Topics in the November 2009 Exam Paper for CHEM1101

Click on the links for resources on each topic.

2009-N-2:

- Nuclear and Radiation Chemistry

2009-N-3:

- Band Theory - MO in Solids

2009-N-4:

- Periodic Table and the Periodic Trends
- Filling Energy Levels in Atoms Larger than Hydrogen

2009-N-5:

- Wave Theory of Electrons and Resulting Atomic Energy Levels

2009-N-6:

- Material Properties (Polymers, Liquid Crystals, Metals, Ceramics)
- Lewis Structures

2009-N-7:

- Bonding - MO theory (larger molecules)

2009-N-8:

- Chemical Equilibrium

2009-N-9:

- Thermochemistry
- First and Second Law of Thermodynamics

2009-N-10:

- Thermochemistry
- First and Second Law of Thermodynamics

2009-N-11:

- Gas Laws

2009-N-12:

- First and Second Law of Thermodynamics

2009-N-13:

- Electrochemistry

2009-N-14:

- Nitrogen in the Atmosphere
- Electrochemistry

22/07(a)

The University of Sydney

CHEMISTRY 1A - CHEM1101

SECOND SEMESTER EXAMINATION

CONFIDENTIAL

NOVEMBER 2009 **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 22 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 •.
- Electronic calculators, including programmable calculators, may be used. Students are warned, however, 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 18, 21, 25, 27 and 28 are for rough working only.

OFFICIAL USE ONLY

Multiple choice section

	Marks	
Pages	Max	Gained
2-10	34	

Short answer section

Page	Marks Max	Gained		Marker
11	5			
12	6			
13	6			
14	4			
15	4			
16	6			
17	2			
19	7			
20	6			
22	4			
23	3			
24	6			
26	7			
Total	66			

Marks
5

- Write two possible mechanisms for the radioactive decay of ^{83}Rb to ^{83}Kr.

The half-life of ^{83}Rb is 86.2 days. Calculate the activity (in Bq) of an isotopically pure 1.000 g sample of ^{83}Rb. (The molar mass of ^{83}Rb is 82.915110 g mol^{-1}.)

Answer:

How many days will it take for this sample to diminish to 1 % of its initial activity?

Answer:

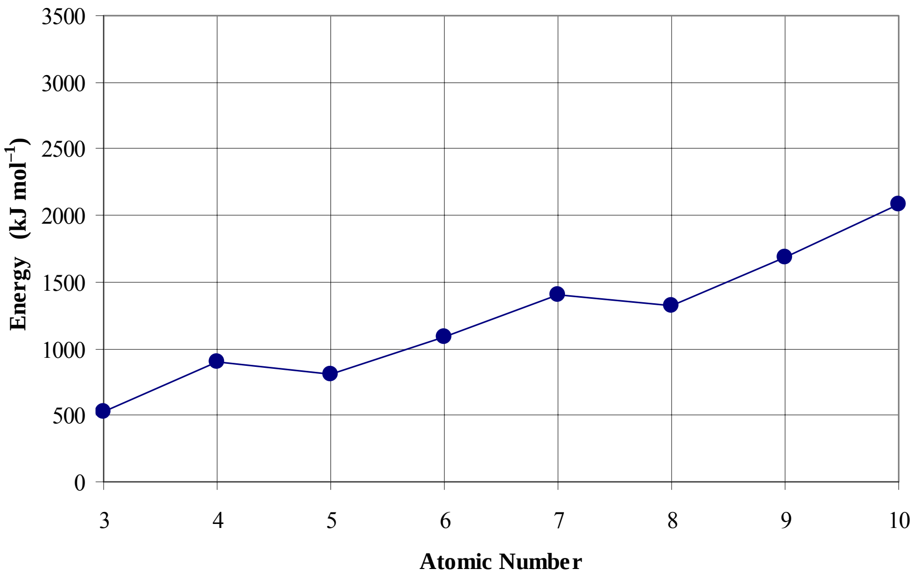
Marks

- Pure silicon is an insulator. Explain, with band structure diagrams, how doping pure silicon with a small amount of aluminium can turn it into a p-type semiconductor. **4**

- Sketch the wave function of a 2*p* orbital as a lobe representation. Clearly mark all nodes (spherical and/or planar) and nuclear positions. **2**

Marks
6

- The graph shows the first ionisation energies for second row elements of the periodic table.



