Name: ________________________ Student Number: _______________

Solutions for Version 1 (with marks)

CHEMISTRY 1A03/1E03 **13 OCTOBER 2006**

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MCMASTER UNIVERSITY - TERM TEST # 1 - DURATION: 100 minutes

This test contains 16 numbered pages and **25** multiple-choice questions. Page 14 is extra space for rough work. Page 15 includes some useful data and equations, and there is a Periodic Table on page 16. You may tear off the last pages to view the periodic table and the data provided. **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.

These question sheets must be returned with your answer sheet. However, no work written on the question sheets will be marked. You must enter your full 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.**

MAKE SURE TO ENTER THE CORRECT VERSION NUMBER OF YOUR TEST (SHOWN AT THE BOTTOM OF EACH PAGE) IN THE CORRECT COLUMN ON THE ANSWER SHEET (SEE INSTRUCTIONS ON PAGE 2).

Answer all questions on the answer sheet, in pencil. Instructions for entering multiple-choice answers are given on page 2. Select **one answer for each question** from the choices (A) through (E).

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.

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. 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.

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QUESTIONS 1–20 ARE WORTH 2 MARKS EACH.

1. $Cl_2(g)$ reacts with a solution of NaBr(aq) by oxidizing bromide ions into bromine, $Br_2(aq)$. What **volume (in mL)** of chlorine gas, measured at 25.00°C and 1.00 atm, is needed to completely react with 25.0 mL of 0.100 M NaBr(aq)?

A) 71.0
B) 30.6 **2**
C) 305
D) 15.2
E) 2.56

Reaction: $Cl_2(g) + 2\ NaBr(aq) \rightarrow Br_2(aq) + 2\ NaCl(aq)$
25.0 mL of 0.100 M NaBr(aq) contain 25 10^{-4} mol NaBr $\rightarrow$ requires n =12.5×10^{-4} mol Cl_2.
PV = nRT, R = 0.08206 L atm K^{-1} mol^{-1}, T = 298.15 K $\rightarrow$ V = 0.0306 L

2. In a lab experiment, a student adds 10.0 mL of a 2.0 M solution of sodium hydroxide to 50.0 mL of a 0.30 M solution of copper(II) nitrate (where II represents the oxidation state of copper). When the reaction reaches completion, what **mass (in grams)** of copper(II) hydroxide is formed? Assume that the only reaction occurring is:

$Cu(NO_3)_2(aq) + 2\ NaOH(aq) \rightarrow Cu(OH)_2(s) + 2\ NaNO_3(aq)$.

A) 1.5
B) 3.9
C) 0.98 **2**
D) 2.0
E) 2.9

10.0 mL of a 2.0 M solution of sodium hydroxide contains 20×10^{-3} mol NaOH
50.0 mL of a 0.30 M solution of copper(II) nitrate contains 15×10^{-3} mol $Cu(NO_3)_2$
hence, NaOH is the limiting reagent
20×10^{-3} mol NaOH will yield 1×10^{-2} mol $Cu(OH)_2$
molar mass of $Cu(OH)_2$ = 97.566 g
mass of NaOH formed = $97.566\times1\times10^{-2}$ = 0.98 g

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3. What is the **correct** chemical formula for potassium hydrogensulfate?

A) K_2HSO_4
B) $K(HSO_4)_2$
C) $KHSO_3$
D) K_2SO_3
E) $KHSO_4$ **2**

Sulfate ion = SO_4^{2-}, hydrogensulfate ion = HSO_4^-, potassium ion = K^+
SO_3^{2-} = sulfite ion, HSO_3^- = hydrogensulfite ion

4. How many **grams** of calcium oxide, CaO, can be produced from 4.20 g of calcium metal and 1.60 g of oxygen gas?

A) 5.61 **2**
B) 5.88
C) 2.80
D) 5.80
E) 2.94

Reaction: $Ca(s) + \frac{1}{2} O_2(g) \rightarrow CaO(s)$
4.20 g calcium metal contain 0.1048 mol Ca(s); 1.60 g oxygen gas contain 0.050 mol $O_2(g)$
hence O_2 is the limiting reagent ; 0.050 mol $O_2(g)$ yield 0.10 mol CaO(s)
molar mass CaO = 56.08 g
mass CaO produced = $56.08 \times 0.10 = 5.61$ g

