

Name: \_\_\_\_\_

Student number: \_\_\_\_\_

**Chemistry 1A03**

**Test 1**

**October 12, 2007**

**McMaster University**

**VERSION 1** **Answers in blue & Full Solutions**

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Duration: 100 minutes

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This test contains 20 numbered pages printed on both sides. There are **25** multiple-choice questions appearing on pages numbered 3 to 17. Page 18 is extra space for rough work. Page 19 includes some useful data and equations, and there is a periodic table on page 20. You may tear off the last page to view the periodic table and the data provided.

**You must enter your name and student number on this question sheet, as well as on the answer sheet.** Your invigilator will be checking your student card for identification. **You are responsible** for ensuring that your copy of the question paper is complete. Bring any discrepancy to the attention of your invigilator.

Questions 1 to 20 are each worth 2 marks, questions 21 – 25 are each worth 3 marks; the total marks available are 55. There is **no** additional penalty for incorrect answers.

**BE SURE TO ENTER THE CORRECT VERSION OF YOUR TEST (shown near the top of page 1), IN THE SPACE PROVIDED ON THE ANSWER SHEET.**

**ANSWER ALL QUESTIONS ON THE ANSWER SHEET, IN PENCIL.**

Instructions for entering multiple-choice answers are given on page 2.

**SELECT ONE AND ONLY ONE ANSWER FOR EACH QUESTION** from the answers (A) through (E). **No work written on the question sheets will be marked.** The question sheets may be collected and reviewed in cases of suspected academic dishonesty.

Academic dishonesty may include, among other actions, communication of any kind (verbal, visual, *etc.*) between students, sharing of materials between students, copying or looking at other students' work. If you have a problem please ask the invigilator to deal with it for you. Do not make contact with other students directly. Try to keep your eyes on your own paper – looking around the room may be interpreted as an attempt to copy.

Only Casio FX 991 electronic calculators may be used; but they must NOT be transferred between students. Use of periodic tables or any aids, other than those provided, is not allowed.

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**Questions 1-20 are worth two (2) marks each.**

1. What are the total numbers of **neutrons, protons, and electrons**, respectively in the  $^{37}\text{Cl}^-$  ion?

- (A) 37, 17, 18  
(B) 20, 17, 16  
(C) 17, 20, 18  
(D) 20, 17, 18  
(E) 18, 18, 17

Cl has atomic number (Z) 17 on the periodic table (see last page of your test). Thus it has 17 protons.  
The ion shown here has a -1 charge, thus it has 17 electrons + 1 electron = 18 electrons.  
The isotope shown has mass number (A) of 37. This means neutrons + protons = 37, and if there are 17 protons then there are 20 neutrons.

2. The material Styrofoam is made by blowing a gas into the polymer polystyrene; polystyrene is made by polymerizing the molecule styrene.  
Styrene has the percent composition by mass of C 92.26% and H 7.74% What is the **empirical formula for styrene?**

- (A)  $\text{CH}_4$   
(B)  $\text{CH}_3$   
(C)  $\text{C}_2\text{H}_3$   
(D)  $\text{CH}_2$   
(E) **CH**

Assume a 100.0 g sample.  
Then we have 92.26 g of C and 7.74 g of H.  
Convert to moles:  
 $\text{C} = 92.26 \text{ g} / 12.011 \text{ g/mol} = 7.68 \text{ mol C}$   
 $\text{H} = 7.74 / 1.0079 \text{ g/mol} = 7.68 \text{ mol H}$   
We have a formula of:  $\text{C}_{7.68} \text{H}_{7.68}$   
Divide each # of moles by the smallest value:  
 $\text{C}_{7.68/7.68} \text{H}_{7.68/7.68} = \text{C}_1\text{H}_1$  is the empirical formula.

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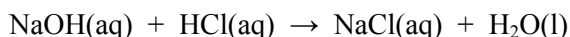
3. Choose the **incorrect name/formula combination**:

- (A) KH potassium hydride
- (B)  $\text{NaCO}_3$  sodium carbonate
- (C) HCl hydrogen chloride
- (D)  $\text{Cu}_3(\text{PO}_4)_2$  copper (II) phosphate
- (E)  $\text{CaSO}_3$  calcium sulfite

The carbonate ion has the formula  $\text{CO}_3^{2-}$ , and so the correct formula for sodium carbonate is  $\text{Na}_2\text{CO}_3$ .

