Topics in the June 2010 Exam Paper for CHEM1101

Click on the links for resources on each topic.

2010-J-2:

- Filling Energy Levels in Atoms Larger than Hydrogen
- Nuclear and Radiation Chemistry

2010-J-3:

- Shape of Atomic Orbitals and Quantum Numbers

2010-J-4:

- Bonding - MO theory (polar bonds)
- Ionic Bonding
- Periodic Table and the Periodic Trends
- Wave Theory of Electrons and Resulting Atomic Energy Levels

2010-J-5:

- Band Theory - MO in Solids
- Liquid Crystals
- Ionic Bonding

2010-J-6:

- Bonding - MO theory (H_2)
- Bonding - MO theory (larger molecules)

2010-J-7:

- Nuclear and Radiation Chemistry

2010-J-8:

2010-J-9:

- Thermochemistry
- First and Second Law of Thermodynamics

2010-J-10:

- Chemical Equilibrium
- Equilibrium and Thermochemistry in Industrial Processes

2010-J-11:

- Chemical Equilibrium

2010-J-12:

- Electrochemistry

2010-J-13:

- Batteries and Corrosion

2010-J-14:

- Types of Intermolecular Forces

2010-J-15:

- Gas Laws
- Nitrogen in the Atmosphere
- Thermochemistry

2205(a)

THE UNIVERSITY OF SYDNEY

CHEMISTRY 1A - CHEM1101

CONFIDENTIAL

FIRST SEMESTER EXAMINATION

JUNE 2010 **TIME ALLOWED: THREE HOURS**

GIVE THE FOLLOWING INFORMATION IN BLOCK LETTERS

FAMILY NAME		SID NUMBER	
OTHER NAMES		TABLE NUMBER	

INSTRUCTIONS TO CANDIDATES

- All questions are to be attempted. There are 24 pages of examinable material.
- Complete the written section of the examination paper in **INK.**
- Read each question carefully. Report the appropriate answer and show all relevant working in the space provided.
- The total score for this paper is 100. The possible score per page is shown in the adjacent tables.
- Each new short answer question begins with a •.
- Only non-programmable, University-approved calculators may be used.
- Students are warned that credit may not be given, even for a correct answer, where there is insufficient evidence of the working required to obtain the solution.
- Numerical values required for any question, standard electrode reduction potentials, a Periodic Table and some useful formulas may be found on the separate data sheets.
- Pages 19, 23 and 28 are for rough working only.

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Multiple choice section

	Marks	
Pages	Max	Gained
2-11	31	

Short answer section

Page	Marks: Max	Gained		Marker
12	6			
13	6			
14	4			
15	4			
16	6			
17	3			
18	6			
20	4			
21	6			
22	5			
24	2			
25	7			
26	4			
27	6			
Total	69			
Check total				

Marks

- Consider the values of the electronic energy levels of an He atom. State which interactions would be expected to increase the energies of the electrons and which would decrease them. **3**

- Radon gas decays into polonium with a half-life of 3.82 days via the following mechanism: **3**

$$^{222}_{86}\text{Rn} \rightarrow \, ^{218}_{84}\text{Po} + \, ^{4}_{2}\text{He}$$

Give three reasons why $^{222}_{86}\text{Rn}$ is biologically a very harmful nuclide.

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY

- Sketch the wavefunction of the 3*s* atomic orbital as described below. Clearly mark all nodes and the relative sign (+ or –) of the wavefunction.

Marks
6

a) using lobe representations

b) by plotting wavefunction *versus* distance from the nucleus

Explain the significance of (a) the lobes, (b) the nodes and (c) the sign of the wavefunction, in terms of the probability of finding an electron at a given point in space relative to the nucleus.

Marks
4

- The alkali hydrides are compounds of Group 1 metals with hydrogen in a 1:1 stoichiometry. Selected properties of the elements that make up these compounds are given in the following table.

Element	First Ionisation Energy (kJ mol^{-1})	Electron Affinity (kJ mol^{-1})	Electronegativity (scale 0-4)
H	1314	–79	2.20
Li	526	–66	0.98
Na	502	–59	0.93
K	425	–55	0.82
Rb	409	–53	0.82
Cs	382	–52	0.79

Is CsH more or less ionic than LiH? Justify your answer with calculations of their partial ionic character.

Explain the trend in the first ionisation energy of these elements.

Marks

- In terms of their electronic origins, briefly explain the concept of allotropes. Use two of the allotropes of carbon as examples. **2**

- Describe the nature of an ionic bond in terms of atomic and molecular orbitals. **2**

Marks
6

- In order to predict if it is possible to form the He_2^+ cation, complete the following steps.