5. Which one of the following reactions is an **oxidation-reduction reaction**?

A) $1/2\ P_4O_6(s) + 3\ H_2O(l) \rightarrow 2\ H_3PO_3(aq)$
B) $NH_4NO_3(s) + \text{heat} \rightarrow N_2O(g) + 2\ H_2O(g)$ **2**
C) $Mg(OH)_2(s) + 2\ HClO_4(aq) \rightarrow 4\ Mg(ClO_4)_2(aq) + 2\ H_2O(l)$
D) $LiNH_2(aq) + 2\ HI(aq) \rightarrow LiI(aq) + NH_4I(aq)$
E) $CdCl_2(aq) + Na_2S(aq) \rightarrow CdS(s) + 2\ NaCl(aq)$

Not responsible for this!

A: Note that P remains in the +III oxidation state.
B: this is the only reaction in which oxidation states change. Nitrogen goes from –III and +V in NH_4NO_3 (NH_4^+ and NO_3^- ions) to +I in N_2O.
E: Note that there was a minor typo: NaS should have read Na_2S

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9. The standard enthalpy of formation of solid $Fe_2O_3(s)$ is -822.2 kJ/mol. Given that ΔH° = -556.7 kJ for the reaction $4\ FeO(s) + O_2(g) \rightarrow 2\ Fe_2O_3(s)$, what is the **standard enthalpy of formation of FeO(s) (in kJ)**?

A) -550.3
B) -1088
C) +271.9
D) -271.9 **2**
E) +550.3

Not responsible for this (yet!)

$\Delta H(rxn) = 2\ \Delta H_f°(Fe_2O_3) – 4\ \Delta H_f°(FeO)$
$\Delta H_f°(FeO) = [2 \times -822.2 – (-556.7)]/4 = -271.9$ kJ

10. Identify the **correct** statement(s) from among the following:
(i) $\Delta H° < 0$ for the reaction $2\ Na(s) + Cl_2(g) \rightarrow 2\ NaCl(s)$
(ii) The vaporization of liquid HCl at -85 °C is exothermic.
(iii) For $Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$, $\Delta H°(\text{reaction}) = \Delta H_f°(CaCO_3(s))$

A) all
B) i, ii
C) ii, iii
D) i, iii
E) i **2**

Not responsible for this (yet!)

(i) Redox reactions between a metal and a non-metal are typically exothermic.
(ii) is endothermic like all vaporization reactions/processes.
(iii) is not a formation reaction. The formation of $CaCO_3(s)$ would be
$Ca(s) + C(graphite) + 3/2\ O_2(g) \rightarrow CaCO_3(s)$.

13. Gray and white tin (Sn) are two allotropes of tin. When $SnO_2(s)$ is formed by the oxidation of *gray* tin by oxygen, the reaction enthalpy is -578.6 kJ, and when $SnO_2(s)$ is formed by the oxidation of *white* tin by oxygen, the reaction enthalpy is -580.7 kJ. Calculate the reaction enthalpy **(in kJ)** for Sn(gray) $\rightarrow$ Sn(white).

A) -1159.3
B) 0.0
C) +2.1 **2**
D) +1159.3
E) -2.1

Not responsible for this (yet!)

$Sn(gray) + O_2 \rightarrow SnO_2 \quad \Delta H_1 = -578.6$ kJ
$Sn(white) + O_2 \rightarrow SnO_2 \quad \Delta H_2 = -580.7$ kJ
$Sn(gray) \rightarrow Sn(white) \quad \Delta H = \Delta H_1 - \Delta H_2 = +2.1$ kJ

14. Which one of the following statements is **false** regarding the following two reactions:
(i) $CO_2(l) \rightarrow CO_2(g)$
(ii) $CO(g) \rightarrow C(g) + O(g)$

Not responsible for this (yet!)

