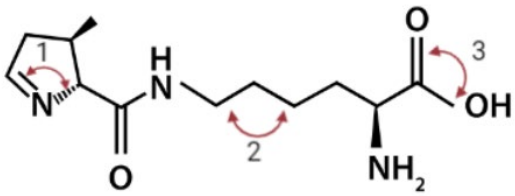
3. From Structure to Properties

KingCh

7) Scientists have discovered that one of the twenty-eight artificially created zirconium isotopes, zirconium-88, had an unusually high affinity for neutrons. In zirconium-88, a proton absorbs an atomic electron, forming a neutron and emitting a neutrino. What is the correct notation for the atom that forms as a result of this transition?

A) ${}^{88}_{39}Y$ B) ${}^{89}_{39}Y$ C) ${}^{89}_{39}Zr$ D) ${}^{88}_{40}Zr$ E) ${}^{89}_{41}Nb$

16) The α amino acid pyrrolysine is absent in humans, but found in some methanogenic bacteria and archeobacteria for synthesis of proteins. The structure of pyrrolysine is shown below:



What are the approximate values of the bond angles labelled 1, 2, and 3, respectively?

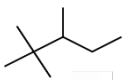
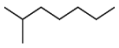
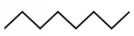
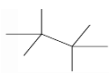
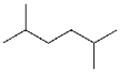
A) 120°, 120°, 120°
B) 109.5°, 109.5°, 120°
C) 109.5°, 120°, 120°
D) 109.5°, 109.5°, 109.5°
E) 120°, 109.5°, 120°

CCC 2021

2) Based on VSEPR theory, which of the following has a 'seesaw' or 'distorted tetrahedral' molecular geometry?

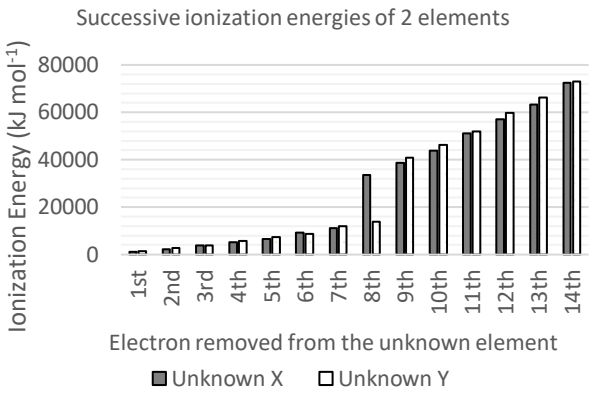
A) H_2O B) CH_4 C) XeF_4 D) BF_3 E) SeF_4

4) A student drew structural diagrams for some of the isomers of octane and wrote down each isomer's boiling point (b.p.). There is an error in the student's work. For which structure did the student **incorrectly** record the boiling point?

A)  b.p. 129°C
B)  b.p. 116°C
C)  b.p. 126°C
D)  b.p. 106°C
E)  b.p. 109°C

6) Given the graph of the successive ionization energies for two unknown atoms, which combination provides the most likely identity of X and Y?

Unknown:	X	Y
A)	Al	Si
B)	Kr	Rb
C)	Cl	Ar
D)	Se	Br
E)	Rb	Sr



16) Which of the following should have the same electron arrangement as BF_4^- around the **central** atom?

A) IF_4^- B) $XeCl_4$ C) ClF_4^+ D) SF_4 E) CCl_4

CCC 2020

5) The melting point of CaS is higher than that of KCl. Explanations for this observation include which of the following?

I. Ca^{2+} is more positively charged than K^+.
II. S^{2-} is more negatively charged than Cl^-.
III. The K^+ ion is smaller than the Ca^{2+} ion.

A) II only B) I and II only C) I and III only
D) II and III only E) I, II, and III

6) Fluorine is the most electronegative element on the periodic table. As a result it always forms polar bonds with other non-metals. Despite this, which of the following fluorine containing compounds would be a non-polar molecule?