  In the boxes below, draw an energy level diagram showing labelled electron orbitals and their occupancies for the two reacting species, He and He^+.

  In the other box below, draw an energy level diagram showing labelled electron orbitals and their occupancies in a postulated He_2^+ molecule. Use the same energy scale.

Energy

He	He^+	He_2^+

Draw the lobe representation of the two occupied molecular orbitals in this molecule. Show all nuclei and nodal surfaces.

What is the bond order of this molecular ion?

Make a prediction about the stability of He_2^+ in comparison to the H_2 molecule.

Marks
3

- Consider the process of electron capture by the manganese-54 isotope.

  Write a balanced nuclear formula.

Explain why the wavelengths of the emitted X-rays after this process are identical to those of the peak X-ray fluorescence emissions obtained during bombardment of Cr by high energy electrons.

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY

Marks
6

- Draw a plausible Lewis structures for isocyanic acid, HNCO.

What are the NC and CO bond orders? NC: CO:

How many lone pairs are on the nitrogen?

Using the VSEPR model, what do you predict the H-N-C and N-C-O bond angles to be? H-N-C: N-C-O:

Draw two plausible Lewis structures for nitrous oxide, N_2O. (Connectivity: N–N–O)

Assuming these two resonance structures contribute equally, what are the NN and NO bond orders? NN: NO:

How many lone pairs are on the central nitrogen?

Using the VSEPR model, what do you predict the N-N-O bond angle to be?

Draw two plausible Lewis structures for the N_2O^{2-} ion. (Connectivity: N–N–O)

Assuming these two resonance structures contribute equally, what are the NN and NO bond orders? NN: NO:

How many lone pairs are on the central nitrogen?

Using the VSEPR model, what do you predict the N-N-O bond angle to be?

Page Total:

Marks
4

- Ethane C_2H_6 can be burnt in the presence of an excess of oxygen to give $CO_2(g)$ and $H_2O(l)$ or under restricted oxygen conditions to give $CO(g)$ and $H_2O(l)$. A balanced equation for the first process is

$$2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l)$$

Write a balanced equation for the combustion under restricted oxygen where $CO(g)$ rather than $CO_2(g)$ is produced.

Using the heats of formation, calculate the difference (in kJ per mole of ethane) in heat released by the two different types of combustion of ethane, *i.e.* combustion with excess O_2 and combustion under restricted O_2 conditions.

Compound	$\Delta_f H^o$ (kJ mol^{-1})
$H_2O(l)$	–285.9
$C_2H_6(g)$	–84.67
$CO_2(g)$	–393.5
$CO(g)$	–110.5

Answer:

Marks
6

- Ammonia, $NH_3(g)$, has a standard Gibbs free energy of formation equal to –16.4 kJ mol^{-1}. Consider the following reaction at 298 K.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

In which direction will this reaction proceed if a mixture of gases is made with:
P_{NH_3} = 1.00 atm P_{H_2} = 0.50 atm P_{N_2} = 0.50 atm

Answer:

What pressure of hydrogen gas should be added to a mixture already containing 0.20 atm NH_3 and 0.50 atm N_2 so that the amounts of NH_3 and N_2 will not change?

Answer:

Marks

- Determine the value of the equilibrium constant (at 298 K) for the following reaction. **3**

$$CO_2(g) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$$

Substance	$\Delta_f H^o$ / kJ mol^{-1}	S^o / J K^{-1} mol^{-1}
$H_2CO_3(aq)$	–700.	187
$H_2O(l)$	–286	70.
$CO_2(g)$	–394	214

Answer:

- Consider the following equilibrium. **2**

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad K_c = 31.4 \text{ at } 588 \text{ K}$$

If a 10.00 L vessel contains 2.50 mol CO(g), 2.50 mol $H_2O(g)$, 5.00 mol $CO_2(g)$ and 5.00 mol $H_2(g)$ at 588 K, what are the concentrations of all species at equilibrium?

[CO] =	[H_2O] =	[CO_2] =	[H_2] =

Marks
2

- Hydrogen peroxide, H_2O_2, can decompose to water and oxygen. Using the following redox potentials, determine whether this decomposition reaction is spontaneous or not.

$$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O \qquad E° = 1.76 \text{ V}$$

$$O_2 + 2H^+ + 2e^- \rightleftharpoons H_2O_2 \qquad E° = 0.70 \text{ V}$$

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Page Total:

Marks
7

- The net reaction discharging the lead acid storage battery is:

$$PbO_2 + Pb + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$$

What reaction occurs at the cathode?

