Topics in the November 2014 Exam Paper for CHEM1101

Click on the links for resources on each topic.

2014-N-2:

- Wave Theory of Electrons and Resulting Atomic Energy Levels
- Shape of Atomic Orbitals and Quantum Numbers
- Filling Energy Levels in Atoms Larger than Hydrogen
- Band Theory - MO in Solids

2014-N-3:

- Periodic Table and the Periodic Trends
- Wave Theory of Electrons and Resulting Atomic Energy Levels

2014-N-4:

- Nuclear and Radiation Chemistry

2014-N-5:

- Wave Theory of Electrons and Resulting Atomic Energy Levels
- Atomic Electronic Spectroscopy

2014-N-7:

- Lewis Structures
- VSEPR
- Types of Intermolecular Forces

2014-N-8:

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

2014-N-9:

- Thermochemistry

2014-N-10:

- Chemical Equilibrium
- First and Second Law of Thermodynamics

2014-N-11:

- Gas Laws
- Thermochemistry
- First and Second Law of Thermodynamics

2014-N-12:

- Chemical Equilibrium

2014-N-13:

- Equilibrium and Thermochemistry in Industrial Processes

2014-N-14:

- Electrochemistry

2014-N-15:

- Electrolytic Cells

2014-N-16:

- Electrochemistry

Confidential

THE UNIVERSITY OF SYDNEY

SEAT NUMBER: ……………………………………

STUDENT ID: ……………………………………

SURNAME: ……………………………………

GIVEN NAMES: ……………………………………

CHEM1101
Chemistry 1A

Final Examination
Semester 2, 2014

Time Allowed: Three hours + 10 minutes reading time

This examination paper consists of 28 pages.

INSTRUCTIONS TO CANDIDATES

1. This is a closed book exam.
2. A simple calculator (programmable versions and PDA's not allowed) may be taken into the exam room.

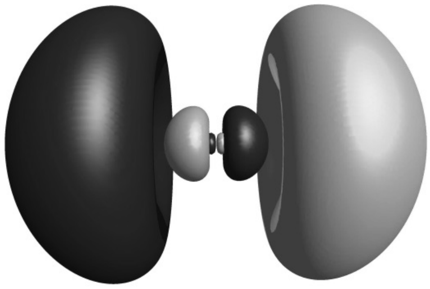
Make	Model

3. The total score for this paper is 100. The possible score per page is shown in the adjacent table.
4. The paper comprises 28 multiple choice questions and 15 pages of short answer questions. ANSWER ALL QUESTIONS.
5. Follow the instructions on page 2 to record your answers to the multiple choice questions. Use a dark lead pencil so that you can erase errors made on the computer sheet.
6. Answer all short answer questions in the spaces provided on this question paper. Credit may not be given where there is insufficient evidence of the working required to obtain the solution.
7. Take care to write legibly. Write your final answers in ink, not pencil.
8. 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.

	Marks			
Page(s)	Max	Gained		Marker
~~2-10~~	~~28~~			~~MCQ~~
11	6			
12	7			
13	6			
14	3			
15	3			
16	9			
17	3			
19	2			
20	3			
21	5			
23	5			
24	4			
25	6			
26	7			
27	3			
Total	72			
Check Total				

Marks

- Consider the 4*p* orbital shown below. Note that, for clarity, the nucleus of the atom is not shown. **3**



How many spherical and planar nodes does this orbital have?

Number of spherical nodes:	Number of planar nodes:

Complete the following table to give a set of quantum numbers that describes an electron in a 4*p* orbital.

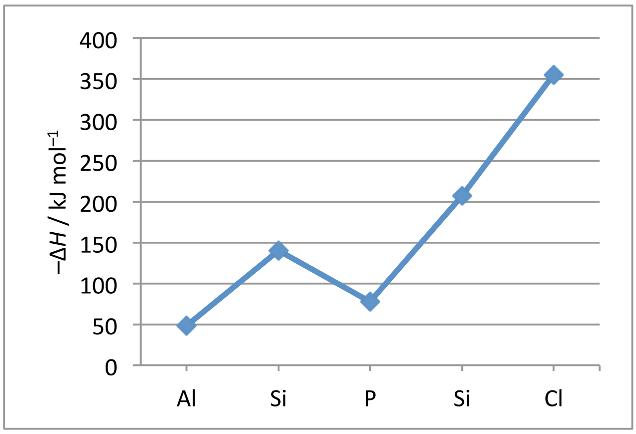
Quantum number	*n*			
Value	4			

- What factors determine the lattice energy of an ionic crystal? **3**

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

Marks
7

- Electron affinity is the enthalpy change for the reaction $A(g) + e \rightarrow A^-(g)$.
  The graph below shows the trend in electron affinities for a sequence of elements in the third row of the Periodic Table.



