CHEMISTRY 1E03 **10 OCTOBER 2008**

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

ANSWERS

QUESTIONS 1–20 ARE WORTH 2 MARKS EACH.

1. The percentage by mass of bicarbonate in an Alka-Seltzer tablet is 32.5 %. Calculate the volume of carbon dioxide gas (**in mL**) generated at 37 °C and 1.00 atm from a 3.29 g tablet according to the reaction:

$$HCO_3^-(aq) + H^+(aq) \rightarrow H_2O(l) + CO_2(g)$$

A) 1370
B) 27.2
C) 446 2 marks
D) 53
E) 618

A 3.29 g tablet contains 3.29 × 0.325 = 1.069 g bicarbonate

Molar mass of bicarbonate (HCO_3^-) = 12.01 + 1.008 + 48.00 = 61.018 g

moles bicarbonate = 1.069 / 61.018 = 1.752×10^{-2} mole

→ # moles of CO_2 produced = 1.752×10^{-2} mole (see reaction above)

PV = nRT → V = $1.752 \times 10^{-2} \times 0.08206 \times 310.15 / 1.00$ = 0.446 L = 446 mL

2. Neutral atoms of ^{16}O, ^{17}O and ^{18}O **all** have:

A) 8 electrons and 8 protons 2 marks
B) 16 protons
C) 16 protons and 16 electrons
D) 8 neutrons and 8 protons
E) 8 neutrons

For all oxygen isotopes, Z = 8, i.e. there are 8 protons in the nucleus and 8 electrons in the neutral atoms. Isotopes differ by the number of neutrons only. ^{16}O has 8 protons and 8 neutrons in the nucleus, etc.

3. 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 cobalt(II) nitrate (where II represents the oxidation state of cobalt). When the reaction reaches completion, what **mass (in grams)** of cobalt(II) hydroxide is formed? Assume that the only reaction occurring is:

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

A) 3.9
B) 1.9
C) 2.9
D) 0.93 2 marks
E) 1.4 0.5 mark answer obtained if 0.015 mole $Co(OH)_2$ is used in the calculation

moles of NaOH = volume × molarity = 0.01 × 2 = 0.02 mole

moles of $Co(NO_3)_2$= volume × molarity = 0.05 × 0.3 = 0.015 mole

For a complete reaction, 0.015 mole $Co(NO_3)_2$ would require 0.03 mole NaOH (see coefficients in the balanced reaction). Hence NaOH is the limiting reagent.

0.02 mole NaOH react with 0.01 mole $Co(NO_3)_2$ to form 0.01 mole $Co(OH)_2$.

Mass of $Co(OH)_2$ formed = # moles × molar mass = 0.01 × (58.93 + 32 + 2.016) = 0.93 g

4. The density of a noble gas is 2.71 g L^{-1} at 3.00 atm and 0 °C. What is the gas?

A) Xe
B) Kr
C) He
D) Ar
E) Ne 2 marks

Assume that the gas is ideal $\rightarrow$ PV = nRT

V = sample mass / density = # moles × molar mass / density = n × M / d
PV = P × n × M/d = nRT $\rightarrow$ M = RT × d/ P = 0.08206 × 273.15 × 2.71 / 3.00 = 20.2 g
$\rightarrow$ the noble gas is Ne

5. Which **one** of the following statements is **false** regarding reactions (i), (ii) and (iii), shown here?
(i) $2NaOH(aq) + NiCl_2(aq) \rightarrow 2\ NaCl(aq) + Ni(OH)_2(s)$
(ii) $PbO_2(aq) + 2HCl(aq) + H_2SO_4(aq) \rightarrow PbSO_4\ (s) + 2H_2O + Cl_2(g)$
(iii) $KOH(aq) + HNO_3(aq) \rightarrow KNO_3(aq) + H_2O(l)$

A) (ii) is an oxidation-reduction reaction.
B) In (iii), HNO_3 acts as an acid.
C) (iii) is a proton-transfer reaction.
D) (i) is a precipitation reaction.
E) In (ii), HCl(aq) acts as an oxidizing agent. 2 marks

In reaction ii, HCl is oxidized to Cl_2, whereas PbO_2 is reduced to $PbSO_4$ (check the oxidation numbers of Cl and Pb). Hence HCl acts as a reducing agent.

6. After balancing it, which **one** statement is **false** regarding the following chemical equation?
$Cl_2(g) + OH^-(aq) \rightarrow Cl^-(aq) + ClO^-(aq) + H_2O(l)$

A) One mole of $H_2O(l)$ is produced for every mole of $OH^-(aq)$ consumed. 2 marks
B) The oxidation number of H does not change.
C) This is a disproportionation reaction.
D) One Cl atom in $Cl_2(g)$ decreases its oxidation number, while the other increases its oxidation number.
E) One mole of ClO^- (aq) is produced for every mole of $Cl_2(g)$ consumed.