A) The molar heat of vaporization of carbon dioxide is ΔH for reaction (i).
B) Reaction (i) is endothermic.
C) Reaction (ii) is endothermic.
D) Both reactions cause work to be done on the surroundings.
E) ΔH for reaction (ii) equals $-\Delta H_f^\circ$ for CO(g). **2**

The reverse reaction of formation of CO(g) would be $CO(g) \rightarrow C(graphite) + \frac{1}{2} O_2(g)$

15. "Every electron in an atom must have its own unique set of quantum numbers" is a statement associated with:

A) Heisenberg
B) Hund
C) de Broglie
D) Pauli **2**
E) Einstein

Statement is equivalent to Pauli's exclusion principle

16. An electron travelling inside an electron microscope has an associated de Broglie wavelength of 0.0500 Å. Calculate its **velocity (in m s^{-1})** .

A) 1.46×10^{8} 2
B) 0.730×10^{8}
C) 14.6×10^{6}
D) 0.730×10^{11}
E) 1.46×10^{3}

$\lambda = h/mv \rightarrow v = h/m\lambda = 6.626\times10^{-34}$ kg m^2 s^{-1} /(9.10×19^{-31} kg $\times$ 0.05×10^{-10} m) = 1.46×10^{8} m/s

17. Which ones of the following statements are **false**?
(i) A hydrogen atom absorbs energy when its electron moves from the level n=1 to the level n=3.
(ii) Einstein was the first person to introduce the idea of quantum numbers to explain atomic spectra.
(iii) The frequency of a light wave increases with the energy of the associated photons.
(iv) The wavelength associated with a moving particle is proportional to its mass.

A) ii, iii
B) ii, iv 2
C) i, iii
D) iii, iv
E) i, ii

(ii) quantum numbers were first introduced by Bohr in his model of the H atom
(iv) see Q16: λ is inversely proportional to m

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18. Identify the **FALSE** statement(s):
(i) (3, 3, -1, -1/2) is a set of (n, l, m_l, m_s) quantum numbers that could describe an electron in a 3d orbital.
(ii) The ground-state electron configuration of the nitride anion (N^{3-}) has three unpaired electrons.
(iii) An Al^{3+} cation in its ground state contains electrons in the shell n = 3.

A) ii
B) ii, iii
C) all **2**
D) iii
E) i

(i) when n = 3, l = 0, 1 or 2
(ii) N^{3-} has 10 electrons and is isolectronic with Ne $1s^2\ 2s^2\ 2p^6$ with all electrons paired
(iii) Al^{3+} has 10 electrons and is isolectronic with Ne $1s^2\ 2s^2\ 2p^6$

19. Which electron configuration corresponds to an **excited state** of a neutral halogen atom (Group 17 / 7A)?

A) $[Ar]3d^2 4s^2 4p^4$
B) $[Ne]3s^2 3p^1 4s^1$
C) $[Ar]3d^5$
D) $[Kr]4d^{10} 5s^2 5p^5$
E) $[Ne]3s^1 3p^6$ **2**

Halogen atoms have ground-state configurations of $ns^2\ np^5$. E is an excited state for Cl (Z = 17).

20. Calculate the **longest wavelength (in μm)** of light **emitted** by an excited hydrogen atom in which the electron occupies the energy level n = 6.

A) 93.7
B) 3.28
C) 7.46 **2**
D) 1.00
E) 2.28

The longest wavelength emitted corresponds to the transition from n = 6 to n = 5.
Photon energy = $h\nu = hc/\lambda = \left| -2.178\times10^{-18}\ (1/5^2 - 1/6^2) \right| \rightarrow \lambda = 7.46\times10^{-6}$ m = 7.46 μm

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QUESTIONS 21-25 ARE WORTH 3 MARKS EACH.