4. Sometimes during titrations, when NaOH is added to a solution of HCl, the equivalence point is missed, evident by the bright pink colour of the phenolphthalein indicator (which turns pink in basic solutions). Under these circumstances, if the concentration of HCl was experimentally determined to be 0.1034 M with a 3.45 % error from the actual value. **Determine the actual concentration of HCl.**

- (A) 0.0946 M
- (B) 0.100 M
- (C) 0.103 M
- (D) 0.107 M
- (E) 0.112 M



If too many moles of NaOH are used, then we have overestimated the moles of HCl present, which means our calculated value of HCl concentration is too high.

The true value must therefore be less than 0.1034 M, so we can express our % error as -3.45 %.

From Lab 1, % error =  $\frac{(\text{true value} - \text{obtained value})}{\text{true value}} * 100\%$

Let x = true value, then

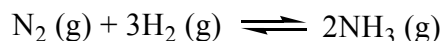
$$-3.45\% = \frac{(x - 0.1034 \text{ M})}{x} * 100\%$$

Solving for x gives x = 0.100 M

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5. The Haber-Bosch Process is one of the most important chemical reactions to produce large-scale amounts of ammonia used in the fertilizer industry. Determine the external **pressure (in atm)** required to contain 17.0 kg of  $\text{NH}_3$  when the reaction is performed in a vessel that has a volume of 250.0 L with temperature set at  $413^\circ\text{C}$ .



- (A) 22800 atm  
 (B) 225 atm  
 (C) 135 atm  
 (D) 13.5 atm  
 (E) 1.00 atm

$$PV = nRT$$

$$\text{Isolate for pressure: } P = nRT/V$$

We require moles of  $\text{NH}_3$ , the gas constant with appropriate units, and T in degrees Kelvin. These conversions are shown in the expression below:

$$P = \frac{[(17.0 \text{ kg} \times 10^3 \text{ g/kg}) / (17.034 \text{ g/mol})](0.08206 \text{ L atm/K mol})(413 + 273.15 \text{ K})}{250.0 \text{ L}}$$

$$P = 224.8 \text{ atm} = 225 \text{ atm}$$

6. Calculate the **frequency (in Hz)** of a photon which excites an electron from the  $n = 2$  to the  $n = 6$  shell of a “hot” hydrogen atom.

- (A)  $6.549 \times 10^{32} \text{ Hz}$   
 (B)  $5.843 \times 10^{16} \text{ Hz}$   
 (C)  $7.308 \times 10^{14} \text{ Hz}$   
 (D)  $2.82 \times 10^{-15} \text{ Hz}$   
 (E)  $4.842 \times 10^{-19} \text{ Hz}$

Energy can be related to frequency,  $E = h\nu$  and also to n levels,  $E = R_H (1/n_i^2 - 1/n_f^2)$ .

$$h\nu = R_H (1/n_i^2 - 1/n_f^2) \text{ where } n_i = 2 \text{ and } n_f = 6$$

$$\nu = R_H (1/n_i^2 - 1/n_f^2) / h$$

$$\nu = (2.178 \times 10^{-18} \text{ J}) (1/2^2 - 1/6^2) / 6.626 \times 10^{-34} \text{ Js}$$

$$\nu = 7.305 \times 10^{14} \text{ s}^{-1} \text{ or Hz}$$

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7. Choose the **INCORRECT** statement:

- (A) The emission spectrum of He atoms, when excited in an electrical discharge tube, is continuous in the visible range.
- (B) Experimental data regarding blackbody radiation is inconsistent with the theories of classical physics.
- (C) The work function of a metal represents the minimum energy a photon requires to eject an electron from that metal.
- (D) The deBroglie wavelength of a particle is inversely proportional to its mass.
- (E) The photoelectric effect experiment demonstrated that energy is quantized.

Statement A is False: Elements do not give continuous spectra, they give line, or discontinuous spectra, because energy changes in an atom are quantized.

(B) True. Classical physics could not explain why energy emission decreases at upper limits.

(C) True. This is the photoelectric effect.

(D) True. Refer to equation on the data page.

(E) True. Observed current is proportional to light intensity.

8. Calculate the **energy**, in **kJ/mol**, for the transition which gives rise to the 217 nm absorption process of lead ions ( $\text{Pb}^{2+}$ ) in a flame atomic absorption spectrometer.