A) SF_4 B) PF_3 C) IF_5 D) BrF_3 E) XeF_4

7) Ronald James Gillespie, who developed Valence Shell Electron Pair Repulsion (VSEPR) theory, isolated the superacid fluorosulfuric acid (HSO_3F) when he combined fluorinated compounds with concentrated sulfuric acid, creating brightly coloured solutions. Which of the following best describes the molecular shape of fluorosulfuric acid, as predicted by VSEPR theory?

A) See saw B) Trigonal bipyramidal C) Tetrahedral
D) Square planar E) Trigonal pyramidal

9) The ionization energies for period 3 element *X* are listed in the table below.

Ionization Energies for element *X* (kJ mol^{-1})				
First	Second	Third	Fourth	Fifth
580	1,815	2,740	11,600	14,800

Based on the data, which statement about element X is **FALSE**?

A) Its most common oxidation state is +3
B) It is displaced from aqueous solution by copper metal
C) It is the most abundant metal in the Earth's crust
D) Its oxide is insoluble in water
E) It is a lustrous metal

19) The subshell filling order used for the quantum mechanical model of the atom is an approximation of the relative subshell energies, which assumes the energies remain fixed. However, there are exceptions to the Aufbau Principle. Which of the following is the correct ground state configuration of an element found on the periodic table?

A) [Ar] $4s^1$ $3d^5$ B) [Ar] $4s^2$ $3d^4$ C) [Ar] $4s^2$ $4d^4$
D) [Ar] $4s^2$ $4p^4$ E) [Ar] $4s^1$ $4p^5$

7) Table 1: Successive Ionization Energies of 3rd Period Elements

Element	IE_1 (kJ $^{-1}$ mol $^{-1}$)	IE_2 (kJ $^{-1}$ mol $^{-1}$)	IE_3 (kJ $^{-1}$ mol $^{-1}$)	IE_4 (kJ $^{-1}$ mol $^{-1}$)	IE_5 (kJ $^{-1}$ mol $^{-1}$)
V	787	1577	3231	4356	16091
W	738	1451	7733	10540	13630
X	1251	2297	3822	5158	6540
Y	496	4562	6912	9543	13353
Z	578	1817	2745	11575	14830

Based on this information, which of the following statements is **FALSE**?

A) Y is sodium
B) X has the smallest radius
C) W is an alkaline earth metal
D) Z forms the largest cation
E) V is a semi-metal

13) In 1962, at the University of British Columbia, Neil Bartlett shattered conventional chemistry wisdom and synthesized xenon tetrafluoride, the first binary compound of a noble gas. Which of the following statements is/are true about a molecule of xenon tetrafluoride?

I) The molecule has no lone pairs on the central atom
II) The molecule has a tetrahedral geometry
III) The molecule has no net molecular dipole

A) I only B) II only C) III only D) II and III E) I, II and III

20) Which of the following accurately represents a trend in atomic radius?

A) F > Cl > Br
B) F > O > N
C) $Cl^- > Na^+ > Mg^{2+}$
D) $Ca^{2+} > K^+ > Ca$
E) $O^{2-} > S^{2-} > Cl$

2) A reaction AB + C, undergoes a single displacement reaction. Which of the following would be a product of the reaction if A is a group 2 metal and C is a group 1 metal?

A) CA_2 B) B C) CB D) A_2 E) C_2B

3) In which of the following situations could hydrogen bonding occur between H_2O and the solute?

A) ammonia gas dissolved in water
B) hydrogen gas dissolved in water
C) carbon dioxide gas in water
D) methane gas dissolved in water
E) hydrogen sulfide gas dissolved in water

5) Which of the following molecules has a molecular dipole?

A) XeF_4 B) SeF_4 C) CF_4 D) SiF_4 E) KrF_2

12) The electron configuration $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^8$ corresponds to which of the following?