Give the electron configurations of the following atoms and singly-charged anions. Use [Ne] to represent core electrons.

Atom	Electron configuration	Ion	Electron configuration
Si		Si^-	
P		P^-	
S		S^-	

Explain why the value for the electron affinity of phosphorus is anomalous.

What trend would you expect for the electron affinities for Si^-, P^- and S^-? Explain your answer.

Marks
6

- The isotope ${}^{60}_{27}Co$ undergoes radioactive decay to produce a stable isotope of nickel. Give the balanced equation for this decay process.

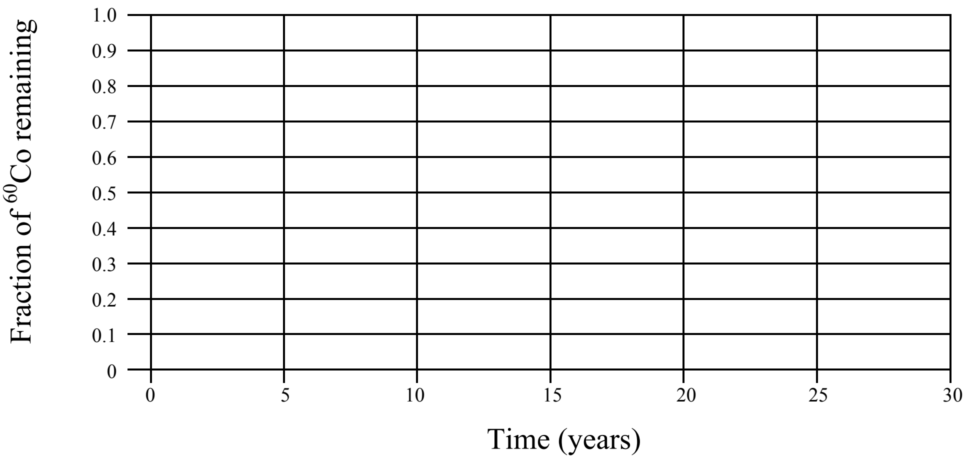
The half-life of ${}^{60}Co$ is 5 years. Calculate the value of the decay constant, λ, (in s^{-1}).

Answer:

What is the molar activity of ${}^{60}Co$ (in Bq mol^{-1})?

Answer:

Complete the graph below.



Estimate from the graph the fraction of ${}^{60}Co$ remaining after 12 years.

Marks
3

- The diagram on the left of page 15 depicts the three lowest energy levels of the hydrogen atom. Consider an excited hydrogen atom with an electron in the 3*s* orbital.

  (A) Indicate all possible jumps this electron can make as the atom returns to the ground state. One possible jump (a) is shown for you as an example.

  (B) Calculate the energy associated with each of these jumps and mark it on the diagram on the right on page 15. Label the transitions. Again, jump (a) is shown as an example.

