University of Waterloo

AVOGADRO EXAM 2010

UNIVERSITY OF WATERLOO
DEPARTMENT OF CHEMISTRY

13 MAY 2010 **TIME: 75 MINUTES**

This exam is being written by several thousand students. Please be sure that you follow the instructions below. We'll send you a report on your performance. Top performers are eligible for a prize. The names of the top 200 students will be published in the September issue of Chem 13 News.

1. Print your **name** here: _____

2. Print your **school name** and **city** on your STUDENT RESPONSE sheet.

3. Select, and enter on the STUDENT RESPONSE sheet, one of the following CODE numbers:

Code 1	**Ontario**, now studying Grade 11 Chemistry in a nonsemestered school
Code 2	**Ontario**, now studying Grade 11 Chemistry in a semestered school
Code 3	**Ontario**, Grade 11 Chemistry already completed
Code 4	Any **other Ontario** student
Code 5	**Manitoba or Saskatchewan** high school student
Code 6	**Québec** high school student
Code 7	**not used**
Code 8	**Alberta or British Columbia** high school student
Code 9	**New Brunswick, Newfoundland, Nova Scotia, or Prince Edward Island** high school student
Code 10	**Northwest Territories, Nunavut, or Yukon** high school student
Code 11	High school student **outside Canada**
Code 12	**Teacher**

4. **Print your name** (last name, first name and optional middle initial) **on the STUDENT RESPONSE sheet**. Also fill in the corresponding circles below your printed name.

5. **Carefully detach the last page.** It is the datasheet.

6. Now answer the exam questions. Questions are **not** in order of difficulty. Indicate your choice on the STUDENT RESPONSE sheet by marking one letter beside the question number.
   - Mark only one answer for each question.
   - Questions are all of the same value.
   - **There is a penalty** (1/4 off) for each incorrect answer, but no penalty if you do not answer.

7. Take care that you make firm, **black** pencil marks, just filling the oval.

   Be careful that any erasures are complete—make the sheet white again.

Carefully detach the last page.
It is the Data Sheet.

1 Compared to an electron, a proton has

A the same charge and about the same mass

B the same charge but a much greater mass

C the opposite charge and much less mass

***D** the opposite charge and a much greater mass

E no charge and a much smaller mass

2 Argon has three isotopes with relative atomic masses of 36.0, 38.0 and 40.0. Given that the relative atomic mass of naturally occurring argon is 39.95, which of the following statements must be correct?

A ^{40}Ar is less abundant than ^{38}Ar.

***B** ^{40}Ar is more abundant than either ^{36}Ar or ^{38}Ar.

C ^{38}Ar is more abundant than ^{36}Ar.

D ^{36}Ar is more abundant than ^{40}Ar.

E Another isotope of lesser mass must exist.

3 An incomplete equation describing the nuclear decay of boron-9 is given below. How many neutrons or protons are also produced?

$$^{9}_{5}B \rightarrow ^{8}_{4}Be + \boxed{?}$$

A one neutron

***B** one proton

C one neutron and one proton

D two protons

E two neutrons

4 When 50.0 mL of water and 50.0 mL of ethanol are mixed, the total volume is found to be 96.5 mL. What is the density of this water-ethanol solution?

Densities, in g/mL:
Water, 1.00
Ethanol , 0.789

A 1.78 g/mL

B 0.895 g/mL

C 0.211 g/mL

D 3.45 mL

***E** 0.927 g/mL

5 Which of the following has a linear geometry?

A O_3

B NO_2^-

***C** C_2H_2

D H_2S

E F_2O

6 Which of the following elements has properties that most closely resemble those of calcium, Ca?

A sodium, Na

B potassium, K

***C** magnesium, Mg

D bromine, Br

E krypton, Kr

7 What is the formula of lead(II) nitrate?

A Pb_3N_2

B Pb_2N_3

C Pb_2NO_3

***D** $Pb(NO_3)_2$

E $PbNO_3$

8 Which of the following reacts with moisture in the air to form acid rain?

***A** sulfur trioxide, SO_3

B nitrogen, N_2

C carbon dioxide, CO_2

D methane, CH_4

E ozone, O_3

9 Which of the following is an example of chemical change?

A boiling water

B dissolving alcohol in water

C heating copper metal

D compressing a gas

***E** rusting of iron

10 What is $[Na^+]$ in a solution obtained by mixing 50.0 mL of 0.100 mol/L $NaNO_3(aq)$ and 25.0 mL of 0.100 mol/L $Na_2CO_3(aq)$?