What reaction occurs at the anode?

Why are the cathode and anode not in separate compartments, as in the Cu/Zn battery?

How does H_2SO_4 serve as the 'salt bridge'? Which ions flow in which direction to maintain electroneutrality?

What is the formula for the equilibrium constant for the discharge reaction above?

The cell potential for this battery is 2.05 V. If the concentration of the H_2SO_4 is 4.5 M, what is the standard potential of the cell at 25 °C?

Answer:

Marks
4

- Rationalise the order of the boiling points of the following liquids in terms of their intermolecular forces.

liquid	F_2	HCl	HBr	HI	Cl_2	HF	Br_2	I_2
b.p. (° C)	–188	–85	–67	–35	–34	20	59	184

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY

Marks

- You would like to make a gas thermometer using a mole of N_2 at 1 atm. Assuming that you can treat the gas as ideal, determine how much the volume increases (in mL) per degree °C. **2**

Answer:

- Most of the solar radiation is arriving at the Earth's surface in the form of visible light. Explain, briefly, why the principal contributions to the Greenhouse Effect come from gases that do not absorb in the visible but, instead, in the infrared frequencies. **2**

- Consider two blocks of steel: block A is 1.00 kg and block B is 600. g. Both blocks start from the same temperature and are heated so that 600. J flows into each of the blocks in the form of heat. What is the final difference in temperature, T_A-T_B, between block A and block B. The specific heat of steel is 0.460 J g^{-1} K^{-1}. Show all working. **2**

Answer:

Page Total:

CHEM1101 - CHEMISTRY 1A

DATA SHEET

Physical constants

Avogadro constant, $N_A = 6.022 \times 10^{23}$ mol^{-1}
Faraday constant, $F = 96485$ C mol^{-1}
Planck constant, $h = 6.626 \times 10^{-34}$ J s
Speed of light in vacuum, $c = 2.998 \times 10^{8}$ m s^{-1}
Rydberg constant, $E_R = 2.18 \times 10^{-18}$ J
Boltzmann constant, $k_B = 1.381 \times 10^{-23}$ J K^{-1}
Permittivity of a vacuum, $\varepsilon_0 = 8.854 \times 10^{-12}$ C^2 J^{-1} m^{-1}
Gas constant, $R = 8.314$ J K^{-1} mol^{-1}
= 0.08206 L atm K^{-1} mol^{-1}
Charge of electron, $e = 1.602 \times 10^{-19}$ C
Mass of electron, $m_e = 9.1094 \times 10^{-31}$ kg
Mass of proton, $m_p = 1.6726 \times 10^{-27}$ kg
Mass of neutron, $m_n = 1.6749 \times 10^{-27}$ kg

Properties of matter

Volume of 1 mole of ideal gas at 1 atm and 25 °C = 24.5 L
Volume of 1 mole of ideal gas at 1 atm and 0 °C = 22.4 L
Density of water at 298 K = 0.997 g cm^{-3}

Conversion factors

1 atm = 760 mmHg = 101.3 kPa
0 °C = 273 K
1 L = 10^{-3} m^3
1 Å = 10^{-10} m
1 eV = 1.602×10^{-19} J
1 Ci = 3.70×10^{10} Bq
1 Hz = 1 s^{-1}
1 tonne = 10^3 kg
1 W = 1 J s^{-1}