Explain the general trend and both anomalies.

On the above graph, plot your estimates of the second ionisation energies for the second row elements. Make sure your graph clearly shows the general trends.

Marks
4

- Moseley discovered experimentally in 1913 that the atomic number, Z, of an element is inversely proportional to the square root of the wavelength, λ, of fluorescent X-rays emitted when an electron drops from the $n = 2$ to the $n = 1$ shell.

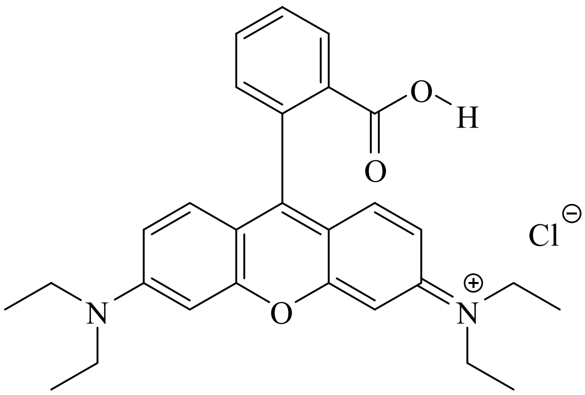
i.e. $$\frac{1}{\sqrt{\lambda}} = kZ$$

If iron emits X-rays of 1.937 Å when a 2*s* electron drops back to the 1*s* shell, determine the identity of the elements contained in an alloy found to emit the same type of X-rays at 1.435 Å and 1.541 Å?

Answer:

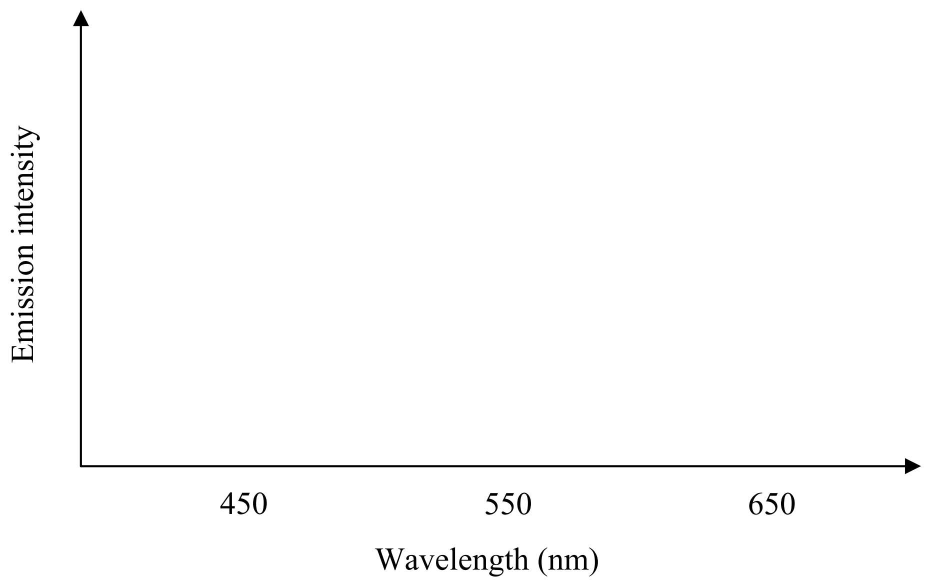
Marks
4

- Rhodamine 6G, whose structure is shown below, is a dye used in various applications such as lasers and environmental monitoring.



Name three functional groups present in the rhodamine 6G molecule.

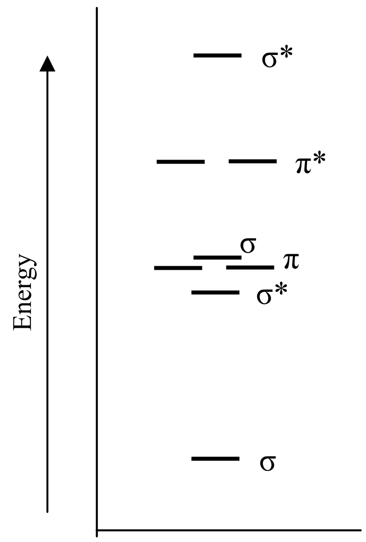
After absorbing green light, rhodamine 6G will emit yellow-orange light. Draw an indicative emission spectrum for this dye on the axes below.