21. Dissolving 3.90 g of CaF_2 in 50.0 mL of pure water (density = 1.00 g·mL^{-1}) causes the temperature of the water to decrease from 20.00 to 16.79 °C. Calculate the **molar enthalpy of dissolution of CaF_2 (in kJ mol^{-1})**. Assume that the solution has the same specific heat capacity as pure water (4.184 J·g^{-1}·K^{-1}).

A) –13.4
B) +1.05
C) –1.05
D) –671
E) +13.4 **3**

Not responsible for this (yet!)

The temperature of the solution drops → the dissolution of CaF_2 in water is endothermic.
Q(dissolution) = $m_{H2O} \times c_{H2O} \times \Delta T$ = 50.0 g × 4.184 J g^{-1} K^{-1} × 3.21 K = 671.532 J
Molar mass of CaF_2 = 78.08
Number of moles CaF_2 in 3.90 g = 3.90/78.08

Q(dissolution for 1 mol CaF_2) = 671.532 × 78.08/3.90 = 13444 J = 13.4 kJ

22. Identify the **correct** statements from among the following:
(i) A 3s orbital has a higher energy than a 2s orbital.
(ii) An electron transition from the level n = 2 to the level n = 1 in a hydrogen atom results in the emission of visible light (wavelength range of 400-750 nm).
(iii) A photon with an energy of 1.988 x 10^{-15} J has a wavelength shorter than 1 nm.
(iv) An electron with a velocity of 7.274 x 10^{4} m s^{-1} has a wavelength longer than 1 nm.
(v) The coloration of a flame by metal salts is due to electronic transitions in the non-metal atoms.

A) i, iii, iv **3**
B) ii, v
C) i, iii, v
D) i, iv
E) i, ii

(i) true: orbital energy increases with n
(ii) false: the transition from n = 2 to n = 1 would emit a high energy UV photon. Visible photons are emitted in transitions ending at the level n = 2 (Balmer series).
(iii) true: $\lambda = 1\times10^{-10}$ m = 0.1 nm
(iv) true: $\lambda = 1\times10^{-8}$ m = 10 nm
(v) false: the color is primarily due to the metal atoms, e.g orange flame with NaCl vs. red flame with LiCl.

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23. Which of the following statements is(are) **true**?

(i) In a hydrogen atom, the 3p and 3d sub-shells both correspond to an energy of -2.420×10^{-17} J for the electron.

(ii) $1s^2\ 2s^2\ 2p^3\ 3s^1$ represents the ground-state electron configuration of an oxygen atom.

(iii) In an aluminum atom, electrons in the 3s and 3p orbitals have different energies.

(iv) In the ground state of a fluorine atom, no electron has a magnetic quantum number (m_l) equal to 2.

(v) The Ca^{2+} and S^{2-} ions contain different numbers of electrons.

A) iii, iv **3**
B) i, iii, iv
C) i, v
D) ii, iii
E) i, ii

(i) $E_n = -2.178\times10^{-18}\times1/n^2 = -2.420\times10^{-19}$ J for the 3p and 3d subshells in the H atom (no splitting of sub-shell energy levels in H)
(ii) it is an excited state of an O atom (Z = 8)
(iii) true: the sub-shell energy levels are split in multi-electron atoms like Al
(iv) true: F $1s^22s^22p^5$ with $m_l = 0$ for s orbitals and $m_l = -1, 0, +1$ for p orbitals
(v) the ions are isoelectronic with 18 electrons, $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$

24. Calculate the standard enthalpy of formation, **$\Delta H_f°$ (in kJ mol^{-1})**, of solid $Mg(OH)_2$, given the following data:

$$2\ Mg(s) + O_2(g) \rightarrow 2\ MgO(s) \qquad \Delta H°_1 = -1203.6 \text{ kJ}$$
$$Mg(OH)_2(s) \rightarrow MgO(s) + H_2O(l) \qquad \Delta H°_2 = +37.1 \text{ kJ}$$
$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l) \qquad \Delta H°_3 = -571.7 \text{ kJ}$$

Not responsible for this (yet!)