***A** 0.133 mol L^{-1}

B 0.200 mol L^{-1}

C 0.300 mol L^{-1}

D 0.167 mol L^{-1}

E 0.125 mol L^{-1}

11 What is the mass of 0.67 mol Na?

A 29 mg

***B** 15 g

C 10 g

D 23 g

E 0.67 g

12 One litre of oxygen gas is compared to one litre of carbon dioxide gas, both at 25 °C and 100 kPa. Which statement is correct?

A The density of the oxygen gas is greater than that of the carbon dioxide gas.

B On average, the kinetic energy of a carbon dioxide molecule is greater than that of an oxygen molecule.

C On average, a carbon dioxide molecule moves faster than does an oxygen molecule.

D On average, the kinetic energy of carbon dioxide molecule is less than that of an oxygen molecule.

***E** The two samples contain the same number of molecules.

13 What is the net ionic equation for the reaction of $Na_2CO_3(aq)$ and $CaCl_2(aq)$?

A $Na^+(aq) + Cl^-(aq) \rightarrow NaCl(s)$

B $Na_2CO_3(aq) + CaCl_2(aq) \rightarrow 2\ NaCl(aq) + CaCO_3(s)$

C $Ca^+(aq) + CO_3^-(aq) \rightarrow CaCO_3(s)$

***D** $Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3(s)$

E $2\ Na^+(aq) + CO_3^{2-}(aq) \rightarrow CO_2(g) + Na_2O(s)$

14 In an experiment, 16.0 g SO_2 is treated with 6.0 g O_2 and 18.0 g SO_3 is obtained. A balanced chemical equation for the reaction is given below.

$$2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g)$$

What is the percentage yield of SO_3 in this experiment?

A 25%

B 38%

C 67%

D 60%

***E** 75%

Molar masses (in g/mol)	
SO_2	64.1
O_2	32.0
SO_3	96.2

Using the molar masses given, the "correct" answer is E. However, the molar mass given for SO_3 is wrong. Question 14 was deleted.

15 What amount of $C_8H_{10}O_2N_4$ contains the same number of C atoms as 2 mol CO_2?

A 2 mol

B 8 mol

C 4 mol

***D** 0.25 mol

E 0.5 mol

16 In which region of the periodic table would you find the elements of highest electronegativity?

A top, left

***B** top, right

C near the middle

D bottom, left

E bottom, right

17 Which of the following has an odd-number of electrons?

A NO_3^-

***B** NO_2

C N_2O

D NO^+

E NO_2^-

18 What is the correct electron arrangement for a scandium (Sc) atom? (The first number in each list refers to the number of electrons in the first shell; the second number refers to the number of electrons in the second shell; and so on.)

***A** 2, 8, 9, 2

B 2, 8, 2, 8, 1

C 2, 8, 8, 3

D 10, 10, 1

E 4, 4, 4, 4, 1

19 A 10.0 L cylinder containing neon gas with a measured pressure of 550 kPa at 298 K is connected through a valve to a 2.50 L cylinder containing 275 kPa of helium gas at 298 K. The valve is opened and the gases mix with no change in temperature. What is the final total pressure in the system?