A) Ni B) Ni^{2+} C) Fe D) Fe^{2+} E) Zn^{2+}

15) The first electron affinity (EA) for any element X is represented by the equation: $X(g) + e^- \rightarrow X^-(g) + EA_1$. Negative values for electron affinity indicate that energy is released when an atom gains an electron. Most highschool textbooks teach the trend that electron affinity increases across a period. According to the table below, which of the following statement(s) is/are true?

Element	Li	Be	B	C	N	O	F	Ne
EA (kJ mol^{-1})	−59.6	0	−26.7	−153.9	−7	−141	−328	0

I. The absolute value of the energy released when an atom gains an electron is always lower for metals than non-metals
II. Metals cannot form anions
III. Neutral atoms with complete subshells do not release energy during anion formation

A) I only B) II only C) III only
D) I and II only E) I and III only

4) Which of the following compounds has the smallest bond angle?

A) BF_3 B) CF_4 C) NF_3 D) OF_2 E) ClF_3

8) Which element would have its highest energy valence electron correspond to the following quantum numbers? n= 4, $\ell = 2$

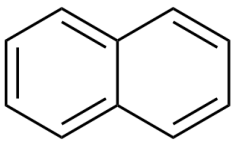
A) Sc B) Y C) K D) Zn E) Ga

9) The 1st and 3rd ionization energies of aluminum are 577.5 kJ mol^{-1} and 2744.8 kJ mol^{-1} respectively. What data best matches the 2nd and 4th ionization energies of aluminum?

	2nd ionization energy (kJ mol^{-1})	4th ionization energy (kJ mol^{-1})
A)	700	3500
B)	700	5000
C)	700	11000
D)	1800	11000
E)	1800	5000

CCC 2017

19) Naphthalene is a white crystalline solid, traditionally used as the primary ingredient in mothballs. It has the chemical formula $C_{10}H_8$, and its structure is shown to the right. Rank the solubility of naphthalene in the following solvents from most to least soluble.

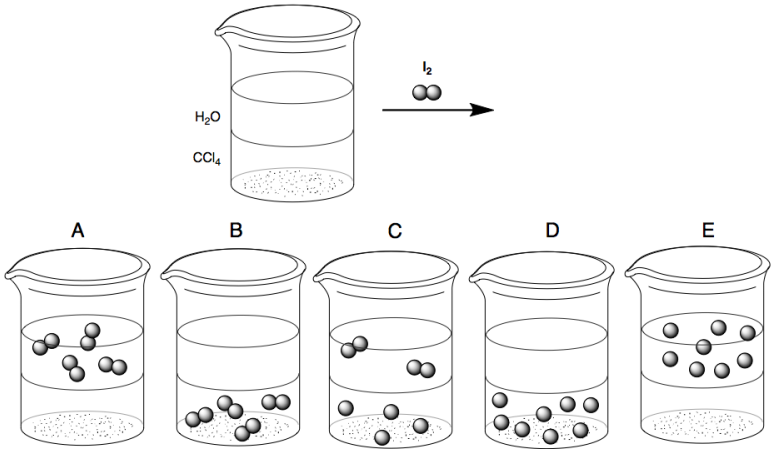


I. water II. hexane III. ethanol IV. hexanol

A) II > IV > III > I B) IV > II > III > I C) I > III > II > IV
D) II > III > IV > I E) IV > III > II > I

CCC 2016

8. Water and carbon tetrachloride (CCl_4) are immiscible liquids. If a student adds solid iodine to a beaker containing water and carbon tetrachloride, stirs vigorously to dissolve the iodine and allows the mixture to settle, which particulate diagram best describes the physical change that occurs?