A) +924.7
B) +1849.5
C) -1849.5
D) -462.3
E) -924.7 **3**

reaction of formation of $Mg(OH)_2$: $Mg(s) + O_2(g) + H_2(g) \rightarrow Mg(OH)_2(s) \quad \Delta H°_4 = ?$
reaction 4 = (0.5×reaction 1) - (reaction 2) + (0.5×reaction 3)
$\Delta H°_4 = 0.5\times\Delta H°_1 - \Delta H°_2 + 0.5\times\Delta H°_3 = -924.75$ kJ for 1 mol $Mg(OH)_2$

25. Which of the following statements are **true**?

(i) Alkali metal hydrides produce hydrogen gas upon reacting with water.

(ii) Aqueous ammonia is a stronger base than potassium hydroxide.

(iii) Redox reactions between alkali metals (Group 1A) and halogens (Group 7A) produce ionic compounds which are soluble in water.

(iv) Hydrofluoric acid is a stronger acid than hydrochloric acid.

(v) Mixing aqueous phosphoric acid and strontium hydroxide produces no *visible* reaction.

A) ii, iv
B) iv, v
C) ii, iii, v
D) i, iii **3**
E) i, iii, v

(i) true, e.g. $NaH + H_2O \rightarrow NaOH + H_2$
(ii) $NH_3(aq)$ or NH_4OH is a weak base, KOH is a strong base
(iii) true, e.g. $2\ Na + Cl_2 \rightarrow 2\ NaCl$
(iv) HF(aq) is a weak acid, HCl(aq) is a strong acid
(v) The reaction produces strontium phosphate, $Sr_3(PO_4)_2$, which is insoluble and precipitates

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- **Some general data are provided on this page.**
- **A Periodic Table with atomic weights is provided on the next page.**

STP = 273.15 K, 1 atm

$R = 8.3145\ J\ K^{-1}\ mol^{-1} = 0.08206\ L\ atm\ K^{-1}\ mol^{-1}$

$c = 2.9979 \times 10^{8}$ m/s

$m_e = 9.10 \times 10^{-31}$ kg

Specific heat of water = 4.184 J / g·°C

F = 96485 C/mol

$N_A = 6.022 \times 10^{23}\ mol^{-1}$

$h = 6.6256 \times 10^{-34}$ Js

density(H_2O, l) = 1.00g/mL

1 atm = 101.325 kPa

$1\ J = 1\ kg\ m^2\ s^{-2} = 1\ kPa\ L = 1\ Pa\ m^3$

$1\ cm^3 = 1$ mL

1 Hz = 1 cycle/s

0°C = 273.15 K

$1\ m = 10^9\ nm = 10^{10}$ Å

$1\ g = 10^3$ mg

$\lambda = h / mv = h / p$

$E_n = -2.178 \times 10^{-18} J / n^2$

$\Delta G = \Delta G^o + RT \ln Q$

$E = E^o - (RT / nF) \ln Q \;=\; E^o - (0.0257 / n) \ln Q \;=\; E^o - (0.0592 / n) \log Q$

Soluble Ionic Compounds:

1. All common compounds of Group 1A(1) and ammonium (NH_4^+) ions.
2. All common nitrates (NO_3^-), acetates (CH_3COO^-), and most perchlorates (ClO_4^-).
3. All common chlorides (Cl^-), bromides (Br^-), and iodides (I^-), *except* those of Ag^+, Pb^{2+}, Cu^+, and Hg_2^{2+}.
4. All common sulfates (SO_4^{2-}), *except* those of Ca^{2+}, Sr^{2+}, Ba^{2+}, and Pb^{2+}.

Insoluble Ionic Compounds:

1. All common metal hydroxides (OH^-), *except* those of Group 1A(1) and the heavier members of Group 2A(2) (beginning with Ca^{2+}).
2. All common carbonates (CO_3^{2-}) and phosphates (PO_4^{3-}), *except* those of Group 1A(1) and NH_4^+.
3. All common sulfides (S^{2-}), *except* those of Group 1A(1), Group 2A(2), and NH_4^+.