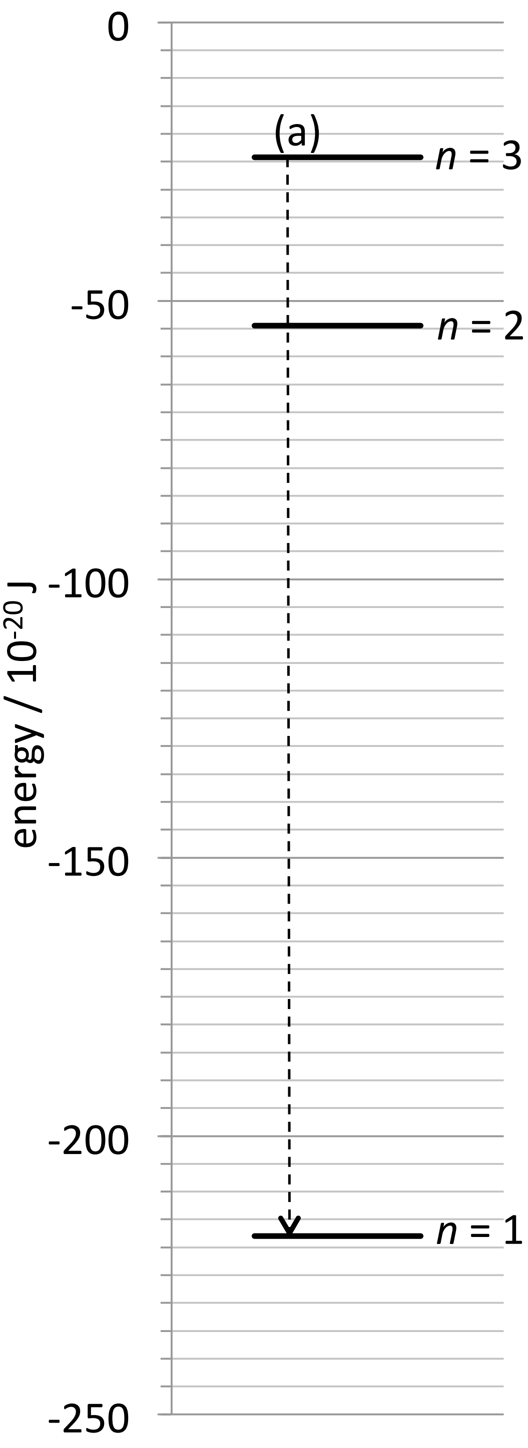
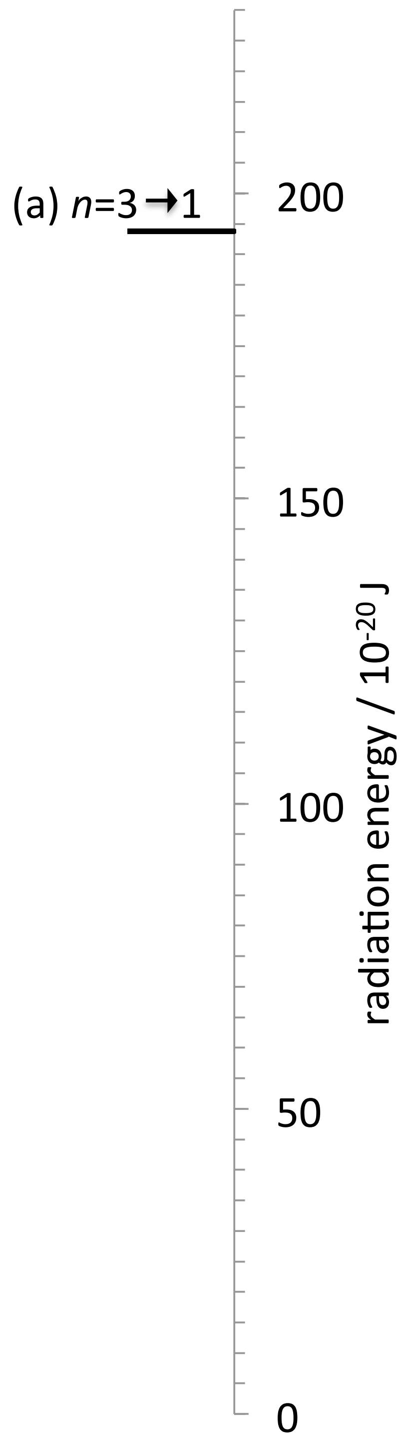
Working

List all of the transitions that are in the visible region and identify the colour associated with each. For reference, the relationship between colours and wavelengths is shown below.

UV	violet	blue	green	yellow	orange	red	IR

400 450 490 560 590 630 700 nm

If the corresponding transitions were obtained from He^{+} instead of H, would they occur at longer or shorter wavelengths? Give a reason for your answer.

Energy levels of H atom	Atomic Spectrum of H atom	Marks 3
		

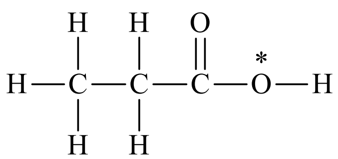
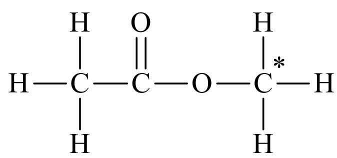
Marks
4

- Draw the Lewis structure of the following species. The central atom is underlined. Give resonance structures where applicable and indicate whether the species has a dipole moment?