10. The first ionization energy of phosphorus is lower than that of:

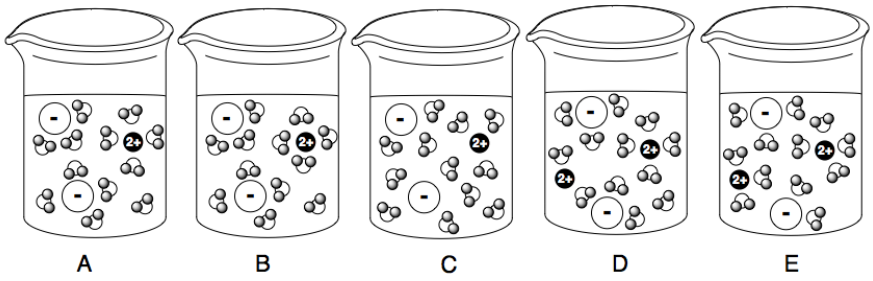
A) chlorine B) silicon C) sodium D) barium E) bismuth

11. In which of the following four compounds is intermolecular hydrogen-bonding present?

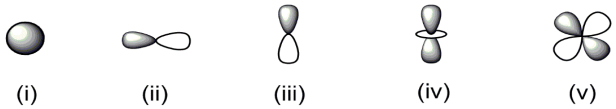
(I) 2-propanol, $(CH_3)_2CHOH$
(II) triethylamine, $(C_2H_5)_3N$
(III) dimethyl ether, $(CH_3)_2O$
(IV) *n*-butylamine, $CH_3CH_2CH_2CH_2NH_2$

A) (I), (III) and (IV) B) (I) and (III) C) (II) and (IV)
D) (I) only E) (I) and (IV)

14. Which particulate diagram best represents a dilute aqueous solution of magnesium chloride (solubility = 59.2 g/100 mL).



15. Assuming all orbitals in a given sublevel have equivalent energy, in which type of orbital(s) would the highest energy electron(s) in the Sc^{3+} be found? The neutral element scandium has an atomic number of 21.



A) i B) ii C) ii or iii D) iv E) iv or v

17. What is the smallest F—Xe—F bond angle in XeF_4?

A) <90° B) 90° C) 104.5° D) 109.5° E) 120°

2. According to the Aufbau Principle in quantum mechanics, which of the following is the highest energy electron sublevel?

A) 7s B) 6p C) 6d D) 5f E) 5p

3. In their solid form, which of the following is made up of discrete particles (either atoms, ions or molecules) that only have London Dispersion forces of attraction between them?

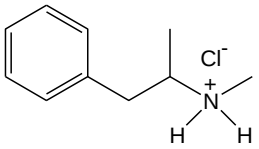
A) Ag B) CO_2 C) C, graphite D) KCl E) NH_3

4. Removing all lone pairs of electrons on the central atom of ClF_3 would change the geometry
   A) from trigonal pyramidal to trigonal planar
   B) from T–shaped to trigonal planar
   C) from trigonal bipyramidal to trigonal pyramidal
   D) from trigonal bipyramidal to trigonal planar
   E) minimally. The shape would remain trigonal planar.

5. Select the arrangement below that lists the bonds in order of ***increasing*** polarity (least polar to most polar):

A) C–F, O–F, Be–F B) O–F, C–F, Be–F C) Be–F, O–F, C–F
D) Be–F, C–F, O–F E) O–F, Be–F, C–F

9. In the television series *Breaking Bad*, Walter White and Jesse Pinkman synthesize methamphetamine (*N*–methyl–1–phenyl–2–propanamine) which is marketed as methamphetamine hydrochloride, or "crystal meth".



methamphetamine hydrochloride

10. Referring to question #9, in the structure of methamphetamine hydrochloride, how many non-bonding valence shell electrons are there? Lone valence electrons are single valence electrons that are not involved in covalent bonds.