Decimal fractions

Fraction	Prefix	Symbol
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

Decimal multiples

Multiple	Prefix	Symbol
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G

CHEM1101 - CHEMISTRY 1A

Standard Reduction Potentials, E°

Reaction	*E*° / V
$Co^{3+}(aq) + e^- \rightarrow Co^{2+}(aq)$	+1.82
$Ce^{4+}(aq) + e^- \rightarrow Ce^{3+}(aq)$	+1.72
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O$	+1.51
$Au^{3+}(aq) + 3e^- \rightarrow Au(s)$	+1.50
$Cl_2 + 2e^- \rightarrow 2Cl^-(aq)$	+1.36
$O_2 + 4H^+(aq) + 4e^- \rightarrow 2H_2O$	+1.23
$Pt^{2+}(aq) + 2e^- \rightarrow Pt(s)$	+1.18
$MnO_2(s) + 4H^+(aq) + e^- \rightarrow Mn^{3+} + 2H_2O$	+0.96
$NO_3^-(aq) + 4H^+(aq) + 3e^- \rightarrow NO(g) + 2H_2O$	+0.96
$Pd^{2+}(aq) + 2e^- \rightarrow Pd(s)$	+0.92
$Ag^+(aq) + e^- \rightarrow Ag(s)$	+0.80
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.77
$Cu^+(aq) + e^- \rightarrow Cu(s)$	+0.53
$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	+0.34
$Sn^{4+}(aq) + 2e^- \rightarrow Sn^{2+}(aq)$	+0.15
$2H^+(aq) + 2e^- \rightarrow H_2(g)$	0 (by definition)
$Fe^{3+}(aq) + 3e^- \rightarrow Fe(s)$	–0.04
$Pb^{2+}(aq) + 2e^- \rightarrow Pb(s)$	–0.13
$Sn^{2+}(aq) + 2e^- \rightarrow Sn(s)$	–0.14
$Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$	–0.24
$Cd^{2+}(aq) + 2e^- \rightarrow Cd(s)$	–0.40
$Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$	–0.44
$Cr^{3+}(aq) + 3e^- \rightarrow Cr(s)$	–0.74
$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$	–0.76
$2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$	–0.83
$Cr^{2+}(aq) + 2e^- \rightarrow Cr(s)$	–0.89
$Al^{3+}(aq) + 3e^- \rightarrow Al(s)$	–1.68
$Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$	–2.36
$Na^+(aq) + e^- \rightarrow Na(s)$	–2.71
$Ca^{2+}(aq) + 2e^- \rightarrow Ca(s)$	–2.87
$Li^+(aq) + e^- \rightarrow Li(s)$	–3.04

CHEM1101 - CHEMISTRY 1A

Useful formulas

Quantum Chemistry	**Electrochemistry**
$E = h\nu = hc/\lambda$	$\Delta G° = -nFE°$
$\lambda = h/mv$	Moles of $e^- = It/F$
$E = -Z^2E_R(1/n^2)$	$E = E° - (RT/nF) \times 2.303 \log Q$
$\Delta x \cdot \Delta(mv) \geq h/4\pi$	$= E° - (RT/nF) \times \ln Q$
$q = 4\pi r^2 \times 5.67 \times 10^{-8} \times T^4$	$E° = (RT/nF) \times 2.303 \log K$
$T\lambda = 2.898 \times 10^6$ K nm	$= (RT/nF) \times \ln K$
	$E = E° - \frac{0.0592}{n} \log Q$ (at 25 °C)
Acids and Bases	**Gas Laws**
$pK_w = pH + pOH = 14.00$	$PV = nRT$
$pK_w = pK_a + pK_b = 14.00$	$(P + n^2a/V^2)(V - nb) = nRT$
$pH = pK_a + \log\{[A^-] / [HA]\}$	$E_k = \frac{1}{2}mv^2$
Radioactivity	**Kinetics**
$t_{1/2} = \ln 2/\lambda$	$t_{1/2} = \ln 2/k$
$A = \lambda N$	$k = Ae^{-Ea/RT}$
$\ln(N_0/N_t) = \lambda t$	$\ln[A] = \ln[A]_o - kt$
^{14}C age $= 8033 \ln(A_0/A_t)$ years	$\ln \frac{k_2}{k_1} = \frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$
Colligative Properties & Solutions	**Thermodynamics & Equilibrium**
$\Pi = cRT$	$\Delta G° = \Delta H° - T\Delta S°$
$P_{solution} = X_{solvent} \times P°_{solvent}$	$\Delta G = \Delta G° + RT \ln Q$
$c = kp$	$\Delta G° = -RT \ln K$
$\Delta T_f = K_f m$	$\Delta_{univ} S° = R \ln K$
$\Delta T_b = K_b m$	$K_p = K_c (RT)^{\Delta n}$
Miscellaneous	**Mathematics**
$A = -\log \frac{I}{I_0}$	If $ax^2 + bx + c = 0$, then $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$
$A = \varepsilon cl$	$\ln x = 2.303 \log x$
$E = -A \frac{e^2}{4\pi\varepsilon_0 r} N_A$	Area of circle $= \pi r^2$
	Surface area of sphere $= 4\pi r^2$