- (A)  $9.15 \times 10^{-19}$  kJ/mol
- (B) 807 kJ/mol
- (C)  $2.82 \times 10^{-18}$  kJ/mol
- (D) 43.6 kJ/mol
- (E) 551 kJ/mol

$$E = hc/\lambda$$

We must also pay attention to units. Use conversions for J and kJ, nm and m, and use Avogadro's number to scale up to the 1/mol unit.

$$E = \frac{(6.626 \times 10^{-34} \text{ Js})(10^{-3} \text{ kJ/J})(2.9979 \times 10^8 \text{ m/s})(6.022 \times 10^{23} \text{ 1/mol})}{(217 \text{ nm} \times 10^{-9} \text{ m/nm})}$$

$$E = 551.2 \text{ kJ/mol} = 551 \text{ kJ/mol}$$

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9. Of the following, **which one corresponds to a pair of correct electron configurations** representing the **ground-state** → **excited state** of the given elements?

- (A) B:  $1s^2 2s^2 2p^1$  →  $1s^2 2s^2 2p^0$   
 (B) Sn:  $[\text{Kr}] 5s^2 4d^{10} 5p^2$  →  $[\text{Kr}] 5s^2 4d^{10} 5p^3$   
 (C) Rb:  $[\text{Kr}] 5s^1$  →  $[\text{Kr}] 4s^1$   
 (D) Cl:  $[\text{Ne}] 3s^2 3p^5$  →  $[\text{Ne}] 3s^2 3p^4 4s^1$   
 (E) O:  $1s^2 2s^2 2p^5$  →  $1s^2 2s^2 2p^4 3s^1$

- (A) Represents an ionization (electron lost)  
 (B) Represents a reduction (electron gained).  
 (C) Is an excited state → ground state transition.  
 (D) Is correct.  
 (E) Represents a ground state → excited state transition, but not for oxygen. Oxygen is  $1s^2 2s^2 2p^4$ .

10. Rank the following electromagnetic radiations **in order of INCREASING ENERGY** (from lowest energy to highest energy):

- (A) X-ray      UVC      UVA      Visible      Infra-Red  
 (B) UVC      UVA      Visible      Infra-Red      X-ray  
 (C) Visible      X-ray      UVA      UVC      Infra-Red  
 (D) Infra-Red      UVA      Visible      UVC      X-ray  
 (E) Infra-Red      Visible      UVA      UVC      X-ray

Refer to diagram of the electromagnetic spectrum, as well as class notes on UV radiation.

The visible region (red to blue) sits in between Infra-Red and UV (ultraviolet). The UV radiation is higher in energy than Infra-Red, and X-radiation sits at even higher energy, so we can say X-Ray > UV > Visible > Infra-Red.

UVA, UVB and UVC are all specific regions of the UV spectrum, with UVA at lowest energy (longest wavelength).

11. Which of the following ions **is/are not isoelectronic** with Ne?

- (i)  $\text{Na}^+$
- (ii)  $\text{Mg}^{2+}$
- (iii)  $\text{S}^{2-}$
- (iv)  $\text{F}^-$
- (v)  $\text{Li}^+$

- (A) i
- (B) iv
- (C) i, iii
- (D) ii, v
- (E) iii, v

Isoelectronic means they have the same number of electrons.  
Ne has configuration  $1s^2 2s^2 2p^6$ , so it has 10 electrons.  
 $\text{F}^-$ ,  $\text{Na}^+$  and  $\text{Mg}^{2+}$  are isoelectronic with Ne.  
 $\text{Li}^+$  has only 2 electrons and is isoelectronic with He.  
 $\text{S}^{2-}$  has 18 electrons, and is isoelectronic with Ar.

12. Identify the reason that best explains why  **$\text{Br}^-$  is not used** as an additive in toothpaste to enhance the resistance to acid demineralization of hydroxyapatite,  $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ ?