A 277 kPa

B 326 kPa

C 413 kPa

***D** 495 kPa

E 599 kPa

20 What is the H-N-H angle in the NH_3 molecule? Choose the closest value.

A 45°

B 90°

***C** 109°

D 120°

E 180°

21 Which of the following molecules has the strongest carbon-carbon bond?

A ethanol, CH_3CH_2OH

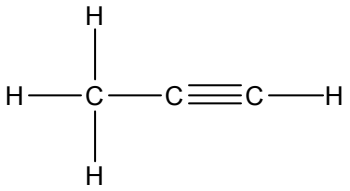
B ethanoic acid, CH_3CO_2H

C ethane, C_2H_6

D ethene, C_2H_4

***E** ethyne, C_2H_2

22 Consider the Lewis structure below for the CH_3CCH molecule.



What is the maximum number of atoms that can lie in the same plane?

A three

B four

***C** five

D six

E seven

23 The following ions all have the same number of electrons.

O^{2-}, F^-, Na^+, Mg^{2+}

In which of following lists are these ions arranged in order of increasing radius (from smallest to largest)?

A $O^{2-} < F^- < Na^+ < Mg^{2+}$

***B** $Mg^{2+} < Na^+ < F^- < O^{2-}$

C $Na^+ < Mg^{2+} < O^{2-} < F^-$

D $Mg^{2+} < Na^+ < O^{2-} < F^-$

E $F^- < O^{2-} < Na^+ < Mg^{2+}$

24 Which of the following is <u>not</u> a Bronsted-Lowry conjugate acid-base pair?

A NH_3 and NH_2^-

B OH^- and O^{2-}

***C** H_3O^+ and OH^-

D HCl and Cl^-

E NH_4^+ and NH_3

25 A 0.350 g sample of acid HX requires 25.4 mL of 0.140 mol/L NaOH(aq) for complete reaction. What is the molar mass of the acid?

A 42.3 g/mol

B 68.4 g/mol

***C** 98.4 g/mol

D 121 g/mol

E 84.6 g/mol

26 What is the density of carbon dioxide gas at 0.00 ^{o}C and 101.3 kPa?

***A** 1.96 g/L

B 0.0446 g/L

C 22.4 g/L

D 44.6 g/L

E 0.509 g/L

27 An element M forms an ion M^{3+}. The atom M and the ion M^{3+} have the same

***A** number of protons

B number of electrons

C radius

D ionization energy

E chemical properties

28 Methanoic acid, HCOOH, is a weak electrolyte. In a solution prepared by dissolving 0.10 mol HCOOH in water to make 1.0 L of solution, approximately 4.1% of the HCOOH molecules ionize. What is the pH of this solution?

A 0.61

B 1.39

***C** 2.39

D 4.10

E 6.10

29 In March of this year, the International Union of Pure and Applied Chemistry (IUPAC) officially approved the name and atomic symbol (Cn) for element 112. What is the official name of element 112?

***A** copernicium

B californium

C cupenium

D cernium

E cuternium

30 Element 114 would be placed directly below lead (element 82). At the present time, nuclear scientists have managed to synthesize only a few atoms of element 114 at any one time and thus, the physical appearance of a larger sample is not yet known. Based on its position in the periodic table, element 114 is most likely to be a

A reddish-brown volatile liquid

B a pale yellow green gas

C a colourless crystal

***D** a gray-silvery metal

E a black powdery solid

31 Sodium hydroxide, NaOH, is most likely found in which household product?

A vinegar

B soap

C bleach

D window cleaner

***E** drain cleaner

32 A balloon was filled with helium gas to a volume of 3.0 L on a day when the atmospheric pressure was 101 kPa and the temperature was 31 °C. The following day, the atmospheric pressure and temperature were measured as 98.3 kPa and 33 °C, respectively. The volume of the balloon had not changed. Which of the following statements is consistent with these data?

A Based on the changes in pressure and temperature that occurred, the volume of the balloon would not be expected to change.

B The balloon absorbed some air from the atmosphere.

***C** Some helium gas leaked out of the balloon.

D Helium atoms in the balloon lost energy to the surroundings.

E Based on the changes in pressure and temperature that occurred, the volume of the balloon should have decreased.