Species	Lewis structure	Dipole moment
<u>S</u>F_4		Yes / No
<u>N</u>O_2^-		Yes / No

5

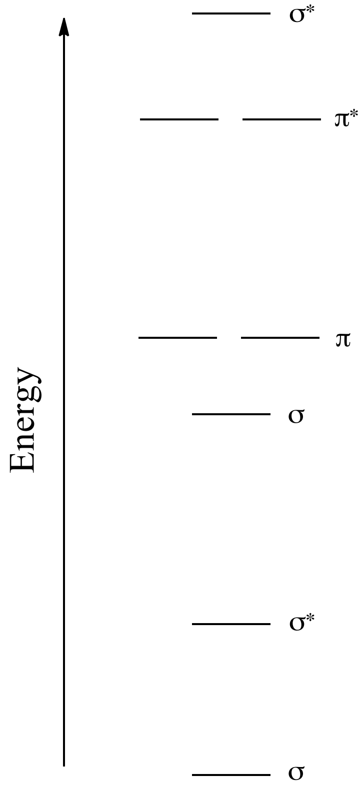
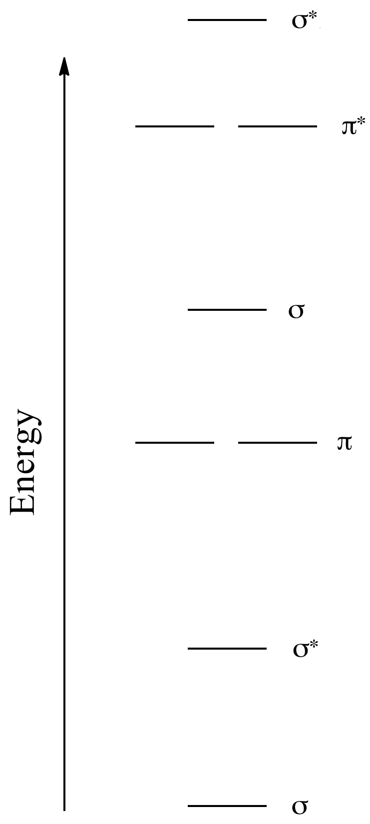
- Complete the table concerning two of the isomers of $C_3H_6O_2$. Identify the geometry around each atom marked with an asterisk and the list the major intermolecular forces present in the liquid.

Isomer	A	B
Chemical structure		
Geometry		
Major intermolecular forces in liquid		

The boiling point of isomer A is 141 °C and that of isomer B is 60 °C. Explain why the boiling point of A is higher than B?

Marks
3

- The molecular orbital energy level diagrams for F_2 and B_2 are shown below. Fill in the valence electrons for each species in its ground state. Hence calculate the bond order for F_2 and B_2 and indicate whether these molecules are paramagnetic or diamagnetic.

	F_2	B_2
		
Bond order		
Paramagnetic or diamagnetic		

Marks
2

- Lead shot was traditionally made by dropping molten lead into a tank of water. A piece of lead, initially at 327 °C is dropped into 200.0 mL of water raising its temperature from 25 to 35 °C. What was the weight of the lead?

  Data: Specific heat capacity of Pb is 0.126 J $K^{-1}g^{-1}$

  Specific heat capacity of $H_2O(l)$ is 4.184 J $K^{-1}g^{-1}$

  The density of water is 1.0 g mL^{-1}

Answer:

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

Marks

2

- Use the following equilibria:

$$2CH_4(g) \rightleftharpoons C_2H_6(g) + H_2(g) \qquad K_1 = 9.5 \times 10^{-13}$$

$$CH_4(g) + H_2O(g) \rightleftharpoons CH_3OH(g) + H_2(g) \qquad K_2 = 2.8 \times 10^{-21}$$

to calculate the equilibrium constant, K_3, for the following reaction.

$$2CH_3OH(g) + H_2(g) \rightleftharpoons C_2H_6(g) + 2H_2O(g)$$

Show all working.

Answer:

1

- The Second Law states that all observable processes must involve a net increase in entropy. When liquid water freezes into ice at 0 °C, the entropy of the water decreases. Since the freezing of water is certainly observable, the processes must still satisfy the Second Law. Provide a brief explanation of how this is so.

Marks
5

- Ethanol, $C_2H_5OH(l)$, is increasingly being used as a fuel. Give the balanced chemical equation for the combustion of ethanol in oxygen to produce carbon dioxide and water.

Use the standard enthalpies of formation given below to calculate the molar heat of combustion of gaseous ethanol. Show all working.