The balanced reaction is : $Cl_2(g) + 2\ OH^-(aq) \rightarrow Cl^-(aq) + ClO^-(aq) + H_2O(l)$ showing that 1 mole of H_2O is produced for 2 moles of OH^- consumed.

7. You mix hydrochloric acid with aqueous silver nitrate in a beaker. What **type of reaction** would you expect to occur?

A) Proton transfer
B) Electron transfer
C) Precipitation 2 marks
D) Redox
E) Acid-base

Aqueous Cl^- ions in presence of aqueous Ag^+ ions will lead to the precipitation of insoluble AgCl. There is no transfer of proton or electron.

8. Which **one** of the following will oxidize $H_2S(g)$?

A) $KMnO_4(aq)$ 2 marks
B) $NH_3(g)$
C) Na(s)
D) $H_2(g)$
E) HBr(aq)

$KMnO_4$ is the only compound in the list that contains an element in a high positive oxidation state, Mn(VII), and that can behave as a strong oxidizing agent.

9. Identify the **oxidizing agent** in the following reaction:
$2\ Cr(OH)_3\ (s) + 3\ ClO^-\ (aq) + 4\ OH^-\ (aq) \rightarrow 2\ CrO_4^{2-}\ (aq) + 3\ Cl^-\ (aq) + 5\ H_2O(l)$

A) OH^-
B) $Cr(OH)_3$
C) ClO^- 2 marks
D) Cl^-
E) CrO_4^{2-}

The oxidation number of Cl decreases from +I in ClO^- to –I in Cl^-, and that of Cr increases from +III in $Cr(OH)_3$ to +VI in CrO_4^{2-}.

10. Identify the **Brønsted-Lowry acid-base** reaction among the following:

A) $H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$
B) $2\ K_3PO_4(aq) + 3\ Pb(NO_3)_2(aq) \rightarrow Pb_3(PO_4)_2(s) + 6\ KNO_3(aq)$
C) $Cu(s) + 4\ HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2\ NO_2(g) + 2\ H_2O(l)$
D) $Ca(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + H_2(g)$
E) $HSO_4^-\ (aq) + H_2O(l) \rightarrow H_3O^+(aq) + SO_4^{2-}(aq)$ 2 marks

E) is the only reaction where a proton is transferred, from HSO_4^- to H_2O, and hence is an acid-base reaction.

11. Which one of the following statements is **false**?

A) When neither energy nor matter can enter or escape a system, it is said to be isolated.
B) The difference between the enthalpy and the energy of a system is an amount PV.
C) Heat flow into a system increases the energy of a system.
D) Energy and enthalpy are both state functions.
E) Work flow out of a system is considered positive. 2 marks

Refer to the lecture notes or the textbook for the various definitions and sign conventions: work flow out of a system is negative (the system is doing work on its surroundings).

12. 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) → Sn(white).

A) +1.05
B) +2.1 2 marks
C) -1159.3
D) +1159.3
E) -2.1 1 mark

$Sn(gray) + O_2 \rightarrow SnO_2$ $\Delta H_1 = -578.6$ kJ rxn (1)
$Sn(white) + O_2 \rightarrow SnO_2$ $\Delta H_2 = -580.7$ kJ rxn (2)
$Sn(gray) \rightarrow Sn(white)$ $\Delta H_3 = ???$ rxn (3)
rxn(3) = rxn(1) – rxn(2)

$\Delta H_3 = \Delta H_1 - \Delta H_2 = -578.6 - (-580.7) = +2.1$ kJ

13. In which of the following processes is $\Delta H = \Delta U$?

A) Calcium carbonate is heated to form calcium oxide and carbon dioxide in an open container.
B) The reaction $2\ HI(g) \rightarrow H_2(g) + I_2(g)$ occurs in a sealed container at a constant temperature of 400°C. 2 marks
C) A sample of ammonia gas is cooled from 325°C to 300°C at 1 atm.
D) A sample of solid carbon dioxide (dry ice) sublimes to the gas phase.
E) A sample of steam is condensed into liquid water at 90°C and 1 atm.

By definition, $H = U + PV$ and $\Delta H = \Delta(U+PV) = \Delta U + \Delta(PV)$.
Therefore, $\Delta H = \Delta U$ when $\Delta(PV) = 0$.
In B, there is no change in temperature or in the number of moles of gas during the reaction, so that $PV = nRT$ is also constant, i.e., $\Delta(PV) = 0$.
In all the other cases, there is a volume change for the system and $\Delta(PV) \neq 0$.