- (A)  $\text{Br}^-$  has a smaller electron affinity than  $\text{OH}^-$
- (B)  $\text{Br}^-$  has a lower ionization energy than  $\text{Ca}^{2+}$
- (C)  $\text{Br}^-$  has a larger ionic radius than  $\text{OH}^-$
- (D)  $\text{Br}^-$  has a smaller ionic radius than  $\text{Ca}^{2+}$
- (E)  $\text{Br}^-$  has a higher electronegativity than  $\text{OH}^-$

$\text{F}^-$  is used as a toothpaste additive because it replaces  $\text{OH}^-$  ion lost from hydroxyapatite mineral in tooth enamel. Fluoride ion works well as a replacement for hydroxide ion because it bears the same charge, and is slightly smaller in size. It is also readily delivered to the tooth via toothpaste and drinking water.  
 $\text{Br}^-$  ion is much larger than  $\text{F}^-$  (and  $\text{OH}^-$ ), and thus is not useful for the same purpose.

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13. Identify the reason that **best explains why the second ionization energy ( $IE_2$ ) for Ca is much lower than  $IE_2$  of K.** Compared to K...

- (A) Ca has a larger atomic radius.
- (B) Ca has a smaller ionic radius.
- (C) Ca has a filled valence shell.
- (D) Ca has a filled 4s subshell.
- (E) Ca has a higher electron affinity.

We are being asked to compare the ionization of  $Ca^+$  versus the ionization of  $K^+$ .  
Consider the electron configurations of these ions:  
 $Ca^+$ :  $[Ar] 4s^1$   
 $K^+$ :  $[Ar]$   
K has already lost 1 electron, and as  $K^+$  has a closed shell noble gas electron configuration. It would require a very large amount of energy to ionize a second electron.  
 $Ca^+$  has lost 1 electron, but can still lose another before it attains a closed shell noble gas electron configuration. It will require less energy to ionize a second electron from  $Ca^+$  than from  $K^+$ , as Ca had 2 valence electrons to begin with ( $4s^2$ ), compared to only 1 valence electron for K ( $4s^1$ ).

14. Which of the following gaseous pollutants could **not be detected** by electron capture detection:

- (i) CO
- (ii)  $CFCl_3$
- (iii)  $CH_3Br$
- (iv)  $CH_4$
- (v)  $SF_6$

- (A) v
- (B) ii, iii
- (C) ii, iii, v
- (D) ii, v
- (E) i, iv

Electron capture detection (ECD) is ideal for identifying molecules with high electron affinities (see class notes). Molecules which contain halogen atoms are ideally suited for this detection technique.  
Thus,  $CFCl_3$ ,  $CH_3Br$  and  $SF_6$  would be detected, and CO and  $CH_4$  would not.

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15. Explain why the following reaction **does not occur** under ambient conditions (*i.e.*, 25°C, 1 atm):



- (A) I has a smaller atomic radius than Cl
- (B) I has a higher ionization energy than Cl
- (C) I has a higher electronegativity than Cl
- (D) I has a lower electron affinity than Cl
- (E) I has a greater metallic character than Cl

This reaction highlights the halogen activity series. Iodine has a lower electron affinity than Cl, so it is unable to remove electrons from  $\text{Cl}^-$ . Statement A is simply false. Statement B is false. Statement C is false. Statement E is true, but metallic character describes many possible physical and chemical properties. The most specific answer is Statement D.

16. It was determined experimentally that 15.65 ml of 0.1895 M NaOH was required to reach the equivalence point in a titration with a solution of HCl. Determine the number of grams of HCl contained in the solution.

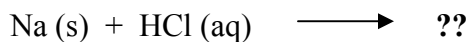
- (A) 0.1081 g
- (B) 0.1000 g
- (C) 0.2489 g
- (D) 0.09873 g
- (E) 0.5689 g

$\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$   
 Mass HCl is required. From the titration data we can determine moles HCl present, then convert to mass.  
 The titration is a 1:1 stoichiometry, so moles NaOH = moles HCl.  
 $\text{mol NaOH} = c \times V = (0.1895 \text{ mol/L})(0.01565 \text{ L}) = 2.96957 \times 10^{-3} \text{ mol}$   
 $\text{mol HCl} = \text{mol NaOH} = 2.9657 \times 10^{-3} \text{ mol}$   
 $\text{mass HCl} = \text{mol} \times \text{molar mass} = 2.96957 \times 10^{-3} \text{ mol} \times 36.45 \text{ g/mol}$   
 $\text{mass HCl} = 0.1081 \text{ g}$

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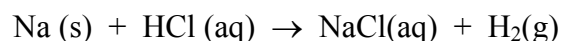
17. Predict all the **products** which are generated in the **reaction** when Na is reacted with an aqueous solution of HCl:



- (A) NaCl (aq),  $\frac{1}{2}$  H<sub>2</sub> (g)
- (B) NaOH (aq),  $\frac{1}{2}$  H<sub>2</sub> (g), Cl<sub>2</sub> (g)
- (C) NaCl (aq),  $\frac{1}{2}$  Cl<sub>2</sub> (g)
- (D) NaOH (aq),  $\frac{1}{2}$  H<sub>2</sub> (g)
- (E) Na is not reactive under acidic conditions

In class we have seen the reaction of Na in water, a vigorous redox reaction in which Na is oxidized and protons from water are reduced to H<sub>2</sub>(g).

In this case the source of protons is the acid, HCl, but otherwise the redox chemistry should be identical:



18. What is the **average S-O bond order** in the charge-minimized Lewis structure for the sulfate anion (SO<sub>4</sub><sup>2-</sup>)?

- (A) 2
- (B) 1.75
- (C) 1.5
- (D) 1.25
- (E) 1

The charge-minimized Lewis structure for the sulfate anion (SO<sub>4</sub><sup>2-</sup>) has 2 S=O double bonds and 2 S-O single bonds. Thus the average bond order =  $\frac{\text{total \# of S-O bonds}}{\text{\# of sites for these bonds to occur}}$   
= (2+2+1+1) / 4 = 6/4 or 1.5

19. Which of the following statements is/are **CORRECT**?

- (i) The bonds in  $\text{CCl}_4$  are more polar than the bonds in  $\text{CBr}_4$ .
- (ii) The formal charge on N in  $\text{NO}_2^-$  is -1.
- (iii) The molecule  $\text{BrF}_5$  has a permanent dipole.

- (A) ii
- (B) iii
- (C) i, ii
- (D) i, iii
- (E) ii, iii

(i) TRUE: A C-Cl bond is more polar than a C-Br bond because Cl is more electronegative than Br.  
(ii) FALSE: In the Lewis structure for nitrite we have a single N-O bond, a double N=O bond, and a lone pair of electrons on the N atom. The formal charge on N is therefore:  $5 - 2 - 3 = 0$ .  
(iii) TRUE:  $\text{BrF}_5$  is an  $\text{AX}_5\text{E}$  molecule, and so it is a square pyramidal shape (asymmetric shape), and has a permanent dipole.

20. Carbon monoxide is a colourless, toxic gas which binds competitively with oxygen to hemoglobin. How many **nonbonding electrons** are there in the Lewis structure for carbon monoxide?

- (A) 2
- (B) 3
- (C) 4
- (D) 5
- (E) 6

In the Lewis structure for CO there is a carbon-oxygen triple bond, with one lone electron pair each on C and O (thus a total of 2 lone pairs, or 4 lone electrons). As a result, both atoms have an octet of electrons, and there is a -1 formal charge on C and a +1 formal charge on O.

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**Questions 17-21 are worth three (3) marks each.**

21. An aqueous solution of sodium fluoride (187 mL, 0.0620 M) is mixed with an aqueous solution of calcium nitrate (82.1 mL, 0.0923 M). A reaction occurs, producing solid calcium fluoride and aqueous sodium nitrate. **Which starting material is in excess, and by how much (mol)?**

|     | <u>Reagent in excess</u>          | <u>Amount in excess (mol)</u> |
|-----|-----------------------------------|-------------------------------|
| (A) | Ca(NO <sub>3</sub> ) <sub>2</sub> | 0.00178                       |
| (B) | NaF                               | 0.00363                       |
| (C) | NaF                               | 0.00125                       |
| (D) | Ca(NO <sub>3</sub> ) <sub>2</sub> | 0.00216                       |
| (E) | NaF                               | 0.00402                       |

The reaction taking place is:  $2 \text{NaF(s)} + \text{Ca(NO}_3)_2\text{(aq)} \rightarrow 2 \text{NaNO}_3\text{(aq)} + \text{CaF}_2\text{(s)}$   
 The ratio of interest is 2 NaF:1 Ca(NO<sub>3</sub>)<sub>2</sub>.