Marks
6

- Carbon forms a homonuclear diatomic molecule which is observed in comets, flames and interstellar clouds.

The molecular orbital energy level diagram provided shows the energies of the orbitals for the valence electrons in the C_2 molecule. Indicate on this diagram the ground state electronic configuration of C_2 using the arrow notation for electron spins.



In its ground state, is C_2 paramagnetic or diamagnetic?

The lowest energy excited state of C_2 possesses two electrons with parallel, unpaired spins. What is the bond order of C_2 in this excited state?

Answer:

Starting in this excited state, further exciting an electron from the lowest σ* orbital to the next lowest σ orbital brings about the doubly excited state responsible for green emission in flames. What is the bond order of this doubly excited state?

Answer:

Marks
2

- The value of the equilibrium constant, K_c, for the following reaction is 0.118 mol L^{-1}.

$$2CO_2(g) + N_2(g) \rightleftharpoons 2CO(g) + 2NO(g)$$

What is the equilibrium concentration of CO(g) if the equilibrium concentration of $[CO_2(g)]$ = 0.492 M, $[N_2(g)]$ = 0.319 M and $[NO(g)]$ = 0.350 M?

Answer:

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY

Marks

- A 50.0 mL solution contained 5.00 g of NaOH in water at 25.00 °C. When it was added to a 250.0 mL solution of 0.100 M HCl at 25.00 °C in a "coffee cup" calorimeter, the temperature of the solution rose to 26.12 °C. **4**

  Is the process an endothermic or exothermic reaction?

  Assuming the specific heat of the solution is 4.18 J K^{-1} g^{-1}, that the calorimeter absorbs a negligible amount of heat, and that the density of the solution is 1.00 g mL^{-1}, calculate $\Delta_r H$ (in kJ mol^{-1}) for the following reaction.

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

Answer:

- Indicate the relative entropy of each system in the following pairs of systems. Use: ">", "<", or "=". **1**

$H_2O(g)$		$H_2O(s)$
$3O_2(g)$		$2O_3(g)$

- Consider butane (C_4H_{10}) and pentane (C_5H_{12}). Which gas has the higher entropy at 40 °C? Give reasons for your answer. **2**

Marks
6

- The thermite reaction is written below. Show that the heat released in this reaction is sufficient for the iron to be produced as molten metal.

$$2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(l)$$

Assume that the values in the table are independent of temperature.

Substance	Enthalpy of formation, $\Delta_f H^o$ kJ mol^{-1}	Molar heat capacity, C_p J K^{-1} mol^{-1}	Melting point ^{o}C	Enthalpy of fusion kJ mol^{-1}
Al	0	24	660	11
Al_2O_3	–1676	79	2054	109
Fe	0	25	1535	14
Fe_2O_3	–824	104	1565	138

Marks

- A helium balloon is filled on the ground, where the atmospheric pressure is 768 mmHg. The volume of the balloon is 8.00 m^3. When the balloon reaches an altitude of 4200 m, its volume is found to be 16.8 m^3. Assuming that the temperature remains constant, what is the air pressure at 4200 m in mmHg? **2**

Answer:

- The volume of a gas is 40.0 mL at –15 °C and 1.30 atm. At what temperature (°C) will the gas have a pressure of 1.00 atm and a volume of 65.0 mL? **2**

Answer:

THE REMAINDER OF THIS PAGE IS FOR ROUGH WORKING ONLY

Marks
3

- Pentane, $CH_3CH_2CH_2CH_2CH_3$, burns completely in oxygen to form CO_2(g) and H_2O(g). Use the bond enthalpies given below to estimate the enthalpy change for this process.