PERIODIC TABLE OF THE ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 HYDROGEN **H** 1.008																	2 HELIUM **He** 4.003
3 LITHIUM **Li** 6.941	4 BERYLLIUM **Be** 9.012											5 BORON **B** 10.81	6 CARBON **C** 12.01	7 NITROGEN **N** 14.01	8 OXYGEN **O** 16.00	9 FLUORINE **F** 19.00	10 NEON **Ne** 20.18
11 SODIUM **Na** 22.99	12 MAGNESIUM **Mg** 24.31											13 ALUMINIUM **Al** 26.98	14 SILICON **Si** 28.09	15 PHOSPHORUS **P** 30.97	16 SULFUR **S** 32.07	17 CHLORINE **Cl** 35.45	18 ARGON **Ar** 39.95
19 POTASSIUM **K** 39.10	20 CALCIUM **Ca** 40.08	21 SCANDIUM **Sc** 44.96	22 TITANIUM **Ti** 47.88	23 VANADIUM **V** 50.94	24 CHROMIUM **Cr** 52.00	25 MANGANESE **Mn** 54.94	26 IRON **Fe** 55.85	27 COBALT **Co** 58.93	28 NICKEL **Ni** 58.69	29 COPPER **Cu** 63.55	30 ZINC **Zn** 65.39	31 GALLIUM **Ga** 69.72	32 GERMANIUM **Ge** 72.59	33 ARSENIC **As** 74.92	34 SELENIUM **Se** 78.96	35 BROMINE **Br** 79.90	36 KRYPTON **Kr** 83.80
37 RUBIDIUM **Rb** 85.47	38 STRONTIUM **Sr** 87.62	39 YTTRIUM **Y** 88.91	40 ZIRCONIUM **Zr** 91.22	41 NIOBIUM **Nb** 92.91	42 MOLYBDENUM **Mo** 95.94	43 TECHNETIUM **Tc** [98.91]	44 RUTHENIUM **Ru** 101.07	45 RHODIUM **Rh** 102.91	46 PALLADIUM **Pd** 106.4	47 SILVER **Ag** 107.87	48 CADMIUM **Cd** 112.40	49 INDIUM **In** 114.82	50 TIN **Sn** 118.69	51 ANTIMONY **Sb** 121.75	52 TELLURIUM **Te** 127.60	53 IODINE **I** 126.90	54 XENON **Xe** 131.30
55 CAESIUM **Cs** 132.91	56 BARIUM **Ba** 137.34	57-71	72 HAFNIUM **Hf** 178.49	73 TANTALUM **Ta** 180.95	74 TUNGSTEN **W** 183.85	75 RHENIUM **Re** 186.2	76 OSMIUM **Os** 190.2	77 IRIDIUM **Ir** 192.22	78 PLATINUM **Pt** 195.09	79 GOLD **Au** 196.97	80 MERCURY **Hg** 200.59	81 THALLIUM **Tl** 204.37	82 LEAD **Pb** 207.2	83 BISMUTH **Bi** 208.98	84 POLONIUM **Po** [210.0]	85 ASTATINE **At** [210.0]	86 RADON **Rn** [222.0]
87 FRANCIUM **Fr** [223.0]	88 RADIUM **Ra** [226.0]	89-103	104 RUTHERFORDIUM **Rf** [261]	105 DUBNIUM **Db** [262]	106 SEABORGIUM **Sg** [266]	107 BOHRIUM **Bh** [262]	108 HASSIUM **Hs** [265]	109 MEITNERIUM **Mt** [266]	110 DARMSTADTIUM **Ds** [271]	111 ROENTGENIUM **Rg** [272]	112 COPERNICIUM **Cn** [283]						

LANTHANOIDS	57 LANTHANUM **La** 138.91	58 CERIUM **Ce** 140.12	59 PRASEODYMIUM **Pr** 140.91	60 NEODYMIUM **Nd** 144.24	61 PROMETHIUM **Pm** [144.9]	62 SAMARIUM **Sm** 150.4	63 EUROPIUM **Eu** 151.96	64 GADOLINIUM **Gd** 157.25	65 TERBIUM **Tb** 158.93	66 DYSPROSIUM **Dy** 162.50	67 HOLMIUM **Ho** 164.93	68 ERBIUM **Er** 167.26	69 THULIUM **Tm** 168.93	70 YTTERBIUM **Yb** 173.04	71 LUTETIUM **Lu** 174.97
ACTINOIDS	89 ACTINIUM **Ac** [227.0]	90 THORIUM **Th** 232.04	91 PROTACTINIUM **Pa** [231.0]	92 URANIUM **U** 238.03	93 NEPTUNIUM **Np** [237.0]	94 PLUTONIUM **Pu** [239.1]	95 AMERICIUM **Am** [243.1]	96 CURIUM **Cm** [247.1]	97 BERKELLIUM **Bk** [247.1]	98 CALIFORNIUM **Cf** [252.1]	99 EINSTEINIUM **Es** [252.1]	100 FERMIUM **Fm** [257.1]	101 MENDELEVIUM **Md** [256.1]	102 NOBELIUM **No** [259.1]	103 LAWRENCIUM **Lr** [260.1]