To determine limiting reagent, determine # moles of each reagent, and see which one does not fulfill the required 2:1 ratio.

mol NaF =  $c \times V = (0.0620 \text{ mol/L})(0.187 \text{ L}) = 0.011594 \text{ mol}$ . This would react with  $(0.011594 \text{ mol} / 2) = 0.005797 \text{ mol Ca(NO}_3)_2$ . Let's see how much Ca(NO<sub>3</sub>)<sub>2</sub> we have:  
 mol Ca(NO<sub>3</sub>)<sub>2</sub> =  $c \times V = (0.0923 \text{ mol/L})(0.0821 \text{ L}) = 0.0075778 \text{ mol}$ . Since we have more than enough Ca(NO<sub>3</sub>)<sub>2</sub> to react with the NaF, then NaF is the limiting reagent, and Ca(NO<sub>3</sub>)<sub>2</sub> is in excess.

mol in excess = actual mol – mol required for reaction =  $0.0075778 - 0.005797 \text{ mol}$   
 mol in excess = 0.00178 mol

22. Choose the **CORRECT** statements:

- (i) The electron pair geometry in SF<sub>2</sub> is tetrahedral.
- (ii) A molecule with polar bonds must have a permanent dipole.
- (iii) A dipole moment is the product of partial charge and the distance between two atoms.
- (iv) Electronegativity (EN) is the ability of a gas phase atom to attract an electron.
- (v) A bond between two atoms with very small  $\Delta EN$  is covalent or weakly polar covalent.

- (A) i, iv
- (B) i, iii, v
- (C) ii, iii, iv
- (D) ii, iv, v
- (E) iii, v

(i) TRUE: SF<sub>2</sub> is an AX<sub>2</sub>E<sub>2</sub> molecule. It has 4 electron pairs, thus its electron pair geometry is tetrahedral. In its molecular shape we see only the atoms.

(ii) FALSE: In a symmetrical molecule (e.g. CO<sub>2</sub>, AX<sub>2</sub>), the bond dipoles will cancel out.

(iii) TRUE – definition of dipole moment (see text or class notes).

(iv) FALSE: the definition given is that for electron affinity. Electronegativity describes the ability of an element to compete for electron density in a bond.

(v) TRUE: Intermediate  $\Delta EN$  leads to polar covalent bonding, and large  $\Delta EN$  leads to ionic bonding.

23. Select the **TRUE** statements regarding shapes by applying the VSEPR model.

- (i) The VSEPR class of  $\text{XeF}_6$  is  $\text{AX}_6$ .
- (ii) The F-Xe-F bond angles in  $\text{XeF}_6$  are not  $90^\circ$ .
- (iii) The shape of  $\text{BrF}_5$  is square pyramidal.
- (iv) The F-Br-F bond angles in  $\text{BrF}_5$  are  $90^\circ$ .
- (v) The H-N-H bond angles in  $\text{NH}_3$  are smaller than the H-C-H bond angles in  $\text{CH}_4$ .

- (A) i, iv
- (B) i, iii, iv
- (C) ii, iii, v
- (D) ii, iv, v
- (E) iii, v

(i) FALSE:  $\text{XeF}_6$  has  $8+6(7) = 50$  electrons. It has 6 single Xe-F bonds, each F has 3 lone electron pairs and the Xe therefore has a lone electron pair also. Its VSEPR class would be  $\text{AX}_6\text{E}$ .

(ii) TRUE: The shape will not be octahedral because of the lone electron pair on Xe, thus bond angles will not be  $90^\circ$ .

(iii) TRUE:  $\text{BrF}_5$  is an  $\text{AX}_5\text{E}$  molecule, with a square pyramidal shape.

(iv) FALSE: In the  $\text{AX}_5\text{E}$  class, the bond angles are non-ideal because of the lone electron pair on the central atom.

(v) TRUE:  $\text{CH}_4$  is an  $\text{AX}_4$  molecule, with ideal H-C-H bond angles of  $109.5^\circ$ . The angles in  $\text{NH}_3$  are smaller ( $107^\circ$ ) because it is an  $\text{AX}_3\text{E}$  molecule. The lone electron pair compresses the H-N-H angles.

24. Which of the following ions or molecules has the **most charge-minimized resonance structures**?

- (A)  $\text{SO}_3$
- (B)  $\text{ClO}_3^-$
- (C)  $\text{PO}_3^{3-}$
- (D)  $\text{O}_3$
- (E)  $\text{BrO}_2^-$

Whenever we draw a Lewis structure we attempt to minimize charges. For this question we need to draw charge-minimized Lewis structures for each molecule/ion, and then determine, based on the Lewis structures, which species has the most resonance structures.