A) 4 B) 6 C) 7 D) 8 E) 10

2. In May 2012, the International Union of Pure and Applied Chemistry (IUPAC) officially approved the names flerovium and livermorium for elements 114 and 116 respectively. The electron configuration of flerovium, element 114 is:

A) [Rn] $7s^2$ $5f^{14}$ $6d^{10}$ $7p^2$ B) [Rn] $7s^2$ $4f^{14}$ $5d^{10}$ $6p^2$
C) [Rn] $7s^2$ $4f^{14}$ $5d^{10}$ $7p^2$ D) [Rn] $7s^2$ $5f^{14}$ $6d^{10}$ $6p^2$
E) [Rn] $7s^2$ $6f^{14}$ $6d^{10}$ $7p^2$

4. The VSEPR theory can be used to predict the geometry of a molecule and whether or not it will have a permanent dipole moment. Which one of the following fluorides will have a non-zero dipole moment?

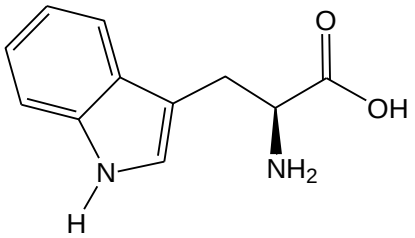
A) BeF_2 B) NF_3 C) XeF_4 D) PF_5 E) SF_6

14. The boiling point of chlorine (–35°C) is higher than that of hydrogen chloride (–85°C) because

A) the London dispersion forces between the larger Cl_2 molecules are stronger than the intermolecular forces between the smaller HCl molecules
B) there are hydrogen bonds between the HCl molecules in addition to the London dispersion forces
C) there are dipole-dipole forces between the HCl molecules in addition to the London dispersion forces
D) the covalent bonds in the Cl_2 molecules are stronger than the bonds in the HCl molecules
E) the polar covalent bonds in the HCl molecules are stronger than the bonds in the Cl_2 molecules

Questions 15 and 16 relate to the following information

L-Tryptophan (structure below) is one of the essential amino acids in the human diet. It is a common medical myth that L-tryptophan consumed during a turkey dinner is responsible for the tiredness felt afterwards even though turkey does not contain an especially large proportion of L-tryptophan. Answer the following two questions about this compound.

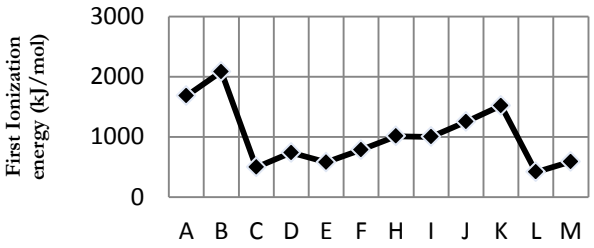


L-tryptophan

15. How many lone pairs of electrons are there in L-tryptophan?

A) 2 B) 4 C) 6 D) 8 E) 12

21. Below is a selection of unidentified consecutive elements on the periodic table (the atomic number increases by 1 from A to B and so on).



An element that is likely to be a halogen is:

A) A B) B C) C D) H E) M

CCC 2013

2. Which of the following atoms has the greatest number of unpaired electrons in its ground state?

A. strontium (Sr) B. bismuth (Bi) C. zirconium (Zr)

D. uranium (U) E. gadolinium (Gd)

3. Which of the following molecules has the smallest angle between two neighbouring covalent bonds?

A. BeH_2 B. BF_3 C. CCl_4 D. NH_3 E. OH_2

11. Given the following data on carbon monoxide (CO) and nitrogen (N_2) molecules, which is the best evaluation of the intermolecular forces in CO?

Compound	Melting point(°C)	Boiling point (°C)	Density at STP (g L^{-1})
Nitrogen	–210	–196	1.251
Carbon monoxide	–205	–191.5	1.250

I. London dispersion forces are the dominant intermolecular forces in carbon monoxide

II. Dipole-dipole interactions are the dominant intermolecular forces in carbon monoxide

III. Carbon monoxide has a dipole moment which contributes significantly to the strength of its intermolecular forces

A. I only B. II only C. III only

D. II and III E. I and III

CCC 2012

2. What is the electron configuration of the cation in $NiCl_2 \cdot 6\ H_2O$?

A. [Ar] $4s^2 3d^6$ **B. [Ar] $3d^8$** C. [Ar] $4s^2 3d^8$

D. [Ar] $4s^2 3d^5$ E. [Ar] $3d^7$

3. Given the following table of **fifth** ionization energies in kJ mol^{-1} for successive elements in the same period of the periodic table:

Fifth ionization energy (kJ mol^{-1})	16,100	6,270	6,950	6,560
Element	A	B	C	D

Element A is most likely in group:

A. 14 B. 15 C. 16 D. 17 E. 18

24. Which **ONE** of the following species has a dipole moment?

A. XeF_4 B. SO_4^{2-} C. CCl_4

D. SeF_4 E. $PbCl_4$

5. When the elements S, Al, Ar, Cl, Ga are ranked in order of increasing magnitude (smallest to largest) exothermic electron affinity, the order is:

A. Al, Ga, S, Cl, Ar B. Ga, Al, S, Cl, Ar C. Ar, Cl, S, Al, Ga

D. Cl, S, Ga, Al, Ar **E. Ar, Ga, Al, S, Cl**

CCC 2011

2. What is the ground state electron configuration of the cation present in potassium chloride?

B. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$ B. $1s^2 2s^2 2p^6 3s^2 3p^6$ C. $1s^2 2s^2 2p^6 3s^2 3p^5$

D. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$ E. $1s^2 2s^2 2p^6 3s^2 3p^3$

3. For the ion $^{31}P^{3-}$, the number of protons, neutrons, electrons, the atomic number, and the mass number, respectively, are:

A. 15, 16, 15, 15, 31 B. 15, 16, 18, 15, 31 C. 31, 31, 3, 15, 30.9737

D. 15, 31, 18, 15, 30.9737 E. 15, 16, 12, 15, 31

5. Cobalt–60 has practical applications for cancer treatment and in the irradiation of food to kill bacteria such as *E–coli*. In its ground state, the number of unpaired electrons in cobalt is:

A. 0 B. 1 C. 2 D. 3 E.4

7. When the elements Cl, Mg, P, S, and Si, are ranked in order of increasing atomic radius (smallest to largest) the order is:

A. Mg, Si, P, S, Cl B. Si, Mg, P, S, Cl C. Cl, S, P, Si, Mg

D. Si, Mg, Cl, S, P E. Cl, Mg, P, S, Si

CCC 2010

2. Which one of the following molecules contains a pair of atoms that share six electrons?

A. CO_2 B. C_2H_2 C. C_2H_4 D. C_2H_6 E. C_6H_6

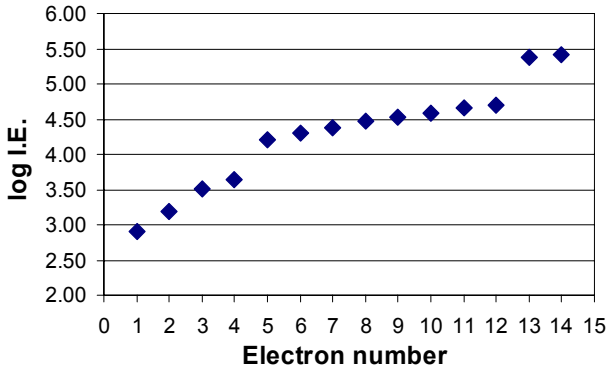
3. In which of the following substances does the bonding have the most ionic character?

A. K B. KBr C. Br_2 D. HBr E. H_2

5. In which one of the following molecules are the atoms NOT all in one plane?

A. C_2H_2 B. C_2H_4 C. C_2H_6 D. C_6H_6 E. CH_2O

6. The following graph shows the logarithm of successive ionization energies (log I.E. in kJ mol^{-1}) as the first 14 electrons are removed from atoms of one particular element.



Which one of the following elements could this be?

A. Ca B. Mg C. S D. Sn E. Si

8. Given the following data:

Hydrogen halide	HF	HCl	HBr	HI
Boiling point, K	293	188	206	238

Which one of the following statements about the hydrogen halides can be deduced from these data?