Compound	$C_2H_5OH(g)$	$CO_2(g)$	$H_2O(g)$
$\Delta_f H°$ / kJ mol^{-1}	–235.3	–393.5	–285.8

Answer:

Calculate the volume change when 150 g of liquid ethanol is burnt in an engine at 1500 °C and 2.0 atm pressure. Assume all gases behave as ideal gases. Show all working.

Answer:

Why can the volume occupied by the liquid ethanol be ignored in this calculation?

Marks
5

- The standard Gibbs free energy of the following reaction is +69.73 kJ mol^{-1}.

$$COCl_2(g) \rightleftharpoons CO(g) + Cl_2(g)$$

What is the expression for the equilibrium constant, K_p, for this reaction?

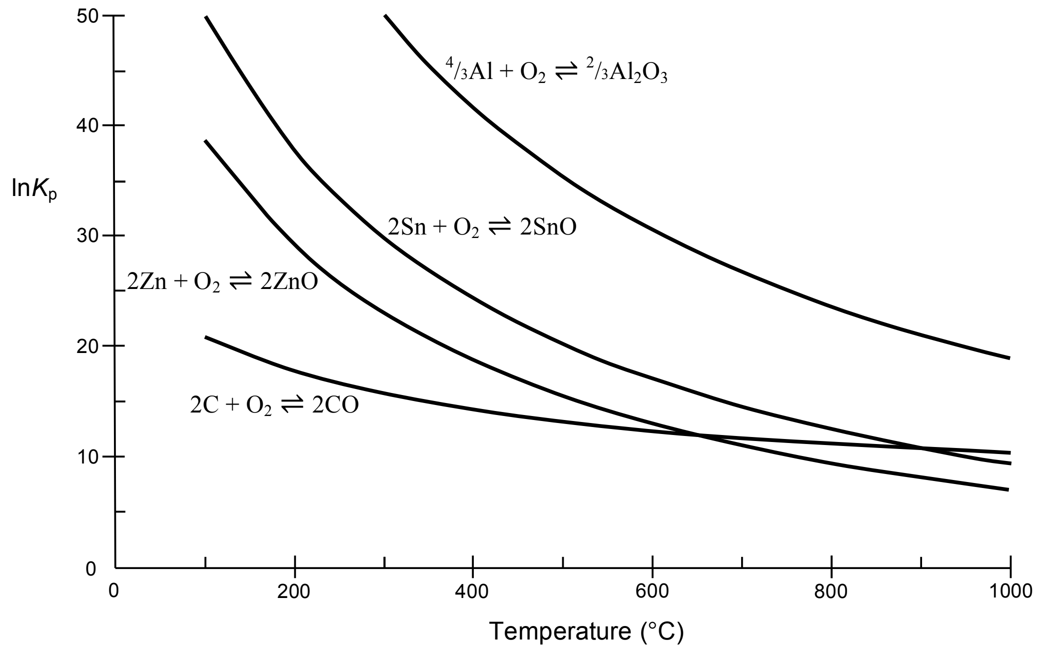
Calculate the value of the equilibrium constant at 298 K.

K_p =

In which direction will this reaction proceed if a mixture of gases is made with:
P_{COCl_2} = 1.00 atm; P_{Cl_2} = 0.01 atm; P_{CO} = 0.50 atm? Show working.

Marks
4

- The diagram below represents the equilibrium constant K_p associated with the formation of the four oxides indicated.



Using the equilibrium constant data above, describe the reaction that proceeds under the following conditions. If you think no reaction will occur, write 'no reaction'.

CO and Sn are combined at 400 °C
Al and SnO are combined at 400 °C
C and ZnO are mixed at 900 °C

Which oxide has the largest (most negative) enthalpy of formation?

Marks
6

- An electrochemical cell consisting of a Ni^{2+}/Ni half-cell with unknown $[Ni^{2+}]$ and a Cu^{2+}/Cu half-cell with $[Cu^{2+}]$ = 2.5 M has a cell voltage of 0.64 V at 298 K. What is the initial concentration of Ni^{2+} in the Ni^{2+}/Ni half-cell?

Answer:

Calculate the equilibrium constant for the reaction at 25 °C.

Answer:

Calculate the standard Gibbs free energy change for the reaction at 25 °C.

Answer:

Marks
7

- Chlorine is produced by the electrolysis of an aqueous sodium chloride solution using inert electrodes. What products are formed at the anode and cathode? Explain your answer.