14. For the process $He(g) \rightarrow He(l)$ at 4.2 K, which one of the following statements is **false**? (All statements refer to the system.)

A) $\Delta U \neq 0$
B) $q < 0$
C) $w < 0$ 2 marks
D) $\Delta V < 0$
E) $\Delta U \neq \Delta H$

Condensation of a gas into a liquid always involves a decrease in volume of the system, i.e. $\Delta V < 0$, so that the work $w = -P\Delta V > 0$.
The heat content of He(l) is less than that of He(g) (true for all pure substances), so that $q < 0$.
Since $\Delta U = q + w$ and q and $w \neq 0$, then $\Delta U \neq 0$.
Because $\Delta V \neq 0$, $\Delta H \neq \Delta U$.

15. Calculate the standard enthalpy of formation (**in kJ mol^{-1}**) for cyclopentane gas, $C_5H_{10}(g)$, using the following reaction enthalpies.

$2\ C_5H_{10}(g) + 15\ O_2(g) \rightarrow 10\ CO_2(g) + 10\ H_2O(l)$	$\Delta H = -3279$ kJ
$C(graphite) + O_2(g) \rightarrow CO_2(g)$	$\Delta H = -393.5$ kJ
$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$	$\Delta H = -1144$ kJ

A) +2314
B) +674
C) –6376 1 mark
D) –774
E) –3188 2 marks

$\Delta H(rxn) = \Sigma\Delta H_f^0(products) - \Sigma\Delta H_f^0\ (reactants) = 10\ \Delta H_f^0(CO_2) + 10\ \Delta H_f^0(H_2O) – 2\ \Delta H_f^0(C_5H_{10})$

$-3279 = 10\ (-393.5) + 10\ (-572) – 2\ \Delta H_f^0(C_5H_{10})$

$\Delta H_f^0(C_5H_{10}) = -3188$ kJ/mol

16. As 20.0 g of solid NH_4NO_3 are dissolved in water to make 100.0 cm^3 of solution, the temperature of the solution changes from 22.3°C to 7.0°C. Calculate the enthalpy of dissolution of NH_4NO_3 (**in kJ mol^{-1}**). Assume that the density and specific heat of the solution are equal to those of pure water (d = 1.00 g·cm^{-3}, c =4.184 J·g^{-1}·K^{-1}).

A) -30.7 1 mark
B) -25.6 1 mark
C) +20.4
D) +25.6 2 marks (obtained if mass of 100 g is used - **see note below**)
E) +30.7 2 marks (obtained if mass of 120 g is used)

Mass of solution = mass of water + mass of dissolved salt = 120 g

$\Delta T = -15.3$°C – Note that the temperature decreases which means that the salt absorbs heat during dissolution, i.e., dissolution of NH_4NO_3 is endothermic and ΔH must be given a positive sign.

Heat transfer $q = m\ c\ \Delta T = 120 \times 4.184 \times 15.3 = 7681.8$ J.
q is the heat absorbed by the dissolution of 20 g of NH_4NO_3.

For the dissolution of one mole of NH_4NO_3 (molar mass = 80.05),
$\Delta H = 7681.8 \times (80.05/20.0) = 30746$ J = 30.7 kJ

Note: The text of the question is misleading since the density of the solution could not be equal to that of pure water. Given this ambiguity, full marks are given for both answers of +30.7 and +25.6 kJ/mol.

17. Which **one** of the following statements is **false**?

A) As the principal quantum number, n**,** of an orbital increases, so does the average distance between nucleus and electron.
B) Light is emitted when electrons are promoted to higher energy levels. 2 marks
C) When the orbital quantum number $l = 2$, the possible values of the magnetic quantum number (m_l) are -2, -1, 0, 1, or 2.
D) The photoelectric effect occurs when light strikes the surface of a metal and electrons are ejected.
E) As the wavelength of light increases, the energy decreases.

Refer to the lecture notes or the textbook.

18. It takes 492 kJ of energy to remove one mole of electrons from the atoms on the surface of solid gold. What is the **maximum wavelength (in nm)** of light capable of doing this?

A) 404
B) 817
C) 743
D) 243 2 marks
E) 123

Photon energy $= h\nu = hc/\lambda \geq 492000/ N$ (energy required to extract one electron)

Hence $\lambda \leq hcN / 492000 = 2.43 \times 10^{-7}$ m = 243 nm.

19. What is the minimum frequency, in Hz (or s^{-1}), required to ionize hydrogen atoms in their **second excited state** (i.e. when the electron is in the energy level $\boldsymbol{n}$ **= 3**)?