A. HF has the strongest int**ra**molecular bonding
B. HF has the strongest int**er**molecular bonding
C. HCl has the strongest int**ra**molecular bonding
D. HCl has the strongest int**er**molecular bonding
E. HI has the strongest int**ra**molecular bonding

2. The number of neutrons in ^{121}Sb is:

A. –3 B. 51 C. 70 D. 121 E. 121.75

3. Isotopes are:

A. Two elements in the same group of the periodic table
B. Two elements in the same period of the periodic table
C. Two molecules with the same formula but different arrangements of atoms
D. Two atoms with the same number of neutrons but different numbers of protons
E. Two atoms with the same number of protons but different numbers of neutrons

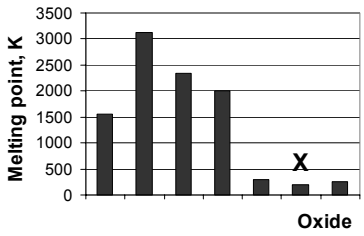
5. The number of lone pairs of electrons on the central atom in the Lewis structures of CO_2, PF_3, $BrCl_3$, NH_2^-, NH_4^+ are, in order,

A. 0, 1, 1, 1, 0 B. 0, 1, 2, 2, 0 C. 0, 1, 2, 2, 1
D. 2, 1, 1, 1, 0 E. 2, 1, 1, 1, 1

6. Three electrons are removed from an iron atom. What is the electronic configuration of the resulting ion in its ground state?

A. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$
B. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$
C. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$
D. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$
E. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^8$

7. The following chart shows the melting points of **oxides of consecutive elements** in the periodic table.



Which one of the following is a correct description of oxide X? It is:

A. A covalent network substance that does not dissolve in water
B. An ionic substance that dissolves in water to give an acidic solution
C. An ionic substance that dissolves in water to give an alkaline solution
D. A covalent molecular substance that dissolves in water to give an acidic solution
E. A covalent molecular substance that dissolves in water to give an alkaline solution

15. Which of the following atoms has the largest atomic radius?

A. Ca B. F C. O D. P E. Si

1. The following substances have all been used in general anaesthetics. Which one MUST be kept away from flames?

   A. Xenon, Xe
   B. Nitrous oxide, N_2O
   C. Chloroform (trichloromethane), $CHCl_3$
   D. Ether (ethoxyethane), $CH_3CH_2–O–CH_2CH_3$
   E. Isoflurane (2-chloro-2-(difluoromethoxy)-1,1,1-trifluoroethane), $CF_3–CHCl–O–CHF_2$

2. Which one of the following species has only one lone pair (non-bonding pair) of electrons on the central atom?

   A. NH_3 B. BrF_3 C. H_2O D. CH_4 E. NH_4^+

3. Which of the following atoms has the smallest atomic radius?

   A. Br B. Cl C. P D. S E. Se

4. Which of the following atoms has the largest first ionization energy?

   A. Al B. B C. C D. N E. Si

5. Which one of the following responses correctly identifies the structure of all the substances shown in the table? All the substances are pure and in their **solid state.**

Substance / Response	LiCl	HCl	CH_3OCH_3	C(graphite)	K
A.	Ionic	Ionic	Molecular	Covalent network	Atomic
B.	Ionic	Metallic	Molecular	Covalent network	Atomic
C.	Ionic	Molecular	Molecular	Covalent network	Metallic
D.	Ionic	Molecular	Metallic	Atomic	Metallic
E.	Molecular	Ionic	Ionic	Atomic	Metallic

6. Select the response below that lists the bonds in order of ***increasing*** polarity (least polar to most polar):

   A. O–F, C–F, Be–F
   B. O–F, Be–F, C–F
   C. Be–F, O–F, C–F
   D. Be–F, C–F, O–F
   E. C–F, O–F, Be–F