Answer:

Write a balanced equation for the overall reaction of the electrolytic cell.

Assuming a $[Cl^{-}]$ of 1.0 M and no overpotential, what would be the minimum voltage required to drive the overall cell reaction at pH 14? Assume gases are at 1 atm.

Answer:

Considering the cell potentials suggest a reason ruthenium oxide electrodes are employed in this reaction rather than carbon electrodes.

	Marks
• What is the voltage of a concentration cell constructed from two beakers containing 2.5 M $CuSO_4$ and 0.025 M $CuSO_4$ at 298 K?	3

Answer:

Explain the changes necessary for the cell to reach equilibrium.

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY.

THIS PAGE IS FOR ROUGH WORKING ONLY

Page Total:

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
10^{12}	tera	T

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	(+0.82 at pH = 7)
$Pt^{2+}(aq) + 2e^- \rightarrow Pt(s)$	+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	
$I_2(aq) + 2e^- \rightarrow 2I^-(aq)$	+0.62	
$Cu^+(aq) + e^- \rightarrow Cu(s)$	+0.53	
$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	+0.34	
$BiO^+(aq) + 2H^+(aq) + 3e^- \rightarrow Bi(s) + H_2O$	+0.32	
$Sn^{4+}(aq) + 2e^- \rightarrow Sn^{2+}(aq)$	+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	(–0.41 at pH = 7)
$Cr^{2+}(aq) + 2e^- \rightarrow Cr(s)$	–0.89	
$Al^{3+}(aq) + 3e^- \rightarrow Al(s)$	–1.68	
$Sc^{3+}(aq) + 3e^- \rightarrow Sc(s)$	–2.09	
$Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$	–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	

Useful formulas

Thermodynamics & Equilibrium $\Delta U = q + w = q - p\Delta V$ $\Delta G° = \Delta H° - T\Delta S°$ $\Delta G = \Delta G° + RT \ln Q$ $\Delta G° = -RT \ln K$ $\Delta_{univ}S° = R \ln K$ $\ln\frac{K_2}{K_1} = \frac{-\Delta H°}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$	**Electrochemistry** $\Delta G° = -nFE°$ $Moles\ of\ e^- = It/F$ $E = E° - (RT/nF) \times 2.303 \log Q$ $= E° - (RT/nF) \times \ln Q$ $E° = (RT/nF) \times 2.303 \log K$ $= (RT/nF) \times \ln K$ $E = E° - \frac{0.0592}{n}\log Q$ (at 25 °C)
Acids and Bases $pK_w = pH + pOH = 14.00$ $pK_w = pK_a + pK_b = 14.00$ $pH = pK_a + \log\{[A^-] / [HA]\}$	**Gas Laws** $PV = nRT$ $(P + n^2a/V^2)(V - nb) = nRT$ $E_k = \frac{1}{2}mv^2$
Radioactivity $t_{1/2} = \ln 2/\lambda$ $A = \lambda N$ $\ln(N_0/N_t) = \lambda t$ ^{14}C age = 8033 $\ln(A_0/A_t)$ years	**Kinetics** $t_{1/2} = \ln 2/k$ $k = Ae^{-Ea/RT}$ $\ln[A] = \ln[A]_o - kt$ $\ln\frac{k_2}{k_1} = \frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$
Mathematics If $ax^2 + bx + c = 0$, then $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ $\ln x = 2.303 \log x$ Area of circle = πr^2 Surface area of sphere = $4\pi r^2$ Volume of sphere = $^4/_3\ \pi r^3$	**Quantum Chemistry** $E = h\nu = hc/\lambda$ $\lambda = h/mv$ $E = -Z^2E_R(1/n^2)$ $\Delta x \cdot \Delta(mv) \geq h/4\pi$ $q = 4\pi r^2 \times 5.67 \times 10^{-8} \times T^4$ $T\lambda = 2.898 \times 10^6$ K nm
Miscellaneous $A = -\log\frac{I}{I_0}$ $A = \varepsilon cl$ $E = -A\frac{e^2}{4\pi\varepsilon_0 r}N_A$	**Colligative Properties & Solutions** $\Pi = cRT$ $P_{solution} = X_{solvent} \times P°_{solvent}$ $c = kp$ $\Delta T_f = K_f m$ $\Delta T_b = K_b m$

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]		114 FLEROVIUM **Fl** [289]		116 LIVERMORIUM **Lv** [293]		

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]