$\text{SO}_3$  has 3 S=O double bonds, and no resonance structures.

$\text{ClO}_3^-$  has 2 Cl=O double bonds, 1 Cl-O single bond and a lone electron pair on Cl. The O with a single bond has a negative formal charge. It has **3 resonance structures**.

$\text{PO}_3^{3-}$  has 3 single P-O bonds and a lone electron pair on P. There are negative formal charges on all 3 O atoms. It has no resonance structures.

$\text{O}_3$  has one O=O double bond and one O-O single bond, with a lone electron pair on the central O atom, (and a positive formal charge on the central O atom, and a negative formal charge on one terminal O atom). It has 2 resonance structures.

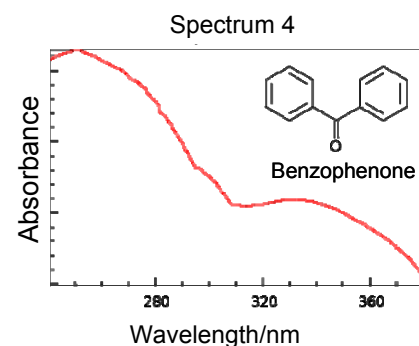
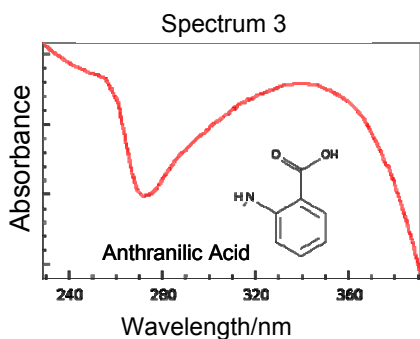
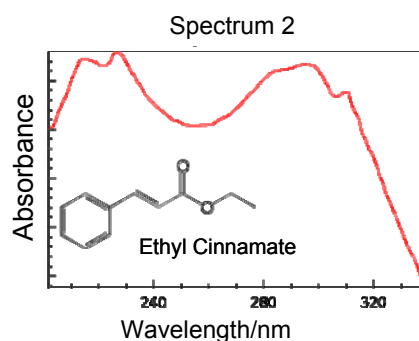
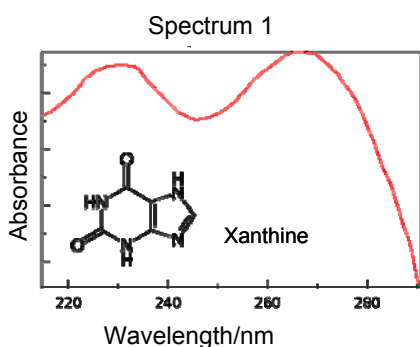
$\text{BrO}_2^-$  has one Br=O double bond, one Br-O single bond, and 2 lone electron pairs on Br. The O with a single bond has a negative formal charge. It has 2 resonance structures.

Name: \_\_\_\_\_

Student number: \_\_\_\_\_

25. You are a chemist, working for L'Oreal, producers of Ombrelle, one of Canada's leading sunscreens. You are in search of a new sunscreen ingredient that provides broad-spectrum protection against both UVA (380-320nm) & UVB (320-280nm) radiation.

Based on the following UV spectra, **which one of the following compounds would be the best choice** in the development of this new sunscreen? Note that the 4 figures have **differing scales along the X-axes**, and the Y-axes are equally scaled. Assume absorbance goes to zero beyond the limits shown in each spectrum.



- (A) Benzophenone                      Spectrum 4  
 (B) Anthranilic Acid                    Spectrum 3  
 (C) Ethyl cinnamate                    Spectrum 2  
 (D) Xanthine                              Spectrum 1  
 (E) None of the compounds are suitable

The best choice of sunscreen ingredient will have the best possible coverage (highest absorbance) in the range 280-380 nm. Of the 4 choices, Spectrum 1 shows absorbance going to 0 at 290 nm (mostly ineffective in the required range). Spectrum 2 goes to zero absorbance at 340 nm – only covers about half the required range. Spectrum 3 shows some degree of coverage over the entire range, with fairly high absorbance over most of the range. Spectrum 4 would be the second choice, as it again has coverage over the entire range, but overall its absorbance values are much lower, particularly as it goes to 0 absorbance at 380.