Bond	Bond enthalpy (kJ mol^{-1})	Bond	Bond enthalpy (kJ mol^{-1})
C–H	414	O–H	463
C–C	346	O–O	144
C=O	804	O=O	498

Answer:

Marks

- The measured potential of the following cell is –0.742 V at 298 K. **4**

  Ag(s) | $AgNO_3$ (0.010 M) || NaI (0.030 M) | AgI(s) | Ag(s)

  Calculate the standard cell potential and determine the equilibrium constant, K_{sp}, for the following reaction at 298K.

  $$AgI(s) \rightarrow Ag^+(aq) + I^-(aq)$$

$E°_{cell}$ =	K_{sp} =

- Circle the molecule in the following pairs that has the stronger intermolecular forces. Identify the types of forces present for the species selected. **2**

molecule pair	types of intermolecular forces
H_2 or N_2	
CH_3Cl or CH_4	
SO_2 or CO_2	
H_2O or H_2S	

Marks

- How does nitric oxide, NO(g), form in a car engine? What happens to the NO once emitted from the tailpipe? Make sure you include the appropriate chemical reactions in your answer.

2

- Calculate the standard potential at 298 K of the following electrochemical cell.

5

$$Cu(s) \mid Cu^{2+}(aq) \parallel Fe^{3+}(aq), Fe^{2+}(aq) \mid Pt(s)$$

Data:

	$\Delta_f H°$ / (kJ mol^{-1})	$S°$ / (J K^{-1} mol^{-1})
Fe^{3+}(aq)	–49	–316
Fe^{2+}(aq)	–89	–138
Cu^{2+}(aq)	65	–100
Cu(s)	0	33

Answer:

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	1 Pa = 1 N m^{-2} = 1 kg m^{-1} s^{-2}
0 °C = 273 K	1 Ci = 3.70×10^{10} Bq
1 L = 10^{-3} m^3	1 Hz = 1 s^{-1}
1 Å = 10^{-10} m	1 tonne = 10^3 kg
1 eV = 1.602×10^{-19} J	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

CHEM1101 - CHEMISTRY 1A

Standard Reduction Potentials, *E*°

Reaction	*E*° / V
$S_2O_8^{2-} + 2e^- \rightarrow 2SO_4^{2-}$	+2.01
$Co^{3+}(aq) + e^- \rightarrow Co^{2+}(aq)$	+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
$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O$	+1.23
$Br_2 + 2e^- \rightarrow 2Br^-(aq)$	+1.10
$MnO_2(s) + 4H^+(aq) + e^- \rightarrow Mn^{3+}(aq) + 2H_2O$	+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
$Sn^{4+}(aq) + 2e^- \rightarrow Sn^{2+}(aq)$	+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
$Co^{2+}(aq) + 2e^- \rightarrow Co(s)$	–0.28
$Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$	–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 $E = h\nu = hc/\lambda$ $\lambda = h/mv$ $E = -Z^2E_R(1/n^2)$ $\Delta x \cdot \Delta(mv) \geq h/4\pi$ $q = 4\pi r^2 \times 5.67 \times 10^{-8} \times T^4$ $T\lambda = 2.898 \times 10^6$ K nm	**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** $PV = nRT$ $(P + n^2a/V^2)(V - nb) = nRT$ $E_k = ½mv^2$
Radioactivity $t_{½} = \ln 2/\lambda$ $A = \lambda N$ $\ln(N_0/N_t) = \lambda t$ ^{14}C age = 8033 $\ln(A_0/A_t)$ years	**Kinetics** $t_{½} = \ln 2/k$ $k = Ae^{-Ea/RT}$ $\ln[A] = \ln[A]_o - kt$ $\ln\frac{k_2}{k_1} = \frac{E_a}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$
Colligative Properties and Solutions $\Pi = cRT$ $P_{solution} = X_{solvent} \times P°_{solvent}$ $c = kp$ $\Delta T_f = K_f m$ $\Delta T_b = K_b m$	**Thermodynamics and Equilibrium** $\Delta G° = \Delta H° - T\Delta S°$ $\Delta G = \Delta G° + RT \ln Q$ $\Delta G° = -RT \ln K$ $\Delta_{univ}S° = R \ln K$ $K_p = K_c (RT)^{\Delta n}$
Miscellaneous $A = -\log\frac{I}{I_0}$ $A = \varepsilon cl$ $E = -A\frac{e^2}{4\pi\varepsilon_0 r}N_A$	**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 = $4\pi r^2$

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]							

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]