A) 3.66×10^{14} 2 marks
B) 2.74×10^{-7}
C) 1.10×10^{15} 0.5 mark
D) 8.23×10^{14}
E) 3.29×10^{15}

The enery levels in a hydrogen atom are given as $E_n = -K / n^2$ with $K = 2.178 \times 10^{-18}$ J
Ionization from the second excited state corresponds to the transition from the energy level $n = 3$ to $n = \infty$. The energy required for the transition is $E_\infty - E_3 = 0 - (-K/9) = K/9$

The photon energy required for the ionization is $h\nu \geq K/9$, hence $\nu \geq K/9h$

$\nu \geq 2.178 \times 10^{-18} / (9 \times 6.6256 \times 10^{-34}) = 3.66 \times 10^{14}$

20. Which **one** of the following electron configurations is **not** a ground-state configuration of any neutral atom?

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

The ground state configuration for 20 electrons is $[Ne]3s^2\ 3p^6\ 4s^2$.

QUESTIONS 21-25 ARE WORTH 3 MARKS EACH.

21. One mole of Ar gas is compressed by an external pressure of 2.00 atm, to a final volume of 10.0 L from an initial volume of 20.0 L. Using calorimetry, 1.00 kJ of heat is observed to flow from the gas during the compression. What is the change in energy of the gas**, ΔU (in kJ)**?

A) 3.03
B) –1.03 1.5 mark (answer obtained with wrong sign convention)
C) 1.03 3 marks
D) 2.03
E) –3.03

$\Delta U = q + w$

$q = -1000$ J

$w = -P\Delta V = -2\ (10-20) = 20$ atm.L $= 20 \times 8.3145 / 0.08206$ J $= 2026$ J

$\Delta U = 1026$ J $= 1.03$ kJ

22. Which of the following statements is(are) **true**?
(i) The ground-state electron configuration of magnesium has no unpaired electron.
(ii) $1s^2\ 2s^2\ 2p^3\ 3s^1$ represents the ground-state electron configuration of an oxygen atom.
(iii) An aluminum atom in its ground state contains 10 core electrons.
(iv) In the ground-state of a fluorine atom, no electron has a magnetic quantum number, m_l, equal to 2.

A) i, ii, iii 1 mark
B) iii, iv 2 marks
C) i only 1 mark
D) i, iii, iv 3 marks
E) i, ii

Refer to the lecture notes or textbook.

23. When the reaction $MnO_4^-(aq) + I^-(aq) \rightarrow I_2(s) + MnO_2(s)$is balanced in **basic** solution so that all stoichiometric coefficients are the smallest possible **integers**, the number of electrons transferred and the coefficient for OH^- are (in that order):

A) 3, 12
B) 3, 9
C) 3, 4 2 marks
D) 6, 4 1 mark
E) 6, 8 3 marks

The balanced reaction with integer coefficients:

$4\ H_2O + 2\ MnO_4^-(aq) + 6\ I^-(aq) \rightarrow 3\ I_2(s) + 2\ MnO_2(s) + 6\ OH^-(aq)$

24. The empirical formula of a compound is CH. At 200 °C, 0.145 g of this compound in the gas phase occupies a volume of 97.2 mL at a pressure of 0.75 atm. What is the molecular formula of the compound?

A) C_2H_2
B) C_8H_8
C) C_7H_7
D) C_6H_6 3 marks
E) C_5H_5

Assume that the gas is ideal $\rightarrow PV = nRT$

Number of moles $n = PV / RT = 0.75 \times 0.0972 /(0.08206 \times 473.15) = 1.911\times10^{-3}$ mole
Molar mass = sample mass / # moles = $0.145 / 1.911\times10^{-3} = 75.85$ g
Molar mass of $C_yH_y = y \times (12.01 + 1.008)$ g

$y = 75.85 / 13.018 = 5.83 \approx 6$ $\rightarrow$ the molecular formula is C_6H_6

25. Identify the **false** statement(s):
(i) The energy of a closed system cannot change.
(ii) For a chemical system to do mechanical work, its volume must decrease.
(iii) The freezing of a pure substance is always an exothermic process.
(iv) The equation $w + q = 0$ expresses the first law of thermodynamics, applied to an isolated system.

A) iii, iv
B) i 1.5 mark
C) i, ii 3 marks
D) ii, iv 1 mark
E) Iii

(i) A closed system cannot exchange matter but can exchange energy with its surroundings.
(ii) A system does work by expanding against its surroundings.
(iii) Freezing = liquid $\rightarrow$ solid transformation. The enthalpy of a pure substance in the solid state is always lower than in the liquid state.
(iv) The energy U of an isolated system does not change, $\Delta U = q + w = 0$.