33 To prepare exactly 250 mL of 0.10 mol/L HCl(aq) starting from 1.0 L of 0.20 mol/L HCl(aq), one should

A slowly add exactly 125 mL of 0.20 mol/L HCl(aq) to exactly 125 mL of water.

***B** slowly add exactly 125 mL of 0.20 mol/L HCl(aq) to about 100 mL of water and then dilute with water to a total volume of 250 mL.

C evaporate 750 mL of water from 1.0 L of 0.20 mol/L HCl(aq).

D slowly add exactly 125 mL of water to exactly 125 mL of 0.20 mol/L HCl(aq).

E add 750 mL of 0.10 mol/L NaOH to 1.0 L of 0.20 mol/L HCl(aq).

34 Which of the following dilute solutions would allow a chemist to distinguish between dilute solutions of NaCl(aq) and $NaNO_3$(aq)?

A NaOH(aq)

B HCl(aq)

C NH_3(aq)

D H_2SO_4(aq)

***E** $AgNO_3$(aq)

35 Compared to a chlorine atom, a sodium atom has a larger

***A** radius

B mass

C number of electrons

D ionization energy

E electronegativity

36 Which of the following bonds has the greatest ionic character?

A C−H

B O−H

C O−F

***D** H−F

E C−O

37 A compound is found to be 85.62% carbon by mass and 14.38% hydrogen. What is the simplest formula of this compound?

A CH

***B** CH_2

C CH_3

D CH_4

E C_3H_4

For question 33, the intended answer was "B", but the volume of water was mistakenly given as 200 mL when 100 mL is what was intended. Question 33 was deleted. Answer "A" is not the correct answer because 125 mL of HCl(aq) and 125 mL of water may not give exactly 250 mL of solution because volumes are not exactly additive. See question 4 for an extreme example.

38 Mercury(II) sulfide, HgS, is practically insoluble in pure water. Its solubility at 25 °C is probably no more than 3×10^{-25} g/L. Of the following quantities of pure water, which is the smallest quantity that could be used to make a saturated solution of HgS?

A 20,000 L

B 1000 L

C 10,000 L

***D** 2000 L

E 200 L

Molar masses (in g/mol)	
Hg	200.6
S	32.07

39 What is the pH of a solution prepared by mixing 50.0 mL of 0.010 mol/L HCl(aq) and 50.0 mL of 0.010 mol/L $Ca(OH)_2$(aq)? Assume the temperature is 25 °C.

$K_w = 1.0\times10^{-14}$ at 25 °C

A 2.00

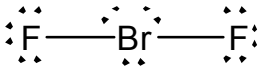
B 2.30

C 7.00

***D** 11.70

E 12.00

40 Consider the Lewis structure below. What is the charge on this molecule or ion?



A −2

***B** −1

C 0

D +1

E +2

DATA SHEET
AVOGADRO EXAM 2010

DETACH CAREFULLY

1 1A																	18 8A
1 **H** 1.008	2 2A											13 3A	14 4A	15 5A	16 6A	17 7A	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31	3 3B	4 4B	5 5B	6 6B	7 7B	8 ←	9 8B	10 →	11 1B	12 2B	13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57-71 **La-Lu**	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226	89-103 **Ac-Lr**	104 **Rf**	105 **Db**	106 **Sg**	107 **Bh**	108 **Hs**	109 **Mt**	110 **Ds**	111 **Sg**	112 **Cn**						

57 **La** 138.9	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.00	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
89 **Ac** 227.	90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** 237.0	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

Constants:

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

R = 0.082058 atm L K^{-1} mol^{-1}

= 8.3145 kPa L K^{-1} mol^{-1}

= 8.3145 J K^{-1} mol^{-1}

K_w = 1.0×10^{-14} (at 298 K)

F = 96 485 C mol^{-1}

Conversion factors:

1 atm = 101.325 kPa = 760 torr = 760 mm Hg

0°C = 273.15 K

Equations: $PV = nRT$ $k\,t_{1/2} = 0.693$ $\text{pH} = \text{pK}_a + \log\left([\text{base}]/[\text{acid}]\right)$ $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$